For my December 2013 diary, go here.

Diary - January 2014

John Baez

January 6, 2014

While the polar vortex moved south toward the Great Lakes and blasted the US with icy weather, Britain got hit with high winds: gusts up to 175 kilometers per hour! Huge waves hit the the coasts of Wales, southwest England and Northern Ireland.

This beautiful, scary demonstration of nature's power happened in Porthcawl, a town on the south coast of Wales. At the end of Porthcawl Pier stands a white lighthouse built in 1860 — but here it is hidden behind the waves! It was the last coal and gas powered lighthouse in the United Kingdom.

January 12, 2014

A brown dwarf is a star too small to fuse hydrogen — less than 80 times the mass of Jupiter. Thanks to some great new telescopes, astronomers have been learning about weather on brown dwarfs! It may look like this artist's picture. (It may not.)

Luhman 16 is a pair of brown dwarfs orbiting each other just 7 light years from us. The smaller one, Luhman 16B, is half covered by huge clouds. These clouds are hot — 1200 °C — so they're probably made of sand, iron or salts. Some of them have been seen to disappear! Why? Maybe 'rain' is carrying this stuff further down into the star, where it melts.

So, we're learning more about something cool: the L/T transition.

Brown dwarfs can't fuse ordinary hydrogen, but a lot of them fuse the isotope of hydrogen called deuterium that people use in H-bombs — at least until this runs out. The atmosphere of a hot brown dwarf is similar to that of a sunspot: it contains molecular hydrogen, carbon monoxide and water vapor. This is called a type M brown dwarf.

But as they run out of fuel, they cool down. The cooler type L brown dwarfs have clouds! But the even cooler type T brown dwarfs do not. Why not?

This is the mystery we may be starting to understand: the clouds may rain down, with material moving deeper into the star! Luhman 16B is right near the L/T transition. Its big brother Luhman 16A is type L.

Finally, as brown dwarfs cool below 300 °C, astronomers expect that ice clouds start to form: first water ice, and eventually ammonia ice. These are the type Y brown dwarfs. Wouldn't that be neat to see? *A star with icy clouds!*

The smallest brown dwarfs are 13 times the mass of Jupiter. Smaller than that, and they can't fuse deuterium.

There's been a lot of news articles about brown dwarfs in the last few days, but I think you should read the heroic astronomy bloggers who covered this story over a year ago. Like Caroline Morley:

- Caroline Morley, Swirling, patchy clouds on a teenage brown dwarf, 28 February 2012.

She doesn't like how people call brown dwarfs "failed stars". I agree! It's like calling a horse a "failed giraffe".

For more, try:

- Brown dwarfs, Scholarpedia.

January 14, 2014

Here you see palms reflected in a reed-lined pond in the Thousand Palms Oasis Preserve in southern California. Lisa and I went on a hike here last month. It's especially nice to come to this pond after hiking through the dry, dusty desert!

The palms here are native to the area: *Washingtonia filifera*, the desert fan palm. They're different than the palm trees you see along city streets in Los Angeles. They grow around oases and streams in the deserts of southern California and western Arizona. I've often seen them in Indian Canyons near Palm Springs... but this was the first time I visited this other oasis.

Around here, the Cahuilla and related tribes used the leaves of fan palms to make sandals, thatch roofs, and baskets. The fruit was eaten raw, cooked, or ground into flour for cakes. The stems were used to make cooking utensils. And standing under these palms near an oasis, it's cool even on a ferociously hot day! It's definitely the place to be.

It's fun to imagine the world of the Cahuilla, where these oases would be hugely desirable places to live, and centers of activity.

The Thousand Palms Oasis Preserve is a privately owned park that lets you in for free. It's part of the Coachella Valley Preserve System, which was set up to protect a rare species of lizard that roams the dunes around here: the Coachella Valley fringe-toed lizard *Uma inornata*. But a lot of other things live in this area: the desert is not deserted!

Tomorrow we go to Erlangen, a completely different place in a completely different climate.

January 26, 2014

One of my favorite parts of Mars is Vastitas Borealis, the vast plains in the north. They're full of dunes, many covered with carbon dioxide frost, some of which do mysterious things in the spring. Here we see some crescent-shaped dunes called barchans. They're about 750 meters long. They slowly move along as wind blows sand up the shallow slope and it rolls down the steep slope. The white stuff is mostly CO_2 frost, with a little water ice.

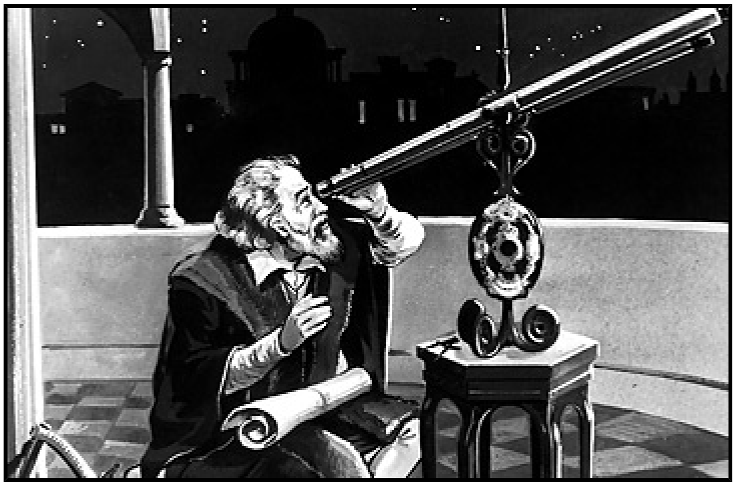
This photo is from the HiRISE project — the High Resolution Image Science Experiment. They write:

> The purpose of this observation is to image dunes where substantial "gullies" formed in the previous Mars winter. These features likely formed due to carbon dioxide defrosting or the weight causing the surface to slump.
>
> The gullies at this site are particularly large, which is intriguing, suggesting that this site be monitored to see if stages of gully formation or details of activity can be observed.

Here's what they said about a similar photo taken in the previous winter:

> Geologists would classify these dunes as "sand-starved" because the ground between the dunes has almost no sand. This ground shows a pattern of cracks that is typical of icy permafrost that undergoes seasonal expansion and contraction. It is also possible that this subsurface ice exists inside the dunes. If so, the dunes are not currently moving, being "stabilized" by this ice.
>
> This idea is supported by the observation that there are small landslide gullies being cut into the dunes, something not seen if the dunes are rejuvenated as they move in the wind. However, to test this idea this area has been repeatedly imaged by multiple cameras on different spacecraft. With meticulous care it will be eventually possible to determine just how much the dunes have moved or changed over the past several years.

January 31, 2014



I knew Newton did alchemy. But I hadn't known Galileo did astrology! Alchemy and astrology weren't disreputable back then, so it's not really surprising. But not many people talk about it - perhaps because Galileo is considered a founder of modern science, and now scientists think astrology doesn't make sense.

Here's the main evidence:

1. Galileo was hired as a *mathematicus* at Padua in 1592. The duties of a *mathematicus* included astrology.

2. The Inquisition first went after Galileo in 1604, on the charge of making astrological predictions that denied free will. Astrology was okay, but *fatalistic* predictions were not.

   He was accused of *haver ragionato che le stelle, i pianeti at gl'influssi celesti necessitino* - having reasoned that the stars, planets and celestial influences were able to determine the course of events. He was acquitted.

3. We have astrological charts that Galileo drew up for his daughters. For his elder daughter Virginia, he wrote:

   > The Moon is very debilitated and in a sign which obeys. She is dominated by family relationships. Saturn signifies submission and severe customs which gives her a sad demeanour, but Jupiter is very well with Mercury, and well-aspected corrects this. She is patient and happy to work very hard. She likes to be alone, does not talk too much, eats little with a strong will but she is not always in condition and may not fulfil her promise.

4. We have astrological charts that Galileo drew up for himself.

5. We have about 20 other astrological charts drawn up by Galileo, including one for the Venetian aristocrat Giovanni Sagredo, who later became a character in Galileo's famous dialogue. We have a letter from Sagredo to Galileo requested a chart reading for a colleague.

You can see this evidence here:

- Nick Kollerstrom, Galileo's Astrology.

But I heard the story first from Darrel Rutkin, here in Erlangen at the Internationales Kolleg für Geisteswissenschaftliche Forschung where my wife is working. Unfortunately his paper seems hard to get online:

- Darrel Rutkin, Galileo astrologer: astrology and mathematical practice in the late-sixteenth and early-seventeenth centuries, *Galileana: Journal of Galilean Studies* **2** (2005), 107-143.

The story of how scientists rejected astrology is interesting and complex. We shouldn't pretend scientists knew all along that it was wrong, by some sort of 'common sense'. Science is not the same as common sense: it takes real work.

For a quick introduction to this story, try:

- H. Darrel Rutkin, Astrology, in *The Cambridge History of Science, Vol. 3: Early Modern Science*, Lorraine Daston and Katharine Park (eds), Cambridge. Cambridge University Press, 2006, pp. 541-561.

Before scientists threw out astrology, they tried to understand, explain or reform it. Here's a tiny snippet:

> Francis Bacon proposed a serious reform of astrology in the *De augmentis scientiarum* of 1623, a Latin enlargement and reworking of his *Advancement of Learning* (1605), written during the forced retirement that followed his impeachment as Lord High Chancellor. Bacon began by identifying the many superstitions and lies that needed to be removed from its domain, including the individual planetary rule of each hour of the day and the astrological figure constructed for precise points of time. Reviewing the four principal divisions of astrological practice — revolutions, nativities, elections, and interrogations — he argued that the last three had little if any foundation, whereas he described revolutions as much more sound, though nonetheless in need of attention.

I didn't know these four kinds of astrology:

> Building on Ptolemy's distinction, Albertus Magnus described the four types of astrological praxis in his *Speculum astronomiae* (*Mirror of the Science of the Stars*, ca. 1260s): 'Revolutions' were concerned with large-scale changes, primarily in the weather but also in state affairs. This was the major feature of the annual prognostications found in almanacs and elsewhere [....] 'Nativities', on the other hand, involved the astrological configuration at a person's birth. 'Interrogations' entertained questions on matters of concern, including personal, medical, and business affairs. Finally, 'elections' determined the most propitious moment to begin an enterprise or perform an activity, such as crowning.

The famous chemist (and alchemist!) Robert Boyle was also involved:

> Bacon's vision of a reformed astrology was further developed by the English natural philosopher and alchemist Robert Boyle (1627-1691), one of the founders of the Royal Society of London. In his "Suspicions about some Hidden Qualities of the Air" (1674), Boyle adapted Bacon's position, declaring that the luminaries, planets, and fixed stars likely emit subtle but corporeal emanations beyond light and heat, which reach to our air. Developing this idea in the appendix, "Of Celestial and Aerial Magnets", Boyle suggested experiments to test apparently good magnets by varying the air in which they were located according to different times, temperatures, and aspects of the planets. In this way, the different natures of the air could be discovered along with possible correspondences between the terrestrial and celestial realms.

For my February 2014 diary, go here.

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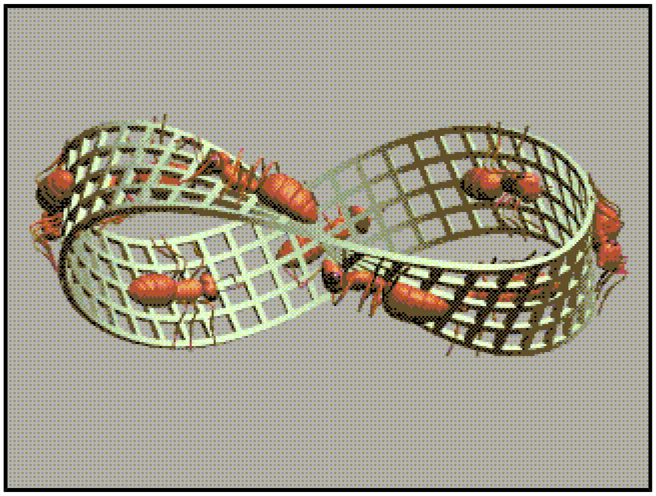
[For my January 2014 diary, go here.]

Diary - February 2014

John Baez

February 1, 2014



My friend Tim Silverman showed me something cool. He told me to take this list of opposites:

```
1     long            short
2     small           large
3     strong          weak
4     sturdy          flimsy
5     useful          useless
6     beneficial      harmful
7     bad             good
8     imperfect       perfect
9     dirty           clean
10    pure            impure
11    mixed           simple
12    plain           decorated
13    furnished       bare
14    empty           full
15    much            little
16    long            short
```

The order of elements in each pair is random. We're going to order them.

Start with the first two pairs: long/short and small/large. Order the second pair to match the first! In other words, switch the order if large is more like long and small is more like like short. Otherwise, leave them alone.

Now ignore the first pair and look at the second and third pairs. Reorder the third pair to match the (possibly new) order of the second pair. And so on: go through the whole list and keep doing this.

I did this, and here's what I got:

```
1     long            short
2     large           small
3     strong          weak
4     sturdy          flimsy
5     useful          useless
6     beneficial      harmful
7     good            bad
8     perfect         imperfect
9     clean           dirty
10    pure            impure
```

```
11   simple          mixed
12   plain           decorated
13   bare            furnished
14   empty           full
15   little          much
16   short           long
```

We started with long/short and we ended with short/long! We've got a Möbius strip in the space of concepts!

Puzzle: why is this happening, and what does it mean?

Mathematicians know more precise way of saying what's going on... which doesn't answer the puzzle. We've got a double cover of the space of topics, where two sheets consist of two opposite adjectives. This double cover is nontrivial, because when we go around a loop the two opposites trade places. Using some math called 'homology theory', we can ask how many different ways this can happen.

The picture of ants on a Möbius strip goes back to Escher, but I found the animated gif here.

Tim Silverman writes:

> Here's how I designed it to work:
>
> What are we doing when we compare these opposites? They don't have much in common semantically. But we do manage to classify them by some very general notion of "positive" vs "negative" and line up positives together and negatives together.
>
> Actually, that was a lie... there are two general notions of "positive" vs "negative" in play. One covers stuff like quantity, dimension, number, intensity, etc. — "more" vs "less" in some very general sense. The other is evaluative: "better" vs "worse" — again in some very general sense.
>
> And some words lie along one axis ("long" vs "short" is pretty much just more/less), some along the other (e.g. "good" vs "bad"), and lots are a mixture of both.and the two types of judgment don't need to align! E.g. with "strong"/"weak", more is better; but with "clean"/"dirty", "more" means "more dirt" — which is bad!
>
> So we have a two-dimensional space, in which we can continuously rotate a vector to point in the opposite direction. So "long" and "large" are positive purely on the more/less scale; "strong", "sturdy", "useful" and perhaps even "beneficial" combine an increasing component of positive evaluation with a decreasing but non-zero degree of positive quantity or degree; "good" is purely evaluative; "perfect", "clean" and "pure" are all cases where the positively evaluated end of the scale is the one denoting an absence of something (imperfections, dirty, impurities); "simple" and "plain" are ambiguous (close to zero) on the axis of evaluation but clearly negative on the more/less scale and this holds true more strongly for "bare" and "empty"; then "little", "small" and "short" have very little or no evaluative component.
>
> When I have the patience, I'll draw a picture.
>
> The interesting thing is that when people are given the puzzle, they generally implicitly assume without question that the "positive" vs "negative" scale is 1-dimensional. Given this, there must be a discontinuity where the polarity switches, so to "understand" the puzzle, people look for the discontinuity — and they often think they've found it! They usually think it's somewhere around 3/4 of the way through, so maybe something is going on there, but I don't think it's the explanation of the puzzle.

January 30, 2014

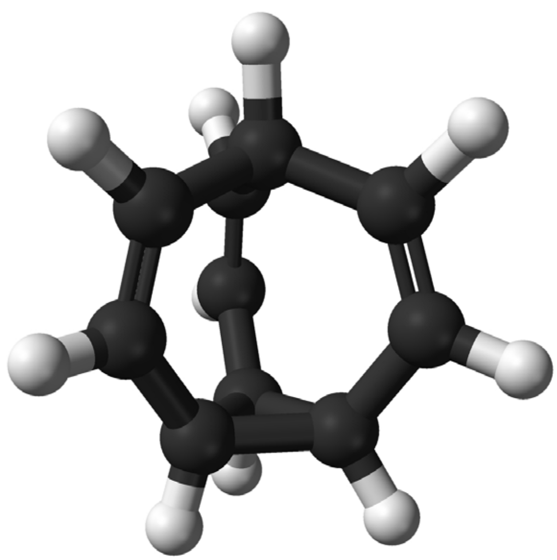
I'm finally in a stable relationship!

When Lisa and I came to Erlangen, they put us in a really dreadful apartment in a boring little town nearby called Uttenreuth. This apartment had no soul, it had no privacy, the doorknob kept falling off... and we were not living in the charming city we'd expected; we had to take a bus to town. So we found another place. It's a house with two stories, but it's tiny: this is the whole upstairs, and downstairs there's a bedroom and bathroom. It used to be a stable!

We bump our heads on the ceiling... but the place has charm. It's on a quiet street called Loewenichstrasse, full of old buildings, right next to a park, but still just a 15 minute walk to the heart of town.

I'd been waiting for a couple weeks for a sunny day, so I could take a photo of this place. It was sunny this morning. Then it got cold again and started raining. But I didn't come to Germany for the weather. I came here for the Gemütlichkeit, the Weissbier and the Mohnschnecke! So I'm happy now.

February 9, 2014



In the late 1950's, the great organic chemist William "Bull" Doering ran weekly seminars at Yale. They were secretly called "Bull sessions" by grad students and postdocs, and they were feared by those who were poorly prepared. So, when Doering came up with the idea this molecule — a close relative of a chemical called fulvalene — two of his grad students named it 'bullvalene'. He dreamt it up in 1963, and was synthesized later that year.

Bullvalene has 10 carbon atoms (in black) and 10 hydrogens (in white). The cool thing about it is that these atoms are constantly rearranging themselves, quite quickly.

Molecules where some atoms easily change places are called 'fluxional molecules'. But what's special about bullvalene is that all ten carbon atoms trade places!

So, there are

$$10! = 1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7 \times 8 \times 9 \times 10 = 3{,}628{,}800$$

different versions of bullvalene, and it keeps switching between these versions.

But since the molecule has 3-fold rotational symmetry, chemists say bullvalene has 10!/3 valence tautomers, where

$$10! / 3 = 1 \times 2 \times 4 \times 5 \times 6 \times 7 \times 8 \times 9 \times 10 = 1{,}209{,}600$$

For more, read this:

- Addison Ault, The bullvalene story: the conception of bullvalene, a molecule that has no permanent structure, *J. Chem. Educ.* **78** (2001), 924-927.

Though it's published by a chemistry society in a journal of chemistry education, they charge $35 to access this article for 48 hours... so students won't actually read it! This is an example of how the practice of science needs to be reformed. Luckily, you can get the article for free somewhere else... for now.

Luckily, you can also learn about bullvalene from Wikipedia:

- Bullvalene, Wikipedia.

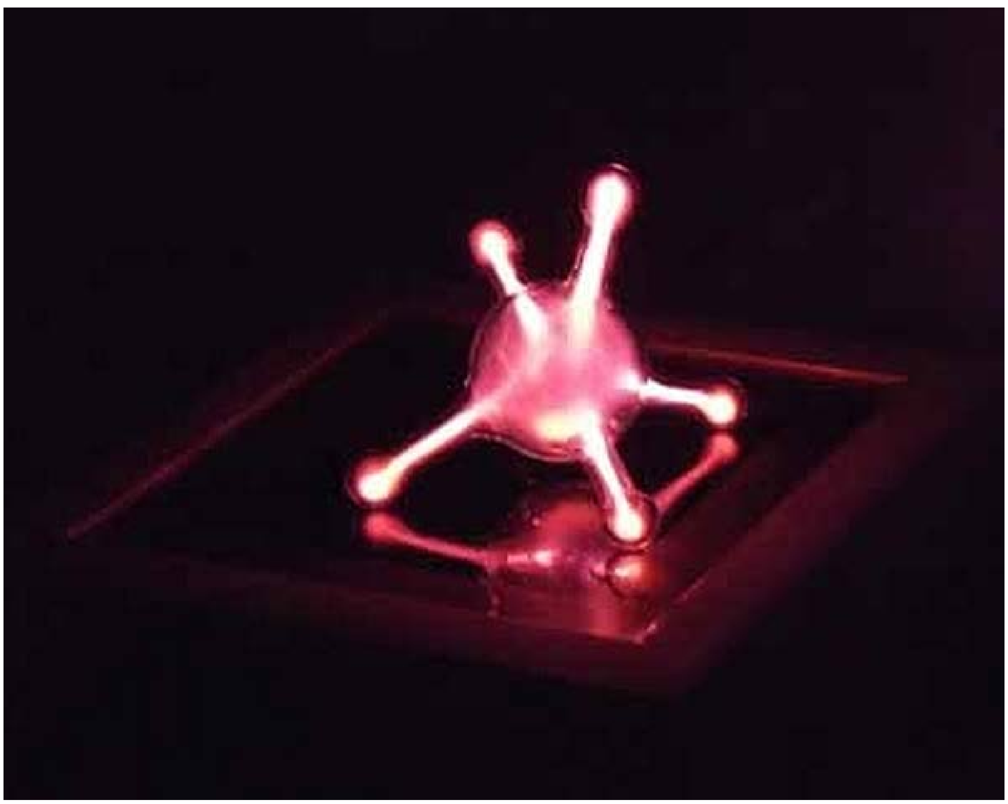
There you can see the process that bullvalene uses to rearrange itself... and see related molecules like 'semibullvalene' and 'bullvalone'. Also try:

- Fluxional molecule, Wikipedia.

But here's a puzzle for physicists who know about bosons and fermions:

Puzzle: Identical atoms are indistinguishable, so what does it mean to say two traded places? How do we tell? Does this concept have any meaning?

February 10, 2014



There's more to chemistry than I learned in school.

Take a carbon and stick on 4 hydrogens: you get methane, the gas we like to burn. Yeah, I knew that. But take a carbon and stick on 5 hydrogens: then an electron falls off and you get *methanium!*

Huh?

Yes, it's a bit like ammonium. Take nitrogen and stick on 3 hydrogens, and you get ammonia. Stick on 4, an electron falls off and you get ammonium, a positively charged ion: NH_4^+. Similarly, methanium is CH_5^+.

But here's the cool thing about methanium. It's fluxional: it keeps changing. Usually three of the hydrogens form an equilateral triangle around the equator while the other two sit at the north and south pole. But now and then — in fact very often! — they trade places.

I recently told you about bullvalone, a fluxional molecule where all 10 carbons keep changing places. But I didn't tell you that they only change places if it's warm enough. When it's really cold, they lock into place.

What's cool about methanium is that it's fluxional *no matter how cold it is*. The uncertainty principle of quantum mechanics is enough to make the 5 hydrogens change places even at absolute zero!

You could say this is due to 'quantum zero-point energy', but I'm afraid to mention that, because then kooks will come out and tell us their schemes for exploiting this energy and saving the world.

Sorry, it doesn't work like that. It's just that even when methanium is at its lowest possible energy, when we can't possibly extract any energy out of it, the positions of the hydrogen atoms aren't fixed. If we keep measuring them they will change, thanks to the uncertainty principle. And they will change positions enough to actually trade places at a significant rate.

But the truth is cooler than fiction. Scientists have actually seen methanium in outer space, doing its thing.

For more see:

- Methanium, Wikipedia.

This picture is actually a glowing neon sculpture called "Methanium" made by a company called Wizard Glass

For my March 2014 diary, go here.

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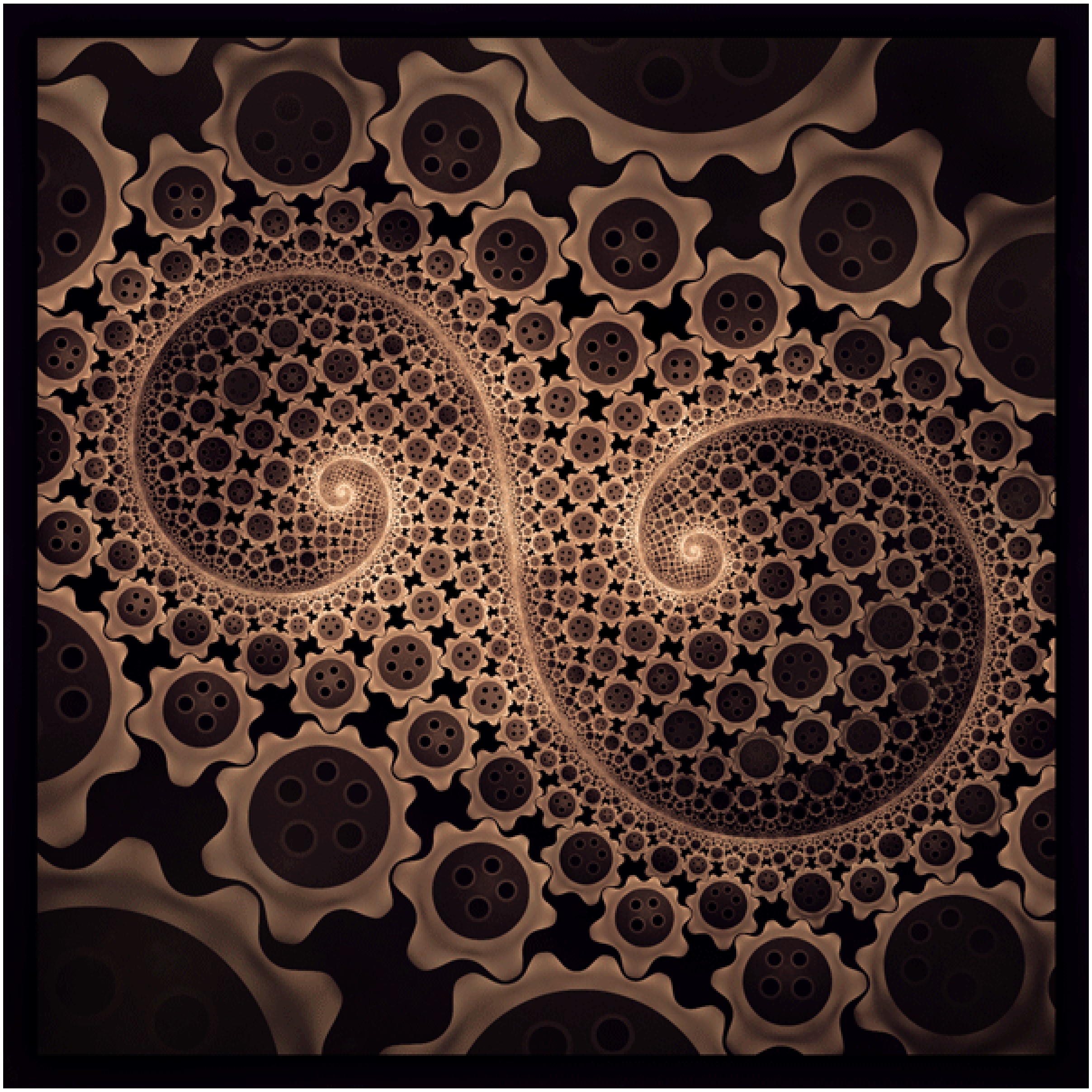
Diary - March 2014

John Baez

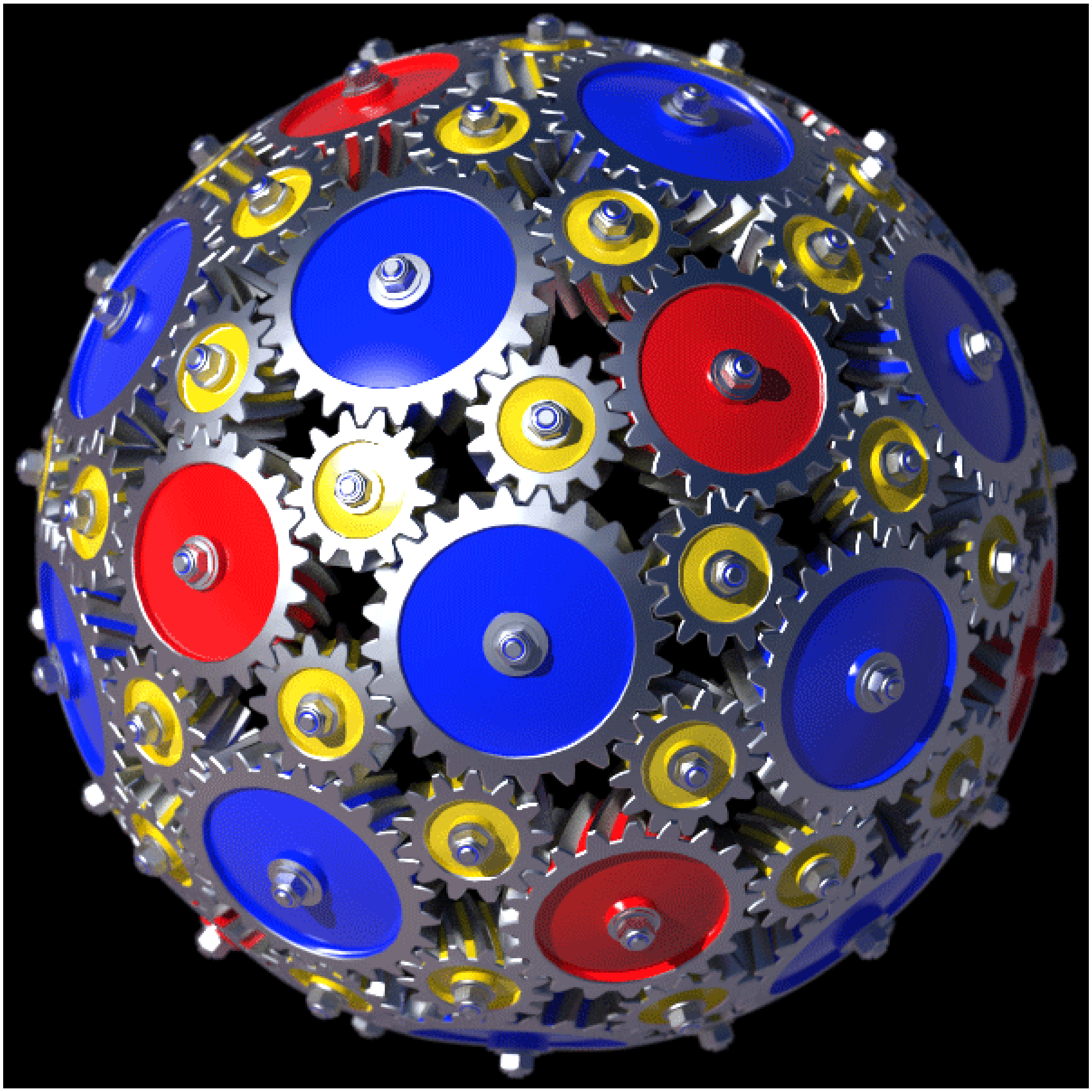
March 10, 2014



I've got gears on my mind — maybe even *in* my mind!

Even the tiniest gears here are indeed turning. This moving picture is by someone called ~zy0rg, and I found it on deviantart.

March 11, 2014



Let's count the gears on this thing!

If you stare at it, you can see it's based on a regular dodecahedron, a shape with 12 pentagons as faces. The blue gears are the corners of these pentagons. There's a red gear in the middle of each pentagon, and there are 2 yellow gears next to the edge of each pentagon.

Since the regular dodecahedron has 12 pentagons, and there's a red gear in each one, there must be **12 red gears**.

The dodecahedron has 20 corners, since these are the faces of its dual, the icosahedron, which has 20 faces. Or, if you don't know that, you can say: each pentagon has 5 corners, but 3 pentagons meet at each corner, so there are 12 × 5 / 3 = 20 corners. Either way, there are **20 blue gears**.

Finally, the dodecahedron has 30 edges. To see this we can use Euler's formula

$$V - E + F = 2$$

so

$$20 - E + 12 = 2$$

so

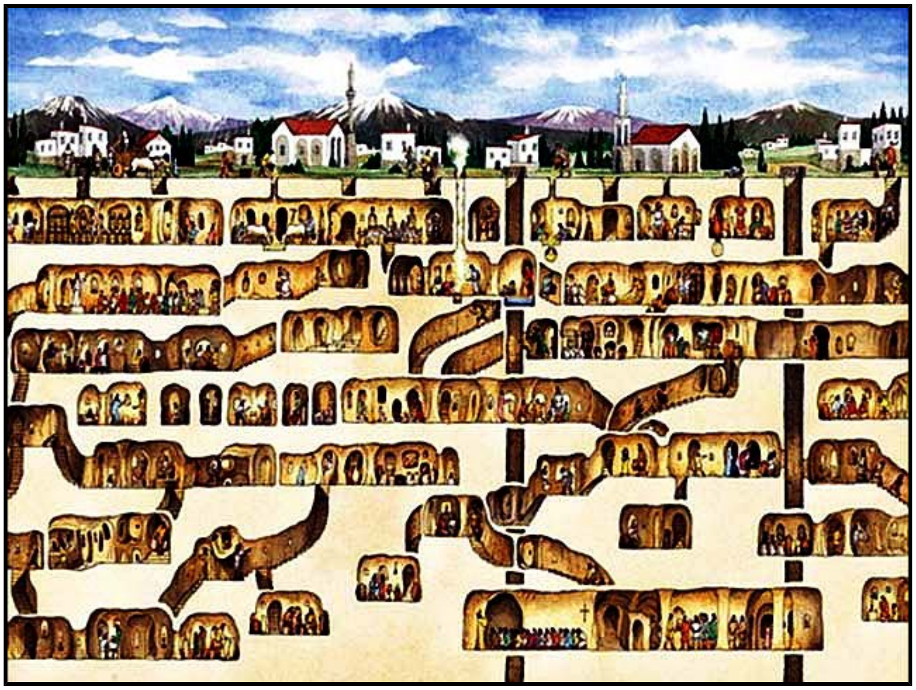
$$E = 30$$

Or, we can say each pentagon has 5 edges, but 2 pentagons share each edge, so there are 12 × 5 / 2 = 30 edges. Either way, we get 30 edges, and 2 yellow gears for each edge, so 60 yellow gears.

So, there's a total of 12 + 20 + 60 = 92 gears. It's often not enlightening to total up parts of different kinds like this, and I think it's not enlightening here. 92 is not a number I run into often in my studies of geometry and group theory. Factorizing it shows why: it's 2 × 2 × 23. The number 23 is not a big player in these games.

This animated gif was created by someone named TaffGoch, and you can find other interesting things of theirs at Deviantart.

March 17, 2014



Derinkuyu is an ancient multi-level underground city in Turkey. Going 60 meters deep, it was large enough to house 20,000 people along with their livestock and food supplies!

It may have been built by the Phrygians in the 8th-7th centuries BC... or maybe by Hittites fleeing the Phrygians. It seems to have been enlarged much later in the Byzantine era.

But here's the cool part: it's the largest of over 200 underground cities in the Cappadocia region of Turkey... and it's connected by a tunnel to the second largest one!

Why did people build so many underground cities there? I don't know - can you find out? It was relatively easy to do, because the area has a lot of soft volcanic rock. But as any detective show will teach you, there must be motive, not just means and opportunity.

Half of Derinkuyu is open to tourists... have you been there?

March 22, 2014

"From early boyhood, cowardly, dishonorable, cruel, lecherous, foul-mouthed and debauched."

That's what emperor Julian of the Roman Empire said about Commodus, the son of Marcus Aurelius, who was emperor from 180 to 192 AD.

He never took after his father the philosopher, but he first showed his true colors after a failed assassination plot in 181. The would-be assassin was tortured and revealed a plot involving his sister.

Later one of the plotters revealed a second plot, and Commodus became paranoid. He sacked all his top commanders and started executing anyone he took a dislike to, including senators... and settled into a three-year binge of debauchery with a string of male lovers and a harem of 300 women: like Saddam Hussein, he had henchmen grab any woman who appealed to him.

As time went on, he only became worse. He developed a taste for voyeurism and had his political favorites have sex with his concubines while he watched. By 188 he had removed all responsible politicians from his inner circles and surrounded himself with a freak show. Often he would amuse himself by cutting off someone's foot or blinding them in one eye. He practiced surgery on live people and let them bleed to death. He liked to sit people at a fancy banquet and serve them food mixed with shit, to see their reactions. I could go on, but it becomes even more disgusting, and I don't want to spoil your day.

As time went on, his delusions of grandeur increased. He renamed the months: August became 'Commodus', and so on. He had always enjoyed killing animals — killing 100 lions with javelins, slicing off the heads of ostriches with special crescent-headed arrows, and so on — and fighting as a gladiator in the Colosseum. But eventually he declared that he was Hercules! He cut off the head of the sun god outside the Colosseum and replaced it with his own portrait, adding a club and a lion to make him look like Hercules. He announced his plan to kill 12,000 gladiators with one hand tied behind his back.

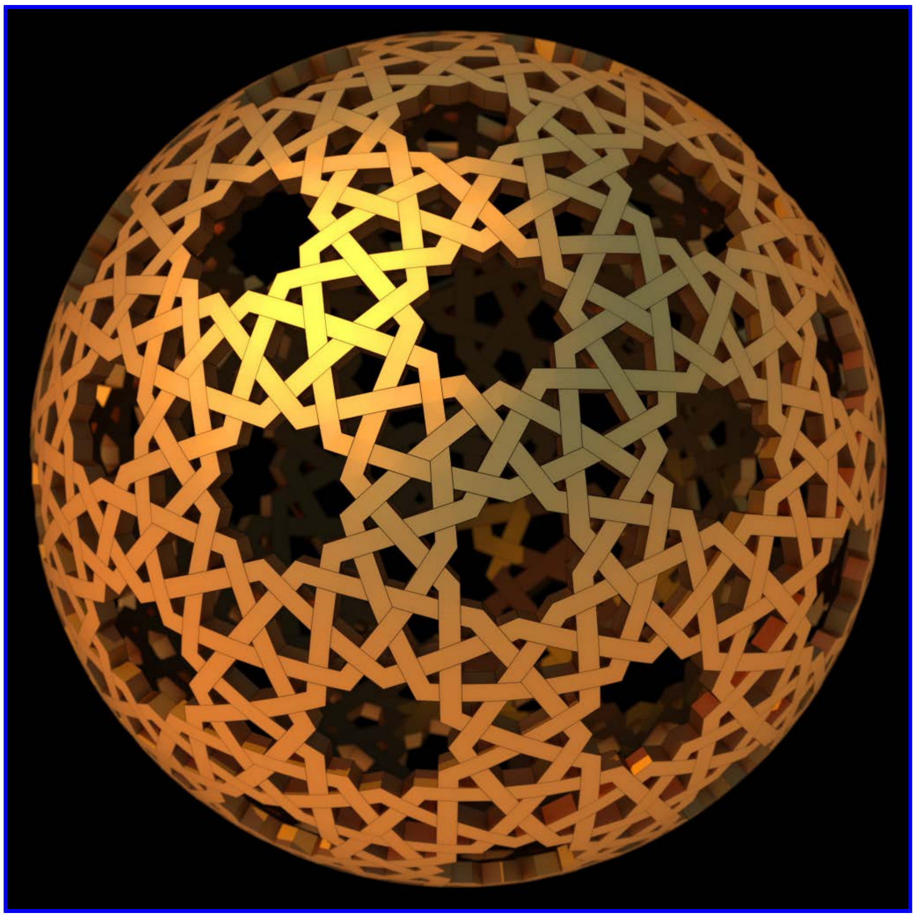
In 193 he was finally killed, in a plot led by his favorite mistress. An attempt to poison him failed, so his gym trainer strangled him.

All this is from an excellent biography of Marcus Aurelius by Frank McLynn. Marcus Aurelius was wise in some ways, but leaving the empire to Commodus was a colossal failure of judgement.

The photo above, by William Storage, shows a sculpture of Commodus at the Getty Museum in Los Angeles. For more of his beautiful photos go here:

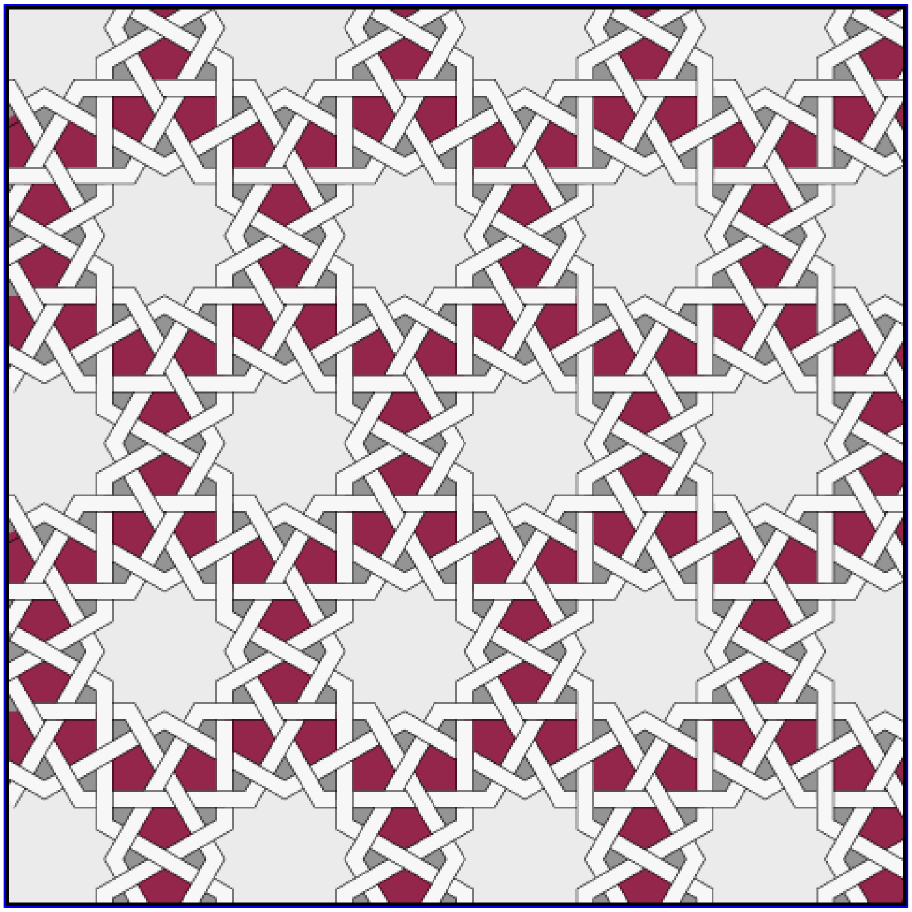
- William Storage, Roman Imperial Portraiture.

March 23, 2014



This beautiful golden pattern was created by Taffgoch. He did it by taking a traditional Islamic tiling pattern made of interlocking hexagons and replacing some of them by pentagons. This lets the original flat pattern 'curl up' and become spherical!

Here is the original flat pattern:



Taffgoch says it's based on a Moroccan tile pattern of the type known as zillij, but I'd say it's an example of girih, or 'strapwork'. It's fun to see how Taffgoch transformed it into the round version... improving it step by step.

Puzzle: how many pentagons, and how many hexagons, are in this spherical zillij?

This is similar to a question about fullerenes, which are sheets of graphite — hexagons of carbon — that curl up into spheres because some hexagons are replaced by pentagons. Fullerenes come in different sizes, with different numbers of hexagons. But as long as a fullerene is spherical in its topology, with 3 pentagons or hexagons meeting at each corner, the number of pentagons is fixed!

I'll compute this number now, so if you want to answer the puzzle on your own, maybe you should stop reading. However, this spherical zillij pattern is not exactly the same as a fullerene... so it's not obvious that it has the same number of pentagons.

Here's how it goes. Suppose we have a sphere tiled with P pentagons and H hexagons, with 3 of these polygons meeting at each vertex.

How many edges are there in this tiling? Each pentagon has 5 edges, and each hexagon has 6, but each edge is shared by 2 shapes so the number of edges is

$$E = (5P + 6H)/2$$

How many vertices are there? This is where we need to know 3 polygons meet at each vertex. Then by the same reasoning as above, the number of vertices is

$$V = (5P + 6H)/3$$

How many faces are there? That's easy:

$$F = P + H$$

Now Euler's formula, a fact from topology, says

$$V - E + F = 2$$

So, plugging in the equations for V, E, F, we get

$$(5P + 6H)/3 - (5P + 6H)/2 + (P + H) = 2$$

or

$$P + H = 2 + (5P + 6H)/6$$

or

$$P = 12$$

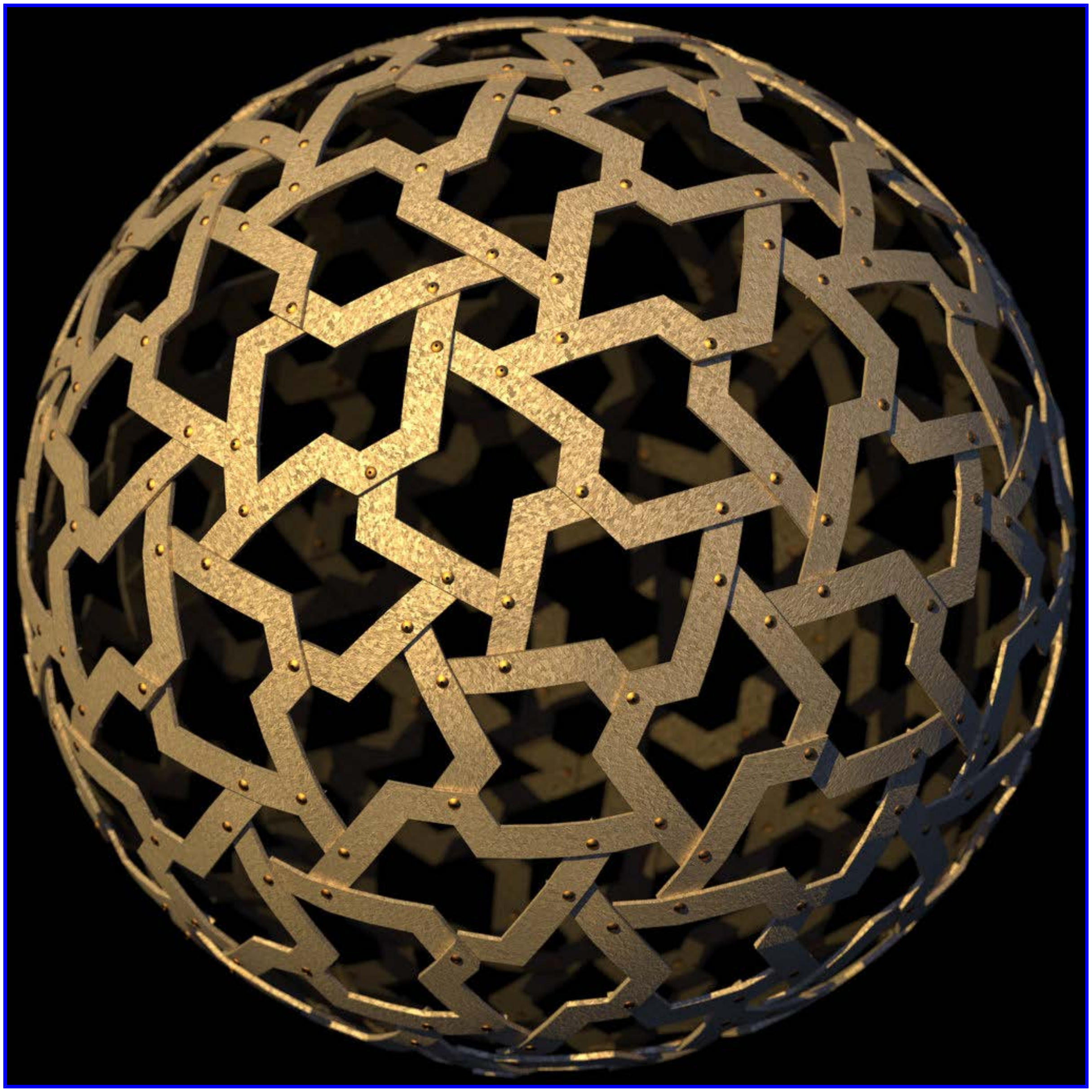
Note that H cancels out, so we learn nothing about how many hexagons there are. But pentagons love the number 12... and ultimately, that's why this shape here has

$$5 \times 12 = 60$$

rotational symmetries!

Puzzle: suppose we have a doughnut with g holes tiled by pentagons and hexagons, 3 meeting at each corner. How many pentagons are there?

March 30, 2014



This is a computer-generated image by Taffgoch, made to look nicely weathered... but it's based on an actual model, made by a monk named Father Magnus Wenninger:

Wenninger's story is interesting. In the 1940s went to the Bahamas to teach at a Benedictine school there. He was asked whether he wanted to teach English or math. He chose math. But not having taken many math courses in college, he struggled at first to stay a few pages ahead of the students! He taught algebra, Euclidean geometry, trig and analytic geometry.

In the 1950's he felt he was getting stale, so he went to Columbia Teachers College in the summer for 4 years. He got interested in the 'new math'... and started studying polyhedra.

In 1966 he wrote a booklet called Polyhedron Models for the Classroom. He wrote to H. S. M. Coxeter, the world's expert on polyhedra and higher-dimensional polytopes, sometimes called the 'king of geometry'. Apparently Coxeter sent Wenninger a copy of his book Uniform Polyhedra.

A uniform polyhedron is one that has regular polygons as faces and is symmetrical enough that there's a symmetry carrying any vertex to any other. There are 75 uniform polyhedra - not counting the infinite list of prisms and 'antiprisms'... and a very weird thing called the great disnub dirhombidodecahedron... which is a topic for another day.

After getting Coxeter's book, Magnus Wenninger spent a lot of time making models of uniform polyhedra. He made 65 of them and put them on display in his classroom. Then he decided to publish a book about them. He had the models photographed and wrote the accompanying text, which he sent to Cambridge University Press.

They said they'd be interested in the book only if Wenninger built all 75 of the uniform polyhedra! And so he did...

It took him 10 years to finish the book, *Polyhedron Models*, which was published in 1971. Mathematics is full of stories of amazing persistence, and this is one!

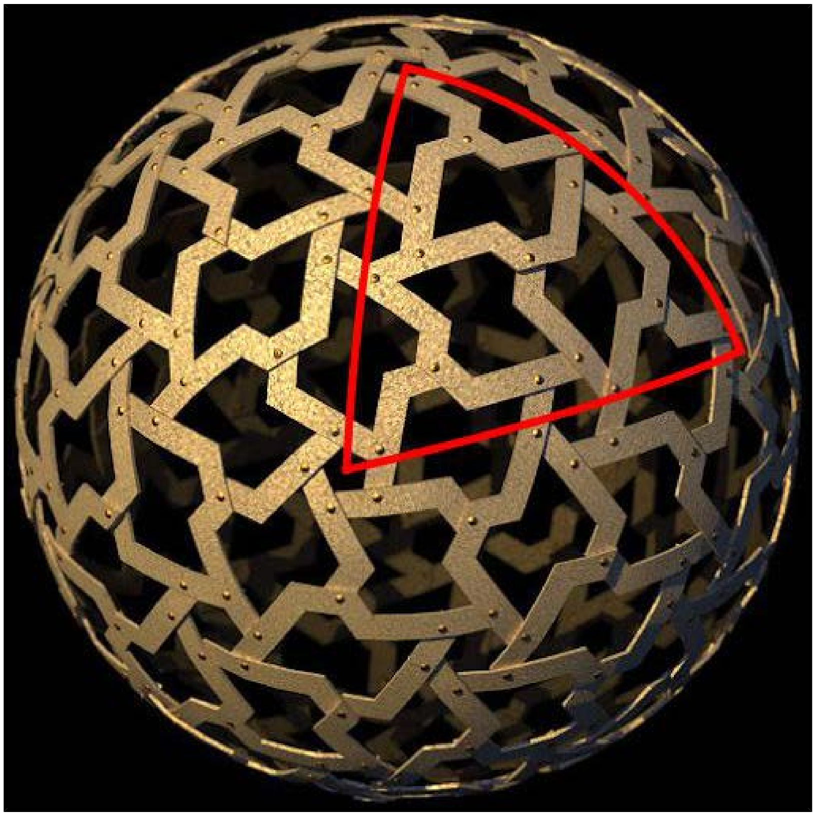
The key, which not everyone realizes, is that math is immensely fun. To leave behind this world of woe and lose yourself in a world of beauty and perfection — it's dangerously addictive.

Puzzle: this shape is covered with little pentagons, little hexagons and funny-looking nonconvex shapes. How many of each are there?

This puzzle is closely related to the question in my March 23rd diary entry. It only takes a tiny bit of persistence to figure it out... at least compared to Wenninger's persistence. But if you get stuck, read on!

First, a solution by Greg Egan:

> Marking out one face of an icosahedron as 1/20 of the whole makes it much easier to count things by eye:



Doing that, it's clear that each 1/20 contains:

- 3/5 of a pentagon
- 3/2 of a hexagon
- 6 non-convex shapes

So the total counts for the whole structure are:

- 20 × 3/5 = 12 pentagons (one per icosahedral vertex)
- 20 × 3/2 = 30 hexagons (one per icosahedral edge)
- 20 × 6 = 120 non-convex shapes (2 per icosahedral edge plus 3 per icosahedral face).

Second, a solution by Julia Young, posted on G+. It's more involved, but I like how it uses less 'looking at the shape' and more 'pure reasoning':

> We can figure this out using the Euler characteristic. Since this is a polyhedron, the Euler characteristic is 2. So the number of faces plus the number of vertices minus the number of edges should equal 2. So this shape satisfies f+v-e=2 where f is the number of faces, v is the number of vertices, and e is the number of edges.
>
> One thing needs clarifying, to avoid confusion before we continue. While the non-convex shapes technically have eight corners and eight sides, I'm going to stipulate that an edge is the curve where two faces meet and a vertex is a point where three faces meet (or, equivalently for this shape, where three edges intersect). With vertices and edges defined this way, the non-convex shapes each have six edges and six vertices.
>
> Let p=the number of pentagons on this surface, h=the number of hexagons, and n=the number of non-convex shapes. Then we have that f=p+h+n.
>
> Since for each pentagon there are 5 vertices, for each hexagon there are 6 vertices, for each non-convex shape there are 6 vertices, and for each vertex there are 3 faces, the total number of vertices is v=(5p+6h+6n)/3.

> Similarly, for each pentagon there are 5 edges, for each hexagon there are 6 edges, for each non-convex shape there are 6 edges, and for each edge there are 2 faces, the number of edges is e=(5p+6h+6n)/2.
>
> Substituting these into the equation f+v-e=2 and simplifying leads us to conclude there are 12 pentagons.
>
> From here, we note by observing the image, that there are two ways the non-convex shapes interact with other shapes. Each non-convex shape satisfies one of the following conditions:
>
> > (1) The non-convex shape shares an edge with 1 hexagon and 1 pentagon, or
> >
> > (2) The non-convex shape shares an edge with 2 hexagons.
>
> Let a=the number of non-convex shapes that satisfy (1). Let b=the number of non-convex shapes that satisfy (2). Note that a+b=n, since each non-convex shape satisfies exactly one of these two conditions.
>
> For each non-convex shape satisfying (1), there is 1 pentagon and for each pentagon there are 5 non-convex shapes satisfying (1). Thus, we have the relationship 5p=a. So a=60.
>
> For each hexagon, there are 2 non-convex shapes that satisfy (1), and for each non-convex shape satisfying (1) there is 1 hexagon. So 2h=a, hence, h=30.
>
> Finally, for each hexagon there are 4 non-convex shapes that satisfy (2), and for each non-convex shape satisfying (2) there are 2 hexagons. So 4h=2b and b=60.
>
> Therefore, there are 12 pentagons, 30 hexagons, and 120 non-convex shapes on this particular polyhedron created by Wenninger.

Here's an interesting fact revealed by Julia's analysis: for the purposes of topology, the nonconvex shapes act just like hexagons... and this shape might as well consist of hexagons and pentagons with 3 polygons meeting at each vertex. In my March 23rd entry, I noted that whenever we have a sphere tiled by hexagons and pentagons, with 3 polygons meeting at each corner, there must be 12 pentagons. I used the same method as Julia: Euler's formula together with a simple counting argument.

But that's just the start of her analysis: then things get more interesting!.

I got my tale of Wenninger from this article:

- Magnus Wenninger, Wikipedia.

and the image from here:

- Taffgoch, Order in Chaos, Deviantart.

For my April 2014 diary, go here.

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For my March 2014 diary, go here.

Diary - April 2014

April 1, 2014

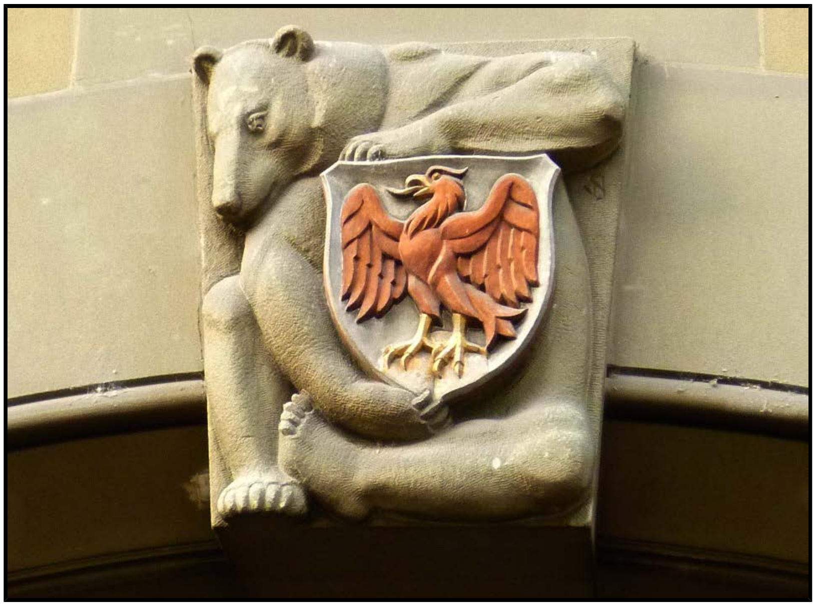
Lisa and I visited Bern, where she has a colleague in the university. It's a great place — still sort of medieval in flavor. The name of this city sounds a bit like 'bear'. And indeed, there are statues and pictures of bears all over Bern.

Legend has it that, in 1191, Duke Berthold V of Zähringen vowed to name the city after the first animal he met in the forest that was to be chopped down for his new city. The story goes:

Then they caught a bear first, which is why the city was called Bern; and so the citizens had their coat and shield, which was a black bear in a white shield, going upright.

Others deny this, but everyone seems to agree that in 1513, when the Bernese returned home victorious from the Battle of Novara, they carried home a living bear... and for centuries, the city has kept bears in a pit called the Bärengraben.

This pit has been moved now and then, and in 1994 it was rebuilt to improve conditions for the bears. But keeping bears in a pit still seemed nasty to many people, so in 2000 the city built a special park for bears by the river Aar — the BärenPark — which is connected to the pit by a tunnel. So now the bears can visit the pit if they want, but they don't have to stay there. When I passed the pit, none were there. No surprise!



April 5, 2014

I'm in Erlangen, where the great German mathematician Emmy Noether was born in 1882. She was the daughter of the well-known mathematician Max Noether - but as a woman, she was only allowed to audit courses at the university here. Somehow she finished a PhD thesis in 1907. She then worked here without pay for 7 years, since women were excluded from academic jobs.

Her thesis advisor, Paul Gordan, specialized in doing complicated calculations to find all the polynomials that were unchanged by certain symmetries. Around this time David Hilbert proved a powerful general theorem that said all these polynomials could be gotten by adding, subtracting and multiplying a finite set of them, called 'generators'. But he didn't say how to find these generators! Gordan said "this is not mathematics; this is theology."

Noether did her thesis, On Complete Systems of Invariants for Ternary Biquadratic Forms, in the style of Gordan's work. It was well received, but she later said it was "crap". While working without pay, she learned Hilbert's ideas and started revolutionizing the subject of algebra.

In 1915 she was invited to the University of Gvttingen by David Hilbert and Felix Klein. Their attempt to recruit her was fought by the philologists and historians, who didn't want a woman on the faculty. Hilbert fought back, saying "After all, we are a university, not a bath house."

It took years for her to actually get paid, but she started working at Göttingen and soon proved the theorem physicists remember her for, relating symmetries and conservation laws. They call it Noether's Theorem.

Her theorem applies to classical mechanics and classical field theory, but there's also a quantum version, and more recently Brendan Fong and I proved a 'stochastic' version, which applies to random processes. The stochastic version is weirdly different from the quantum version, but Ville Bergholm has just written a nice article discussing this issue, and some results he discovered with Jacob Biamonte and Mauro Faccin:

- Ville Bergholm, Noether's theorem: quantum vs stochastic.

Check it out!

Emmy Noether finally started getting a salary in 1923, sixteen years after finishing her thesis. If anyone asks why there are fewer famous women mathematicians than men, consider pointing this out!

Noether did extraordinary work until 1933, when the Nazis kicked her out of the University of Gvttingen. She wound up in Bryn Mawr College, a women's college near Philadelphia. She died of complications from surgery in 1935.

But here are some of the wonderful things she did:

In 1921 she stated the general definition of 'ring' and 'ideal', and proved that in a ring where every increasing sequence of ideals stops growing after finitely many steps, every ideal has finitely many generators. Such rings are now called Noetherian.

In 1927 she gave a massive generalization of the fundamental theorem of arithmetic, about unique factorization into primes. She characterized commutative rings in which the ideals have unique factorization into prime ideals as the integral domains that are Noetherian, 0- or 1-dimensional, and integrally closed in their quotient fields. Sorry - this sounds technical, and it is! But everyone who studies modern number theory takes this result as basic: such rings are now called Dedekind domains, but Noether discovered them.

Even more important than either of these massive results are the beautifully simple 'Noether isomorphism theorems' that everyone learns near the start of a course on group theory.

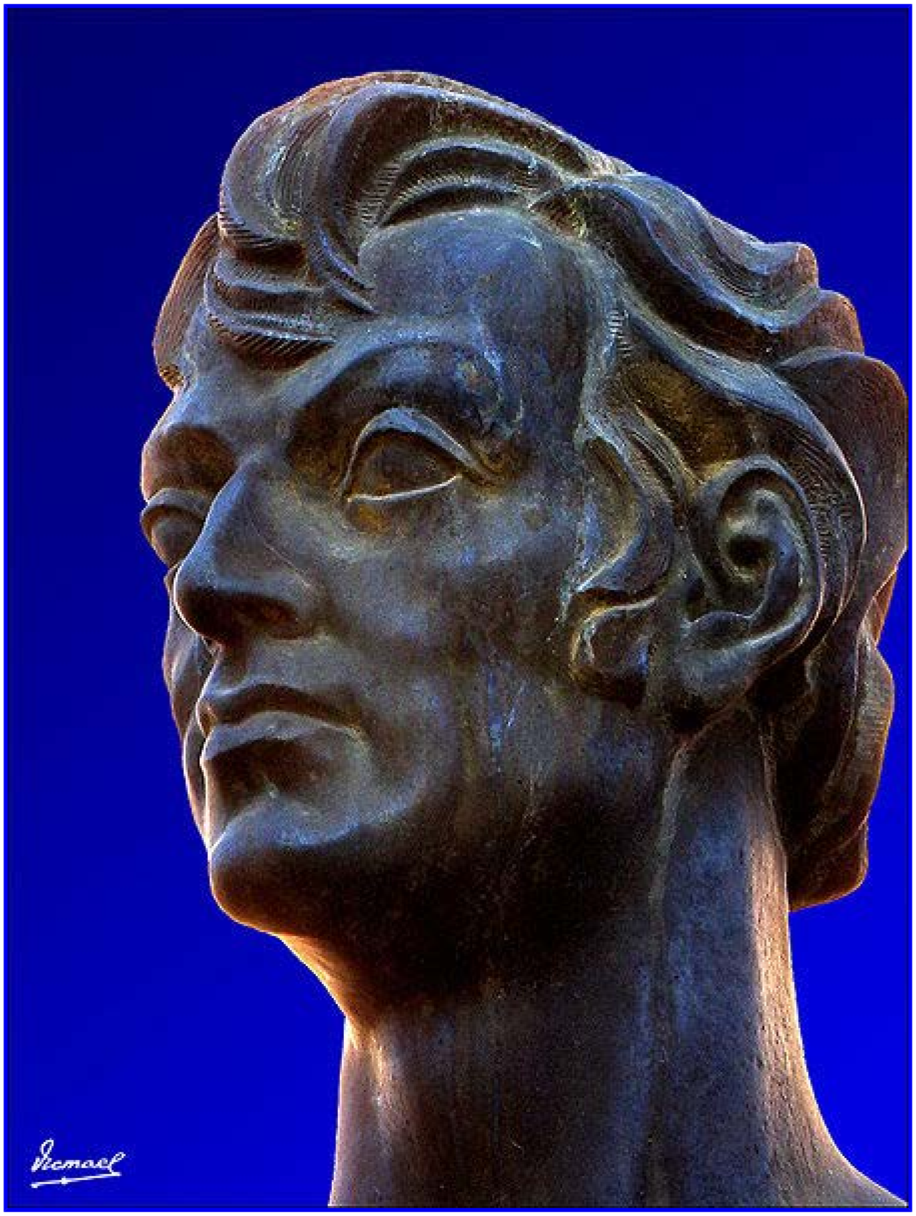
And perhaps even more important was her discovery of 'homology groups' while attending lectures by the famous topologists Alexandrov and Hopf. Other people would have made a whole career out of this discovery, which utterly revolutionized topology. But she only gave it a tiny mention in one of her works on group theory! She was truly a fountain of new ideas.

I now have an office in the Emmy-Noether-Zentrum für Algebra at the university in Erlangen.

For more, try:

- Emmy Noether, Wikipedia.

April 21, 2014



The poet Martial was a kid when Caligula was emperor of Rome. Later he got support from the emperor Domitian. So Martial was an expert on decadence and depravity — and his work shows it.

He's famous for short, snappy, perfectly structured poems with surprise endings. People called them 'epigrams'.

But he's also infamous - because many of those epigrams are rude or even obscene. The *Loeb Classical Library* edition of his work says:

> No account of the work of Martial would be complete without two features being touched upon which have darkened his fame, namely his indecency, and his adulation of Domitian. With regard to the first, however, of the 1171 epigrams in the first twelve books, those open to objection do not exceed a fourth, and if the 350 epigrams in Books XIII and XIV be included, the proportion is still smaller. On the other hand, of the objectionable epigrams the greater part are indescribably foul.

Here's one that's *not* indescribably foul:

> Praedia solus habes et solus, Candide, nummos,
>   aurea solus habes, murrina solus habes,
> Massica solus habes et Opimi Caecuba solus,
>   et cor solus habes, solus et ingenium

omnia solus habes — hoc me puta velle negare! —
    uxorem sed habes, Candide, cum populo.

You don't need to know Latin — I sure don't — to appreciate the tight structure. Almost every line has "solus habes" as its 2nd and 3rd words! This means "only you have" — and the poems is about possessiveness, and arrogance.

Here's a decent translation by A. S. Kline:

> Only you have land, then, Candidus,
> Gold plate, cash, and porcelain, only you,
> Massic or Caecuban wine of famous vintage,
> only you — judgement and wit, only you.
> You have it all — well say I don't deny it —
> But everyone has your wife, along with you.

A put-down, with a zinger at the end — typical Martial.

Here's another, also translated by Kline:

> Chloe, I could live without your face,
> without your neck, and hands, and legs
> without your breasts, and ass, and hips,
> and Chloe, not to labour over details,
> I could live without the whole of you.

But now maybe you want to read an "indescribably foul" one, to see how bad they get! Well, you're not getting it here. Try this:

- A. S. Kline, Martial, *Selected Epigrams*.

This is how to get people to read poetry.

Personally I find many of Martial's poems annoying... but it's very interesting to see that art designed to shock is not new to the 20th century. Are we, like the Roman Empire of Martial's day (roughly 40-100 AD), a civilization that's become decadent?

On a brighter note, Martial was a jolly fellow, good to his friends, and he spent a lot of time living out in the countryside. This gives the flavor of it:

> These, my dearest Martialis, are
> the things that bring a happy life:
> wealth left to you, not laboured for;
> rich land, an ever-glowing hearth;
> no law, light business, and a quiet mind;
> a healthy body, gentlemanly powers;
> a wise simplicity, friends not unlike;
> good company, a table without art;
> nights carefree, yet no drunkenness;
> a bed that's modest, true, and yet not cold;
> sleep that makes the hours of darkness brief:
> the need to be yourself, and nothing more;
> not fearing your last day, not wishing it.

Only the remark that *inherited* wealth makes for true happiness makes this outdated. Roman society, unlike ours, was *openly* aristocratic, with social equality not even a goal.

The photo above was taken by someone named Victor Manuel, who put it on WikiCommons. It shows a bronze bust of Martial created by the Spanish artist Juan Cruz Melero (1910-1986).

Over on Google+, Annarita Ruberto clarifies:

> The novelty of Marco Valerio Marziale consists in the elimination of mythology, considered false and far-fetched. The aim of his poem is to totally take inspiration from reality.
>
> (I studied Latin and Greek for five years before graduating in Physics;)).

and then:

> With Marziale we have the affirmation of the epigram as a literary device: before him, the epigram, dating back to arcaic Greek age, was essentially a commemorative function and was used to positively remember a thing or a person (and in fact the word "epigram" comes from the greek and means "inscription" from *epigraphein* "to write on &mdas; inscribe"); but thanks to his work it, while retaining its brevity, deals with new issues such as parody, satire, politics and eroticism.
>
> From the stylistic point of view, Marziale opposes the mobility of the epigram both to the epic genre and to Greek tragedy, which through their famous and "heavy" themes kept away from everyday reality. Constant is in fact, in his verses, the literary controversy, often used to defend against those who considered poorly valid (from the artistic point of view) the epigrammatic kind, but also against those who accused him of being aggressive or obscene.
>
> The language he uses is colloquial and everyday. His constant realism, however, allows him to develop a rich language by introducing in literature many terms and phrases that had never before found a place. He is able, finally, to demonstrate great flexibility in alternating elegant and sophisticated phrases with indecent and often vernacular sentences.

For my May 2014 diary, go here.

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[For my April 2014 diary, go here.]

Diary - May 2014

John Baez

May 11, 2014

It looks like an old Dutch painting, but it's a photo of L'Ecurie: a dim-lit, ancient restaurant in what once was a stable. Lisa and I are back in Paris — and every time we come here, we eat at L'Ecurie.

See that wooden rack? That's bread up there. The food is reliably good, and the woman Miny who owns the place is tremendously sweet   when Lisa said how much we like coming back here, she gave Lisa a kiss on the head!

This review by Brian C. gives some of the flavor:

> In the Place de la Montagne St Genevieve very near the Pantheon. A most extraordinary place. The decor has not changed possibly for a hundred years. The bar counter is still a 'zinc'. When you arrive the manager plonks down a sangria in front of you 'on the house'. The menu is small but the quantity is immense. A lot of 'chips' and different bits of beef. Wine comes in carafes. One could say an atmospheric place. No decent woman would attempt the toilet . Nor would few men. I have never seen, even in la France Profonde, a more primitive structure. Even the owner advises people to go across the road to another establishment "if you cannot face the toilet". She has an arrangement! Her sons tell her she should upgrade the whole place but it would most certainly lose character! That would be a pity. But you would think that the toilet could be modernised.

But this tale from the book *Through Darkest Gaul with Trencher and Tastevin* is even better:

> I went on a sunny evening (one of the few this sodden summer) and found an ancient seedy building whose decor, inside and out, could best be described as Dickensian Hippie. The facade was the sort of black which

> might have begun decades ago as any other color, with decoration which included a couple of brightly-painted cartoons and an amazing tattered photo of an ancient bearded gentleman on an enormous tricycle, a parodic Horseman of the Apocalypse. Over the sidewalk hung a sign with a stylized representation of a strutting Etruscan stud. The tables inside were crowded and higgledy-piggledy, so I opted for a small table on the sidewalk in the sun with the grill just the other side of an open window. There I could enjoy everyone else's dinner as well as my own.
>
> I was immediately brought a glass of sangria, a basket of bread, and a generous dish of aïoli which must have kept the staff occupied all day crushing the garlic. The aroma wafting through the window told me that my first course had to be grilled marinated sweet peppers and tomatoes, brushed with the marinade and sprinkled with basil. These proved to be succulent even beyond expectation. For a main course I settled on grilled lamb chops and French fries and was rewarded with lamb which tasted simply of lamb and fries which tasted of potato. My only mistake was to pass up the house wine for an indifferent Provencal rosé. Subsequently I would adopt the maxim,
>
> > Don't stray
> >   From the cliché,
> > Just stay
> >   With the pichet!
>
> At the end of a leisurely meal I was brought a glass of calvados. (Like the sangria, it came with the territory.) By then the restaurant had filled up and a young couple with a baby, evidently friends of the staff, were regretfully informed that there was no room in the inn. Observing a star in the East, I stood up and offered them my table, which they gratefully accepted. Conversation revealed that he was himself a restaurateur, in charge of a riverside restaurant at the Bastille which was mentioned in one of my guide books. It was his night off. I was reassured; "Eat where the chefs eat," is my motto.
>
> He proved to be very familiar with L.Ecurie and knew something of its history. The building itself, he thought, went back to the 16th century and the ground floor had been a restaurant for at least a hundred years. I would later discover that the bar inside was an original zinc. This was the metal from which they were usually made, so that it became the generic term even when the bar was wood or even plastic. Alas, this became common during the last war, when almost all of the zinc bars were melted down by the Germans. This is one of the few to survive, and the maker's seal is evidence that it dates from just after the Great War (as opposed to the others).

All this is still true. But it's just the start! For the whole story, go here:

- John Whiting, L'Ecurie, from *Through Darkest Gaul with Trencher and Tastevin*, 1997.

Clearly this place inspires not just affection but love from many people. The reason, ultimately, is that Miny is more interested in making people happy than making money.

May 24, 2014

This is the category theorist Andrée Ehresmann in an anechoic chamber, computer in hand. Yesterday we went into this room at IRCAM, a famous experimental music laboratory in Paris.

An anechoic chamber is a room with walls designed to absorb all incident sounds — if you snap your fingers, it sounds strangely dead, and one of my hosts said you can lose your sense of orientation. At IRCAM they sometimes suspend a piano inside the anechoic chamber to study its sounds without any echoes getting in the way.

IRCAM is the Institut de Recherche et Coordination Acoustique/Musique. From the outside it looks unimpressive, because most of the rooms are underground. Inside they've got a huge performance space where all the walls are speakers... using computers they can make sounds move around the room. And I got a great demonstration of OMax, a program that can listen to musicians, learn the patterns, and start to improvise along with them in real time.

Andrée Ehresmann is a mathematician who began as analyst but then worked on category theory with her husband Charles, developing concepts such as double categories, internal categories and the like, often for the study of differential geometry. At IRCAM she is working on music theory with Moreno Andreatta and Alexandre Popoff.

They're studying 'K-nets', which are diagrams where the vertices are notes or chords, and the edges are musical operations like transposition (raising or lowering a note or chord) and inversion (flipping a note or chord upside down). K-nets were invented by a music theorist:

- Klumpenhouwer network, Wikipedia.

but they're easiest to define using some category theory. You start with a group G of musical operations (like the 24-element group of transpositions and inversions), think of it acting on a set S (like a set of notes or chords), and then look at a functor from a diagram D into G. Then the vertices of the diagram get labelled with notes or chords in S, while the edges get labelled with musical operations in G.

I had a great time, and hope to spend more time there someday when I return to Paris! Alas, I'm leaving the day after tomorrow.

May 25, 2014

The Alhambra is a marvelous palace in Granada, Spain. It started as a small fortress, but it was renovated in the 11th century by a Moorish king, and converted into a royal palace in 1333 by the Sultan of Granada. The Sultan's Canal carries water from a nearby river, and it goes by aqueduct the Alhambra. This was used for vegetable gardens and drinking water... but also fountains, ponds and a famous 'water stairway', which beautified and cooled the palace grounds.

The Alhambra is also famous for its gorgeous tiling patterns. Since I like the math of these, I photographed the Alhambra tiles when I visited Granada to give a talk at their Department of Algebra. (Yes, they have a department of algebra!) You can see some of my photos in "week267" of This Week's Finds, along with a discussion of the 17 "wallpaper groups" that show up as symmetries of tilings. John Conway has a cool way of proving that these 17 groups are the only options.

But yesterday, someone at Open University wanted a high-resolution copy of an Alhambra tile photo. In the process of giving it to them, I noticed that this picture of a pool isn't bad either. See the goldfish?

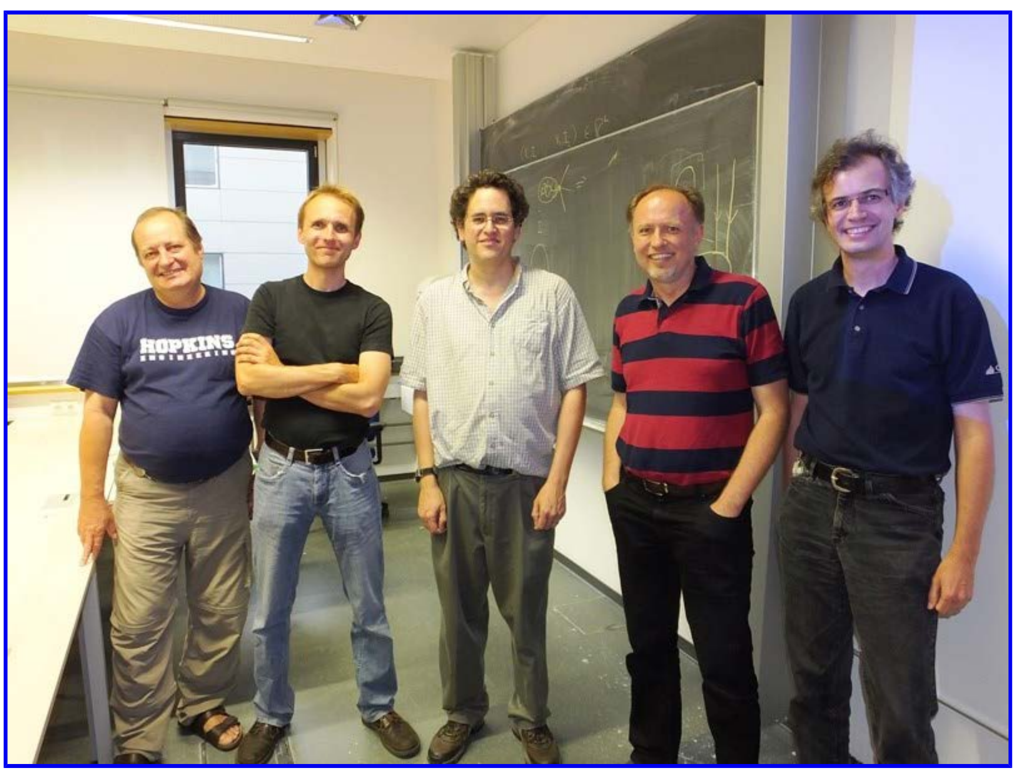
May 26, 2014

Lisa are getting ready to leave Erlangen and return to Riverside. Today I gave a talk at the computer science department here.

It turns out Erlangen is the 'sister city' of Riverside, California. When I first came here, I disovered this accidentally when I was registering at the town hall — I bumped into a little display in the town hall that announced this. But somehow an official from the local government found out I was giving my talk yesterday and wrote an article about it:

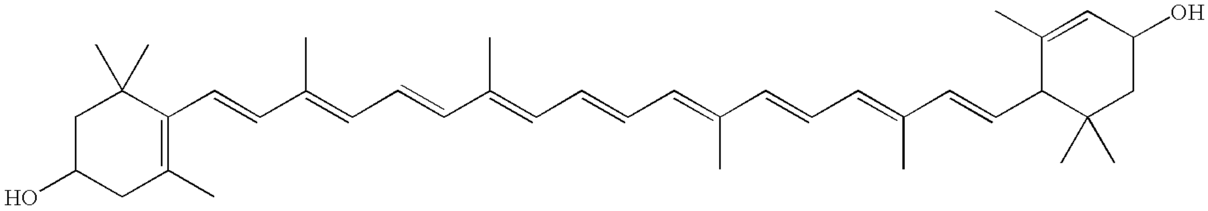
- Mathematikstunde aus Riverside.

You can click to read a translation into English. It doesn't make much sense, but it's flattering.

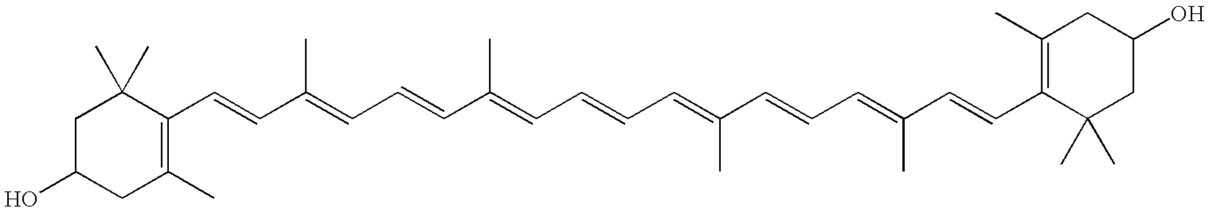


May 27, 2014

Why are egg yolks yellow? They contain two very similar yellow chemicals called **lutein** and **zeaxanthin**. I like these molecules because one of them is perfectly symmetrical, and the other is *almost* perfectly symmetrical. Can you see which is which?



Lutein



Zeaxanthin

These chemicals are synthesized only by plants. They're called **xanthophylls**, from the Greek words for 'yellow' and 'leaf'. You can get lots of xanthophylls from green leafy vegetables like spinach. Plants use use xanthophylls to deal with problems that arise when it's too sunny. Bright sunlight makes a lot of **triplet-state chlorophyll**, an excited form of chlorophyll, which can cause chemical reactions that damage the plant. The xanthophyll cycle is a way of removing excess energy from triplet chlorophyll in a harmless way.

Animals get lutein and zeaxanthin from plants. The retina of your eye contains these chemicals! Since these chemicals look yellow, they absorb purple light... and it seems they help our eyes avoid the damaging effects of that light.

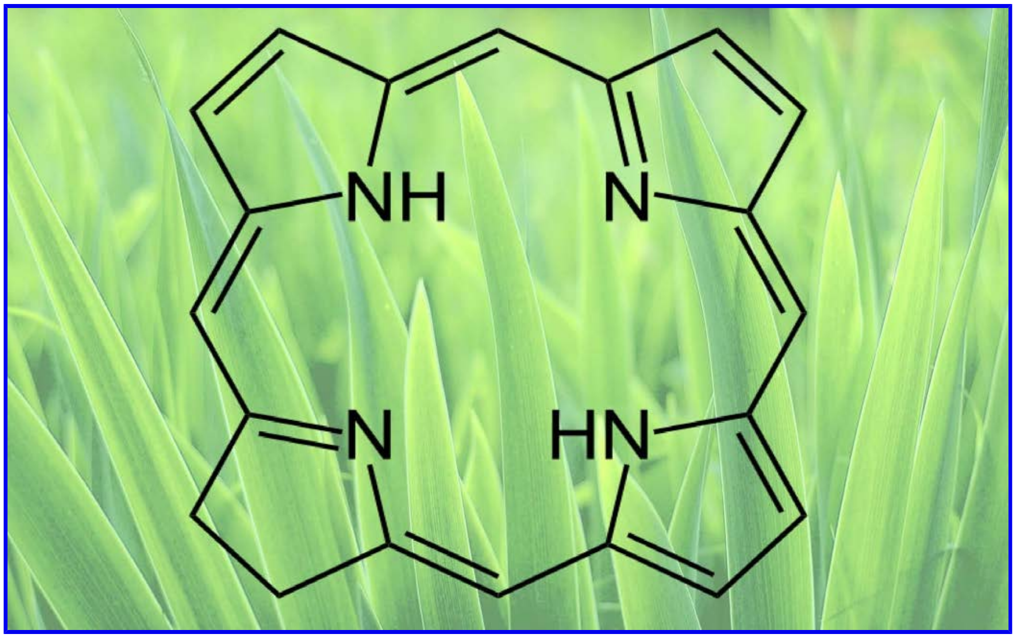
Why do egg yolks contain these chemicals? They're fat-soluble, so it's easy for them to get dissolved in the fatty yolk. But also, they seem to be important antioxidants during the rapid growth of an embryo, and help the embryo mount a good immune response to infections.

These chemicals are colorful because they have a long chain of **conjugated double bonds** between carbon atoms — shown as alternating single and double bonds in this picture. Electrons vibrate back and forth along this chain in a fun quantum way. So, when a photon of the right color hits the molecule, it can easily be absorbed — and its energy goes into the motion of electrons!

Like piano strings, electrons in chains of conjugated double bonds vibrate faster when these chains are shorter. Molecules with a chain of fewer than 8 such bonds absorb only ultraviolet light, so they look colorless to us. With every extra double bond, the system absorbs photons of longer wavelength. Lutein and zeaxanthin absorb purple light — so they look yellow. Carotene, from carrots, absorbs blue light — so it looks orange!

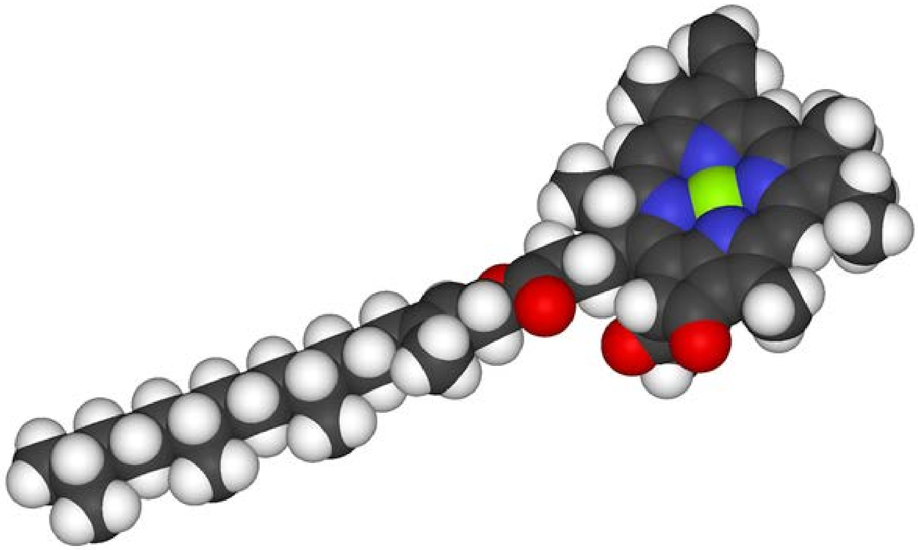
For more, see the great comments on my G+ post.

May 29, 2014



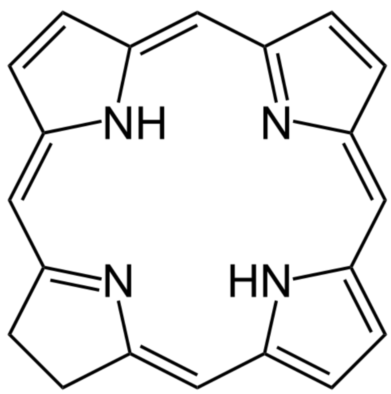
Grass is green because it contains chlorophyll. But why is chlorophyll green?

Chlorophyll contains **chlorin**, shown here... and in the middle of the chlorin, a *magnesium atom with 2 electrons missing!* There are different kinds of chlorophyll — but the most common have a long 'tail' of carbon and hydrogen atoms, called **phytol**. For example, take a look at **chlorophyll *a*:**



The chlorin, with the magnesium ion in its heart, is the part that absorbs light. It has lots of alternating single and double bonds, and this so-called **conjugated system** is really good at absorbing light.

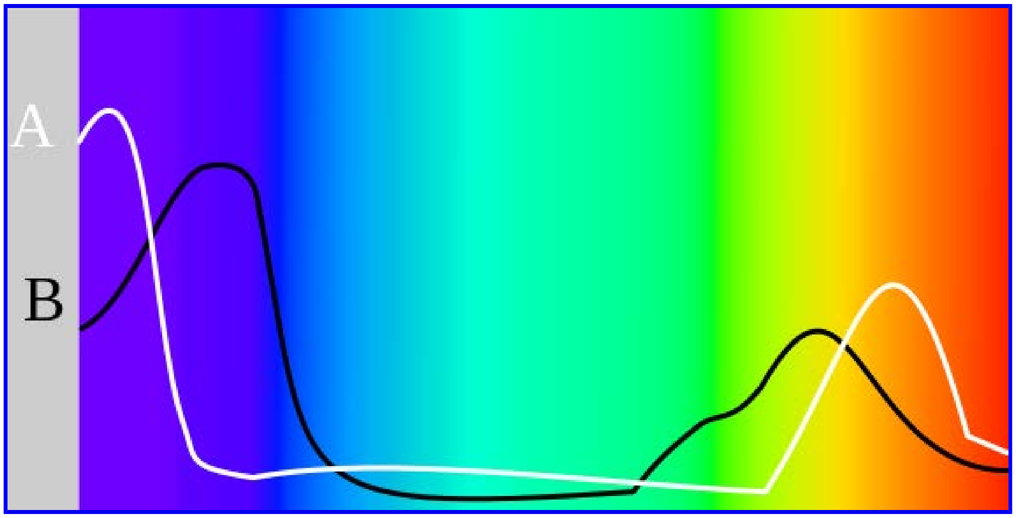
What role does the magnesium ion play, exactly? I don't know! In my May 27th entry I showed you a xanthophyll, a yellow-colored molecule that also absorbs light in the leaves of plants — not for photosynthesis, but for dealing with situations where there's *too much* light. Xanthophylls have a *chain* rather than a *ring* of single and double bonds — and no magnesium: just carbon, hydrogen and sometimes a couple oxygens at the ends. But somehow magnesium is essential for the proper functioning of chlorophyll: without it, plants get sick and die.



I like chlorin because it's almost but not quite symmetrical. At first it looks as symmetrical as a square! But soon you notice that two of the nitrogen atoms are attached to hydrogens and two are not. Look harder, and you'll see even more asymmetries!

Three of the pentagons here have alternating single and double bonds. They're called **pyrrholes**, and electrons in these pentagons easily get excited by light. But the fourth pentagon does not have alternating single and double bonds. It's called a **pyrroline**, and its electrons do *not* get easily excited.

You'll notice I never said why chlorophyll is green. One answer is that it absorbs lots of light at the red and blue ends of the visible spectrum, but not so much green. Here are the absorption spectra of the two most common kinds of chlorophyll — **chlorophyll *a*** and **chlorophyll *b***:



I bet physical chemistry is advanced enough now that we can show the spectrum has to look like this, given the molecule structure of chlorophyll and what we know about quantum mechanics. But there are other ways to tackle the puzzle. For example:

Puzzle. Why aren't plants black, so they can absorb as much light as possible?

You can see a lot of discussion of this very hard puzzle on my Google+ post. In particular, this interesting paper:

- Marcell A. Marosvvlgyi and Hans J. van Gorkom, Cost and color of photosynthesis, *Photosynthesis Research*, 2010.

seems to contain math errors, as discussed here and in some comments on my G+ post:

- V. Verburg, Why are plants green? An investigation into the mathematical details of the paper 'Cost and color of photosynthesis', Bachelor's thesis, Mathematisch Instituut, Universiteit Leiden, 2011.

For my June 2014 diary, go here.

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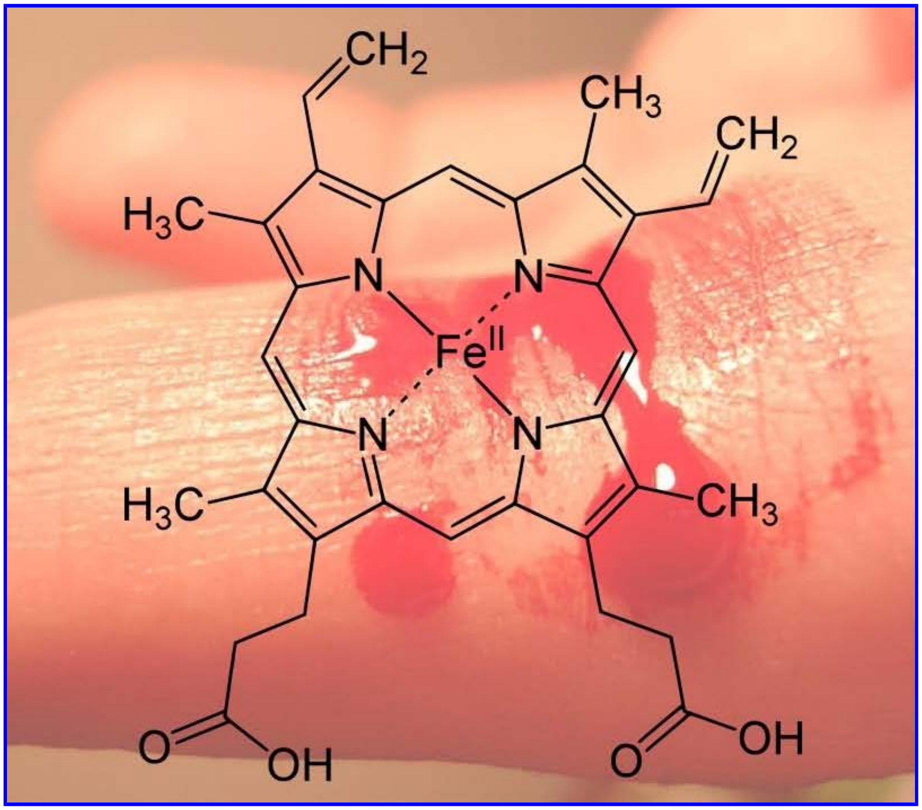
[For my May 2014 diary, go here.]

Diary - June 2014

John Baez

June 3, 2014



Why is blood red? It contains **heme**, a molecule which is very similar to chlorophyll... but with *iron* instead of *magnesium* at its heart!

Like chlorophyll, heme is a **porphyrin**. That means it's made of four pentagons of carbon and nitrogen joined together by bridges of carbon. In chlorophyll *a*, *almost* all the carbons connected by alternating single and double bonds. In heme, they *all* are.

These alternating single and double bonds let electrons roam around in a smeared-out, quantum way... and when light hits the molecule, it's like a kid jumping on a trampoline! It makes these smeared-out electrons vibrate back and forth. But unlike the kid, the light gets *absorbed* if it's vibrating at the right frequency: it transfers *all* its energy to the molecule.

Chemists have a really sexy way of talking. Listen to how they say what I just said:

> Heme and chlorophyll are porphyrins. Porphyrins are heterocyclic macrocycles composed of four modified pyrrole subunits interconnected at their α carbon atoms via methine bridges (=CH-). Porphyrins are aromatic. That is, they obey Hückel's rule for aromaticity, possessing 4n+2 π electrons (where n is the number of carbon atoms) delocalized over the macrocycle. Thus porphyrins are highly conjugated systems. As a consequence, they typically have intense absorption bands in the visible region.

Nothing about kids jumping on trampolines...

But I've got some questions. It's important that chlorophyll absorbs light - that's how plants get energy. It doesn't seem important that heme absorbs light. What heme does is grab *oxygen*, carry it to where it needs to go, and then let it go. So:

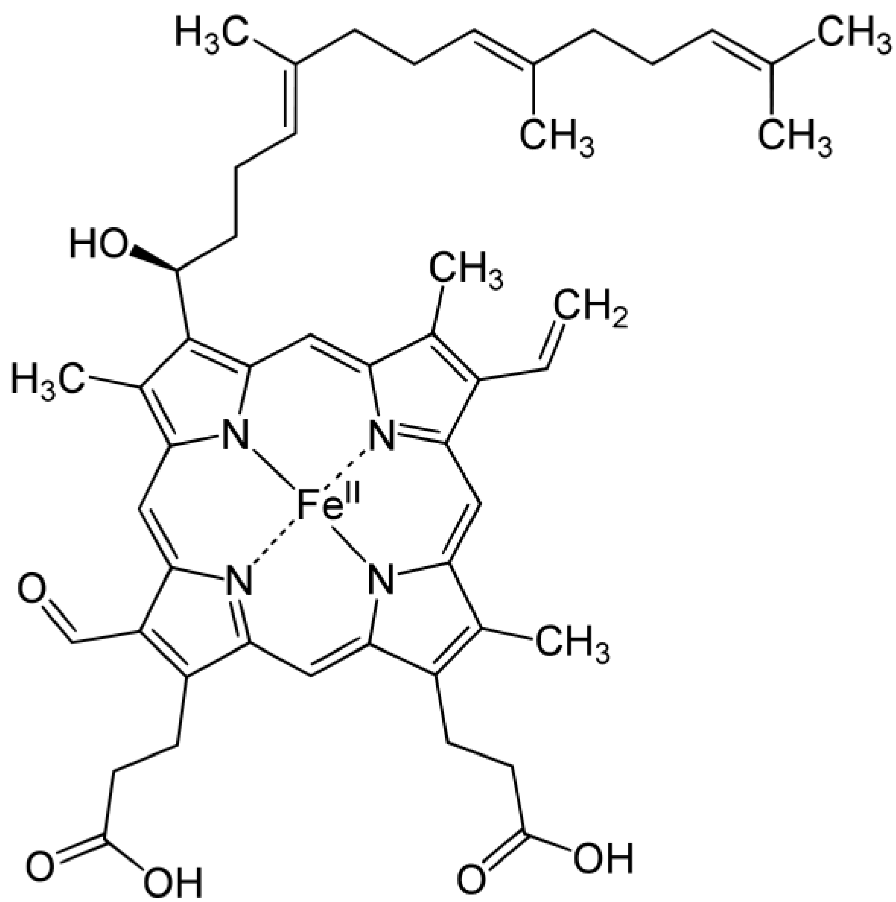
Puzzle 1. Is it just a 'coincidence' that blood is red, or is its color somehow a necessary aspect of its biological function?

Puzzle 2. Did heme evolve from chlorophyll? Did chlorophyll evolve from heme? Did they both evolve from a common molecule? Or in each case did nature arrive separately at the idea of using a porphyrin with a metal ion in the middle?

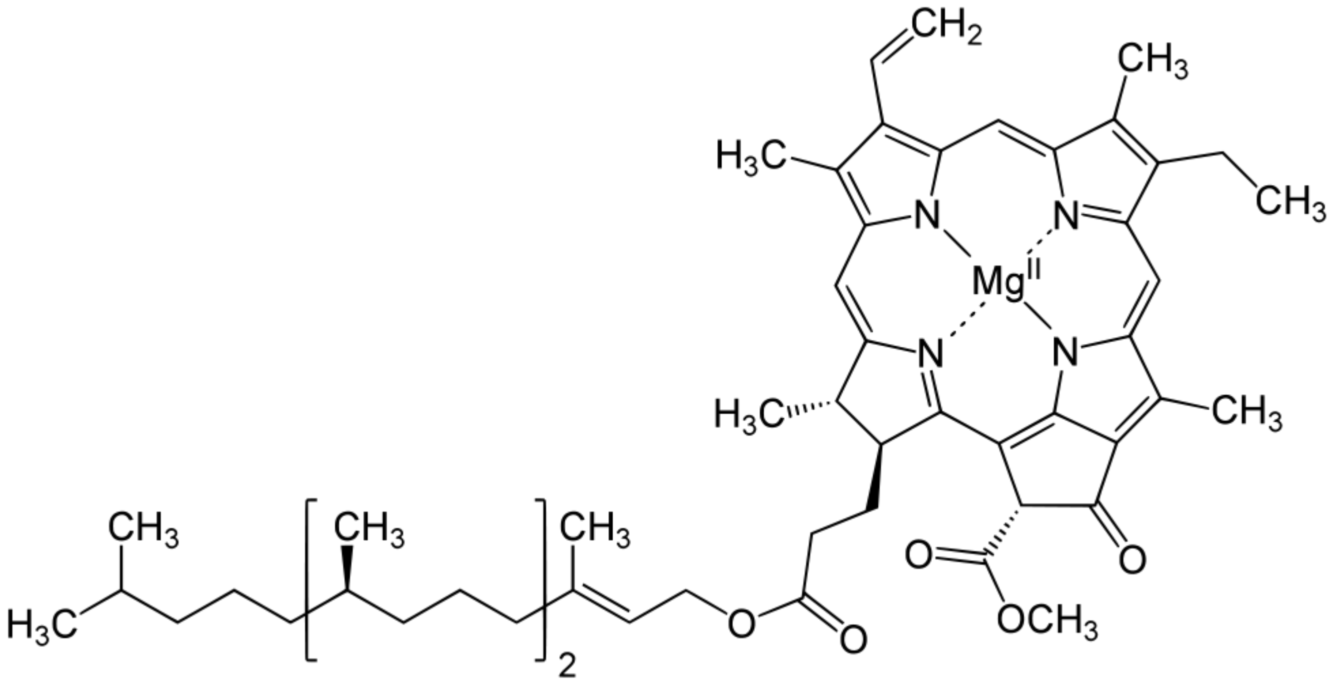
I can give you some hints for Puzzle 2. Hemoglobin and hemoglobin-like molecules are also found in many invertebrates, fungi, and plants. These molecules can carry oxygen, or transport and regulate other things such as carbon dioxide, nitric oxide, hydrogen sulfide and sulfide ions.

There are also porphyrins containing other metals! For example, the blood of crabs contains **hemocyanin**, which has *copper* instead of iron.

The molecule shown above is **heme *b***, the most common form in humans. **Heme *a*** is a lot like chlorophyll *a* — they both have a long chain of carbons attached to the porphyrin. Here is heme *a*:



and here is **chlorophyll *a***:

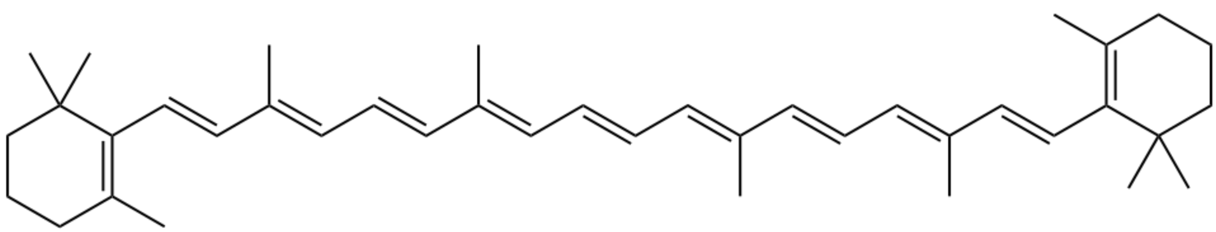


The portion with the bracket around it is repeated twice: that's what the subscript 2 means.

For some attempts to answer my puzzles, read the comments on my Google+ post.

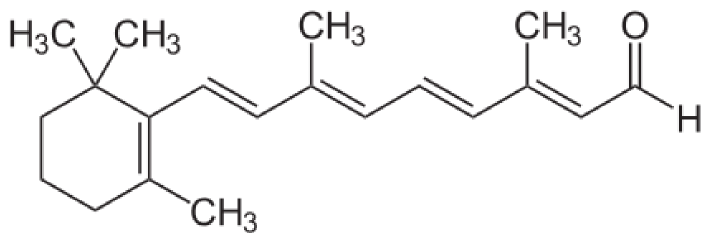
June 5, 2014

Why are carrots orange? Because they contain carotene.



Carotene comes in different forms, but here is one of the most common: **β-carotene**. I like it because it's perfectly symmetrical. It has a long chain of carbons with alternating single and double bonds. Electrons vibrating along this chain absorb blue light. So the carrots have the opposite color: *orange!*

Humans need a chemical called **retinal** in order to see:



It looks roughly like half a carotene molecule — and like carotene, it's good at absorbing light. Attached to a larger protein molecule called an **opsin**, retinal acts like a kind of antenna, catching particles of light.

Humans can't produce retinal without help from the foods we eat. Any chemical we can use to produce retinal is called **vitamin A**. So vitamin A isn't one specific chemical: it's a group. But beta carotene counts as a form of vitamin A.

So, you can do something amazing without even thinking about it: you can eat a carrot, extract the beta carotene, break it in half, turn it into retinal, attach it to an opsin, and *see!* That's why eating carrots is good for your vision.

It's no coincidence that plants contain carotene: its light-absorbing abilities play a role in photosynthesis. But...

Puzzle 1. Why do carrots, which are *underground*, contain a lot of carotene?

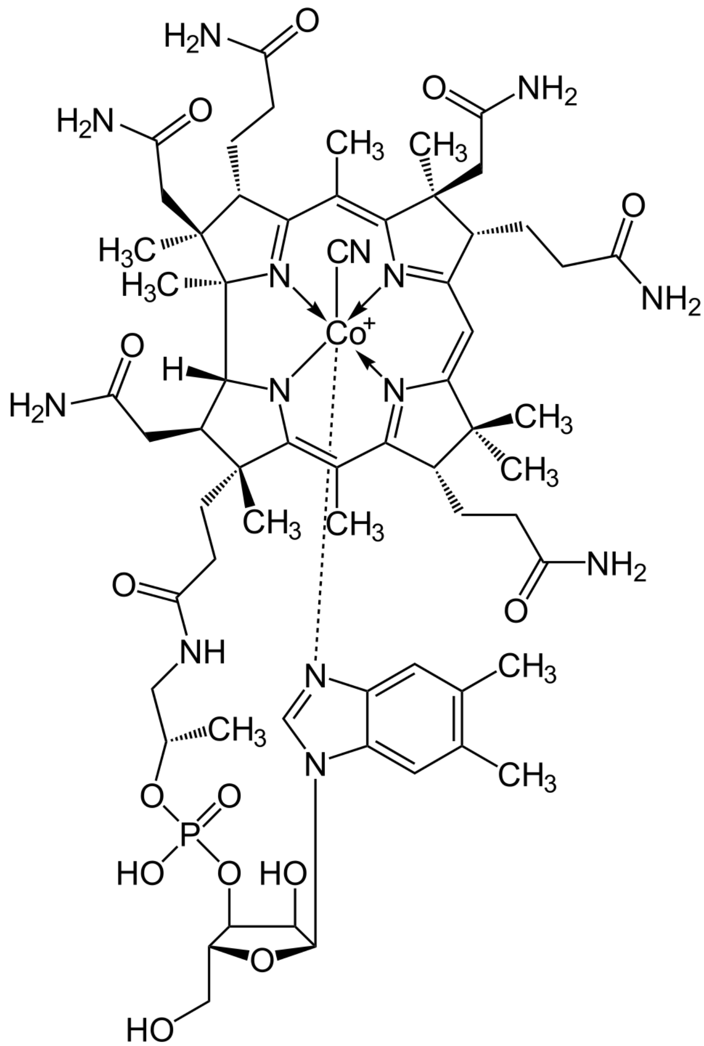
Puzzle 2. Why are *oranges* orange?

You can see alpha-, beta-, gamma- and delta-carotene here:

- Carotene: the multiple forms, Wikipedia.

For answers to the puzzles, see my Google+ post.

June 6, 2014



Look at this amazing molecule! It looks a bit like chlorophyll or heme, but it's got an atom of *cobalt* in the middle where those others have magnesium or iron.

What's amazing is not that this molecule exists. What's amazing is that you need to eat it — or something very like it. It's called **vitamin B12**, and you need about 2 micrograms a day.

In the middle ages, German miners called some rocks **kobold** ore — German for 'goblin' ore — because they were poor in known metals and gave poisonous fumes when you heated them. In 1739 a Swedish chemist named Georg Brandt discovered that these rocks contained a new metal. So this metal, **cobalt**, is named after goblins!

It took a lot longer to realize that cobalt is essential for human life. In 1934, three chemists won the Nobel prize for discovering that eating liver could prevent a disease called **pernicious anemia**. The crucial chemical in liver — now called vitamin B12 — was isolated in 1947. But its structure was only understood in 1956.

Animals can't make vitamin B12 — only bacteria, and a kingdom of older life forms called **archaea**, can do it. But animals store it, so if you eat liver, or other kinds of meat, or fish, or eggs or milk, you'll get vitamin B12. And you don't need very much!

The molecule here is a form of vitamin B12 called cyanocobalmin, because it has a cyanide ion — CN — attached to the cobalt. This is an artificial form of B12 you can buy at a drug store.

Puzzle. What is vitamin B11?

For the answer and some nice discussions see my Google+ post.

June 7, 2014

Three days ago my wife Lisa started seeing flashes like lightning in the peripheral vision of her right eye. Then she started seeing black specks like gnats. Years ago she nearly had a detached retina, which doctors bolted down with laser surgery. So she has always been on the lookout for symptoms like this.

We went to the emergency room around 8 pm, shortly after the black specks formed a 'curtain' in the middle of her field of vision. Standing two yards from a mirror, she said: "I can't even see the color of my eyes."

In some ways we're all waiting for something like this to happen.

We're all going to die... or at least, most of us: some 'transhumanists' optimistically freeze their brains in hopes that future generations will revive them, but even if this hope comes true, most people can't afford that. I've gotten used to the idea of dying, so I'm not going to extraordinary lengths to prevent it. The harder part is slowly walking down the stairway of old age: getting used to worse and worse health, slower wits, less energy... down to nothing.

It's a journey of renunciation. Wise old people don't talk about this much, because they know it annoys and (secretly) upsets the young. It's better to let them live in their happy self-absorbed world: no point in spoiling it.

This must be one reason people like having children and grandchildren: as you falter and fade, they (with luck) are still growing stronger. The spotlight nicely shifts from you to them... so when death pulls you off the stage with its hook, nobody pays much attention: overall, the show is still a happy one.

Since I don't have children, I don't know exactly what this feels like. I tend to use math and physics to create that happy dreamworld where everything keeps getting better and better... though I also have students, who will carry on when I conk out.

When I switched from pure math and fancy theoretical physics and started thinking hard about global warming, I had to accept the extra emotional burden of facing a world that was not all bright and beautiful. I think some of my fans left at this point: it turns out they wanted my science explanations to cheer them up! But I've got a lot of built-in pep and happiness, so I don't need a diet of pure candy.

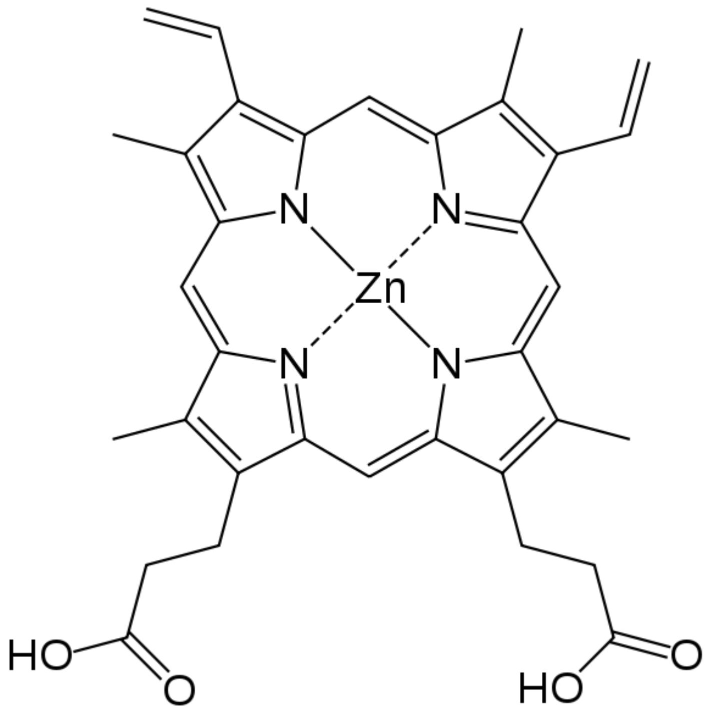
Anyway, it seems that Lisa had a posterior vitreous detachment, where the vitreous membrane separates from the retina. It's not a disaster: three quarters of people over 65 get this condition! Here eye bled a bit when this happened, so she has a bunch of red blood cells floating in her vitreous humor. Supposedly in a month these blood cells will go away, decomposed somehow by the magically self-repairing body.

So, it's not so bad. I know that this is just one more step down that spiral stairway to darkness that Lisa and I are walking, hand in hand. But that's just how it goes.

Lisa seems less perturbed by this than me: while I'm writing this little essay, she's packing her suitcases. At 9 tonight she's taking a shuttle to the airport and then flying to Singapore! I'm going to a conference in Banff for a week, on computation with chemical reaction networks. Then I'll join her in Singapore, where we will spend the summer working.

So life goes on. Until it doesn't. And even then, it goes on.

June 12, 2014



This beautiful molecule looks a lot like heme, but with *zinc* instead of iron at its heart! If you get lead poisoning, your blood will start getting this instead of heme in it.

This molecule is called **zinc protoporphyrin**. It can show up in your blood for several reasons, including:

- lead poisoning
- iron deficiency
- sickle cell anemia
- vanadium poisoning

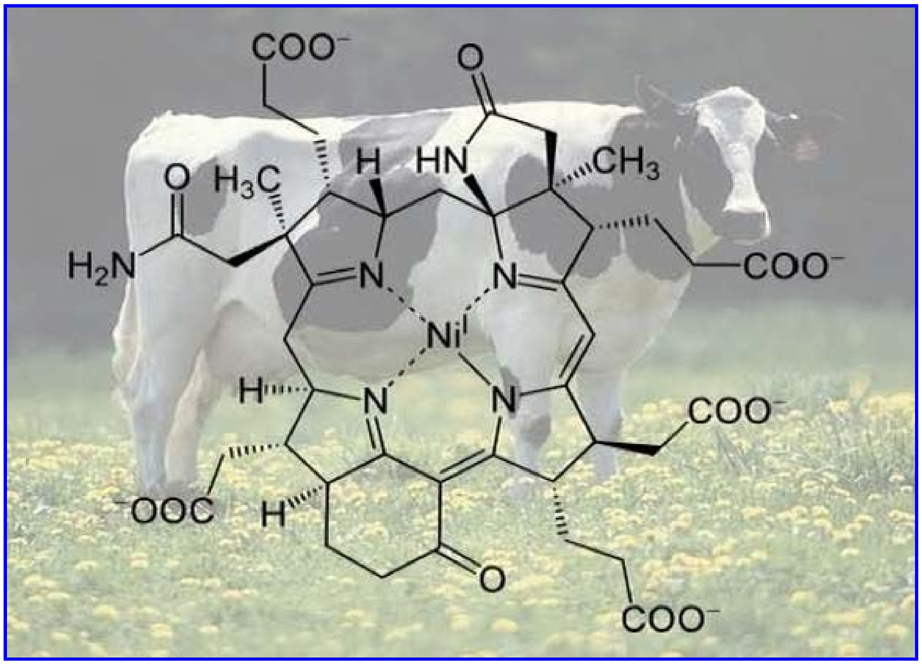
Puzzle 1. Why?

I don't know! I guess it makes sense that if you have an iron deficiency the body might wind up grabbing some similar metal and using it as a substitute for iron in the heme.

Puzzle 2. Does it work? In other words, can it actually help you breathe?

Anyway, people use the presence of zinc protoporphyrin as a test for lead poisoning and other problems. Zinc blood is a bad sign.

June 21, 2014



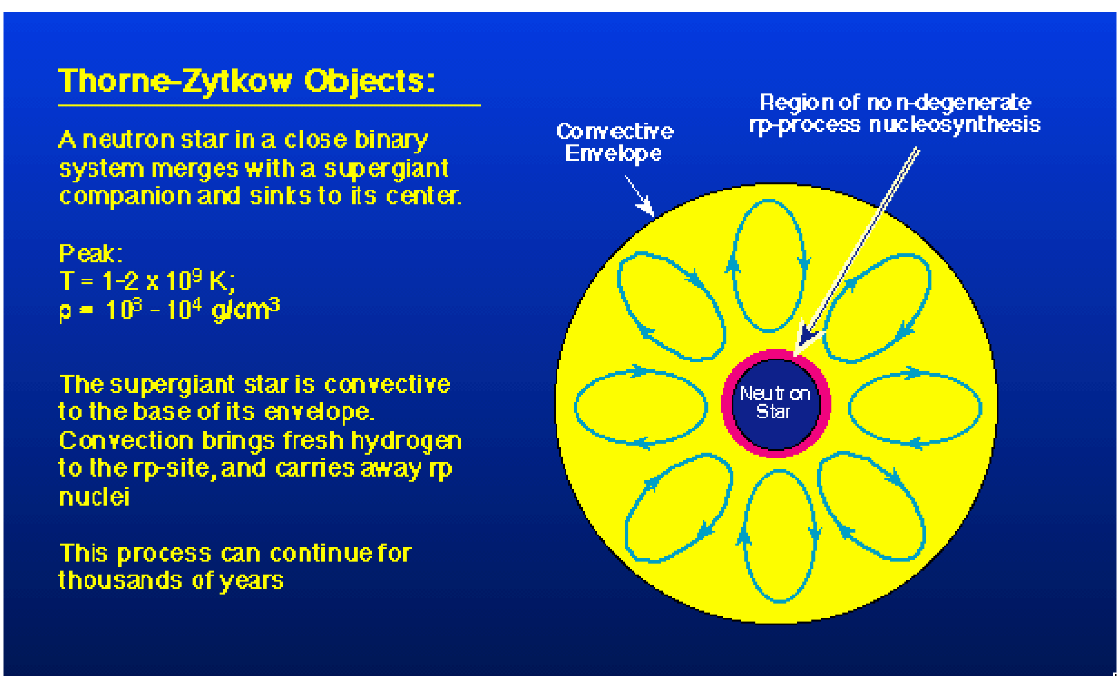
This molecule looks like chlorophyll or heme — but where those have magnesium or iron, this has an atom of *nickel* at its heart! And this molecule, called **cofactor F430**, is part of why cows burp so much.

Like all vertebrates, cows can't break down cellulose, the main ingredient in grass. So they have 4 stomachs, and in the 'rumen' there are trillions of tiny organisms that *can* break down cellulose. These organisms make sugars, which the cows can digest — but also other chemicals, including methane. The cows fart and burp... and since methane is a powerful greenhouse gas, about 40% of all global warming due to agricultural activity comes from this process! Not just from cows, but also sheep and goats.

The tiny organisms that make methane are called **methanobacteria**... but now we know they aren't really bacteria. We've learned a lot about the tree of life in recent decades. Now life is classified into three huge 'domains': Archaea, Bacteria, and Eukaryota. You, the cow, and the grass are all in Eukaryota. Archaea are a very ancient domain, and they include methanobacteria.

Here's something cool: some Archaea called **methanotrophs** use cofactor F430 in reverse to *metabolize* methane instead of make it. Could this go back to the days when Earth's atmosphere had lots of methane? Now these methane-eaters live in mud, marshes, soils, rice paddies, landfills and oceans. If we learn to use them, we could use them to help fight global warming!

June 22, 2014



A **Thorne–Żytkow object** is a giant star that has swallowed a neutron star. The idea of such a thing was invented by Kip Thorne and Anna Żytkow in 1976. Now we may have found one!

A Thorne–Żytkow object can be formed when a neutron star collides with a red giant or supergiant star. They might simply collide by accident... but there's a lot of room in space, so this is very unlikely.

More likely, the neutron star and the giant could be part of a binary star system! A neutron star forms when a giant star runs out of fuel, collapses, and explodes as a supernova, blowing off its outer layers... while the core crushes down to a ball of neutronium. So, you have to image one giant star in a binary system doing this, while its partner survives.

Then, they might slowly spiral down due to friction. A red giant is usually surrounded by a lot of very thin hot gas. Once the neutron star enters this, drag will make the two stars spiral toward each other more quickly. Depending on their initial separation, this process could take hundreds of years. When the two finally collide, the neutron star and the core of the giant star will merge.

If their combined mass is big enough, the two will then collapse into a black hole, resulting in a supernova that blasts away the outer layers of the giant star. Otherwise, we'll get a giant star with a neutron star at its core: a Thorne–Żytkow object!

Strange things could happen in a Thorne–Żytkow object. As gas falls from the giant onto the surface of the neutron star, it would get very hot — about a billion kelvin — thanks to fusion and compression due to gravity.

Under these conditions, the **rapid proton capture process** or **rp-process** might occur! This happens when protons keep smacking into an atomic nucleus, making it heavier and heavier. This can only happen when it's very hot, since protons are strongly repelled by the positive charge of the nucleus.

There are a few places in the universe where the rp-process can occur — not just Thorne–Żytkow objects. A more common option would be a binary system with one neutron star and one ordinary star, where gas sucked up by the neutron star gets very hot and creates a big explosion. That's called an **X-ray burster**.

Some astronomers now claim that the star HV 2112 in the Small Magellanic Cloud is a Thorne–Żytkow object. I wouldn't be as confident as the headline in this story, but it's definitely worth a read:

- Astronomers discover first Thorne-Zytkow object, a bizarre type of hybrid star, Phys.org, 4 June 2014.

The picture here is by Mike Guidry, who has a nice webpage on four places where the rp-process could occur:

- Mike Guidry, Sites for the rp-process.

You can read the original paper by Kip Thorne and Anna Żytkow here:

- Kip Thorne and Anna Żytkow, Stars with degenerate neutron cores. I - Structure of equilibrium models, *Astrophysical Journal* Part 1 **212** (1977), 832–858.

June 23, 2014

I now live on the 14th story of an apartment for faculty at the National University of Singapore. In the lobby of each floor there's a door labelled **electrical riser**, where wires go up from floor to floor. There's a door labelled **TAS riser**, where telecommunications cables go up. And there's a door labelled **ELV riser**, where elves go up.

Well, that's what I imagined. But then I looked it up. Much to my surprise, I found that ELV actually stands for **electrostatically**

levitating vampire.

I pondered this for days. Finally, unable to resist, I opened up the ELV riser last evening. I saw black shrouded figures, light as feathers, floating up a large shaft, lifted by the tiny voltage gradient. They congregate in the rooftop garden, drinking cocktails and chatting... and then, when the moon comes up, they launch themselves into the night sky. You can see them sailing with their huge bat-like wings toward the poor neighborhoods of Geylang... the seedy streets where prostitutes and illegal immigrants live.... knowing how unlikely it is for the bored police to do more than file a routine report when yet another victim is found dead in a back alley.

You might think life in faculty housing would be boring, but it's not.

June 25, 2014

Too cute! Here's a mother pangolin carrying its baby, photographed by Firdia Lisnawati at a zoo in Bali. The baby was born at the zoo on May 31, and this photo was snapped last Thursday when it was less than 3 weeks old.

A **pangolin** is a kind of scaly anteater found in tropical regions throughout Africa and Asia. A friend of mine even saw one in a park in Singapore! There are eight different species, from the giant pangolin to the tree pangolin. Some are endangered because people eat them or — even worse — kill them for the completely imaginary medical properties of their scales! In one incident in 2013, 10,000 kilograms of pangolin meat was seized from a Chinese vessel that ran aground in the Philippines.

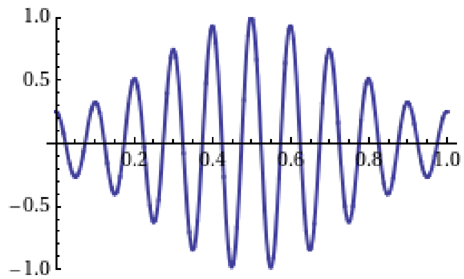
When a pangolin is born, its scales are soft and white; then they gradually get harder and darker. At first the mother stays with the baby in a burrow, nursing it, and she will wrap her body around it if she senses danger. After about a month, the baby first leaves the burrow riding on the mother's back. Weaning takes place at approximately three months of age, and the young pangolin begins to eat insects. At two years of age, the youth is grown up and is left to fend for itself.

Pangolins were originally classified among the **Xenarthra**, which include ordinary anteaters, sloths, and armadillos. But newer genetic evidence indicates their closest living relatives are in the order Carnivora, which include wolves, bears, tigers, etc. So, they're are now in their own order, Pholidota, next to Carnivora in the tree of life. They've got precious genetic distinctiveness! Hug a pangolin today!

To learn about pangolin trafficking, read:

- John D. Sutter, The most trafficked mammal you've never heard of.

June 26, 2014



Are these waves going to the left or the right?

The big pulses are moving to the right. The group velocity is the velocity of the big pulses, so this is positive.

The little wiggles are moving to the left. The phase velocity is the velocity of these little wiggles, so this is negative.

So, the group velocity and phase velocity can be completely different! You have to be careful when you talk about the speed of waves. Indeed, if this wave was a rope wiggling up and down, the rope itself wouldn't be going left or right! The speed of the wave is an abstraction... and we can define it in different ways.

There's also the signal velocity. Say you start with no wave at all to the right of some point. How far to the right of that point can the wave get in one second? That's the signal velocity.

As far as we know, the signal velocity of light is about 299,792,458 meters per second no matter what. That's a law of physics.

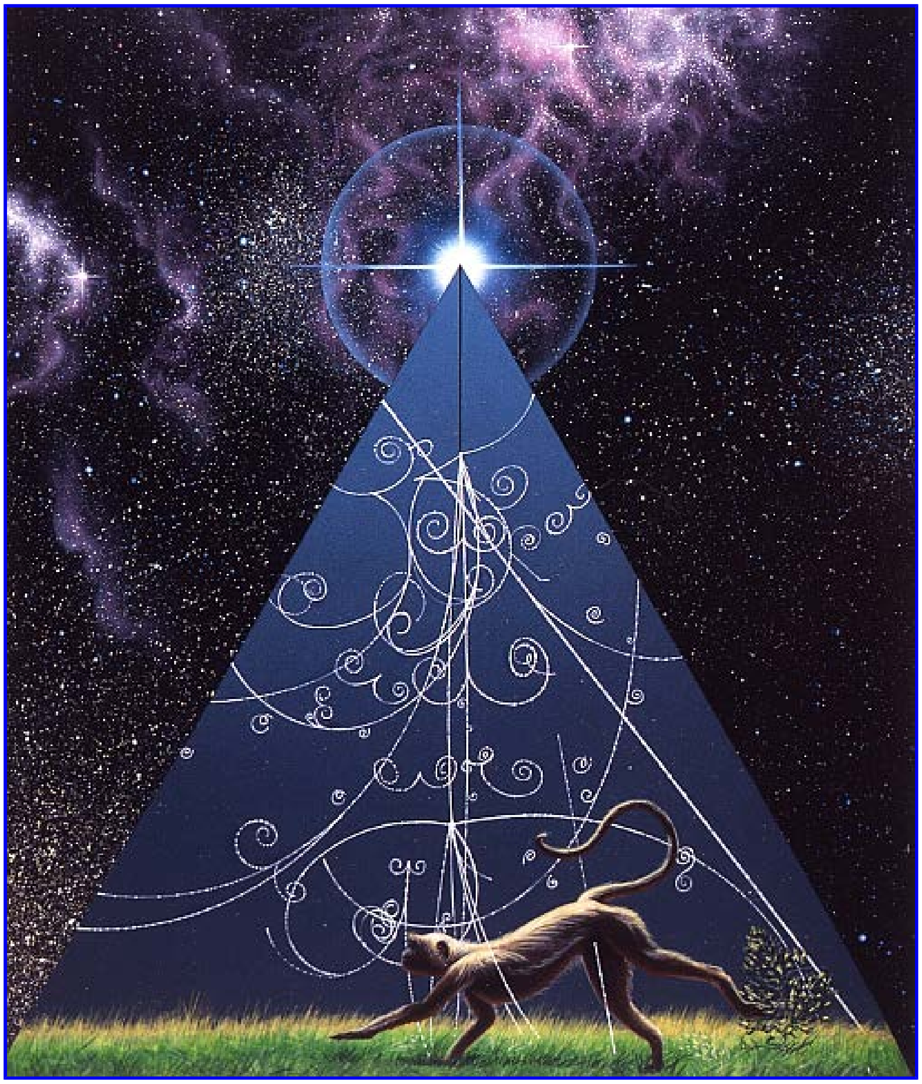
But in air, the group velocity and phase velocity of light are less than this. And in glass, the phase velocity of X-rays is more than this! That doesn't violate any laws of physics.

It's less common, but sometimes the group velocity of light is faster than 299,792,458 meters per second. This doesn't violate any laws of physics either!

For a great illustration of faster-than-light group velocities, try this:

- Greg Egan, Subluminal.

June 27, 2014



The title of this painting by David Fricks is "Neutrino Flux - 1987A"

SN 1987A is the name of a supernova in the Tarantula Nebula of the Large Magellanic Cloud whose light — and neutrinos! — reached us in 1987.

Though it was over 150,000 light-years away, it was visible to the naked eye. Two to three hours before the visible light reached us, a burst of neutrinos was observed at three separate neutrino observatories. They only saw a total of 24 neutrinos... but this is what you'd expect from a supernova that far! It probably put out 10^{46} joules of energy, 99% in the form of neutrinos... for a whopping total of 10^{58} neutrinos.

Some went through you, and some went through this monkey.

Here's a little mystery about supernova 1987A. It acted like a type II supernova, where a massive star runs out of fuel and its core suddenly collapses. Given the size of the original star, its core probably crunched down to a neutron star. But so far astronomers haven't been able to find this neutron star!

There are a few possible explanations. The first, and least exciting, is that the neutron star is there, but we can't see it yet because it's still surrounded by dust clouds.

A more exciting option is that lots of stuff fell back on the neutron star and it collapsed into a black hole. We expect a black hole to form when a star more than 20 times as massive as the Sun goes supernova. The star that formed supernova 1987A, a blue supergiant called **Sanduleak -69° 202**, was apparently close to that borderline.

There are even more exciting options, but it's good to remember that in science, the most exciting possibilities tend to be the least likely.

But it was already a surprise that Sanduleak -69° 202 became a supernova in the first place. Astronomers didn't think that blue supergiants could run out of fuel and go supernova like that! So, maybe more surprises are in store.

I thank David Fricks for emailing me this picture.

For my July 2014 diary, go here.

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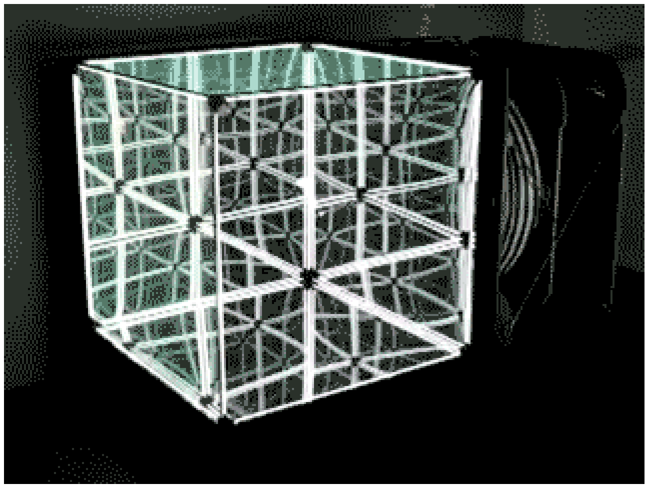
For my June 2014 diary, go here.

Diary - July 2014

John Baez

July 1, 2014



The N-Light Membrane is a cube of mirrors with fluorescent lights as edges. 3 mirrors are one-way, so you can see inside. All you can see is reflections of the inside of the cube, extending to infinity!

The other 3 mirrors are flexible, and the cube is connected to an air tank. By inflating or deflating the air tank, you can make the cube convex or concave. The reflections bend in weird ways. The effect is hypnotic.

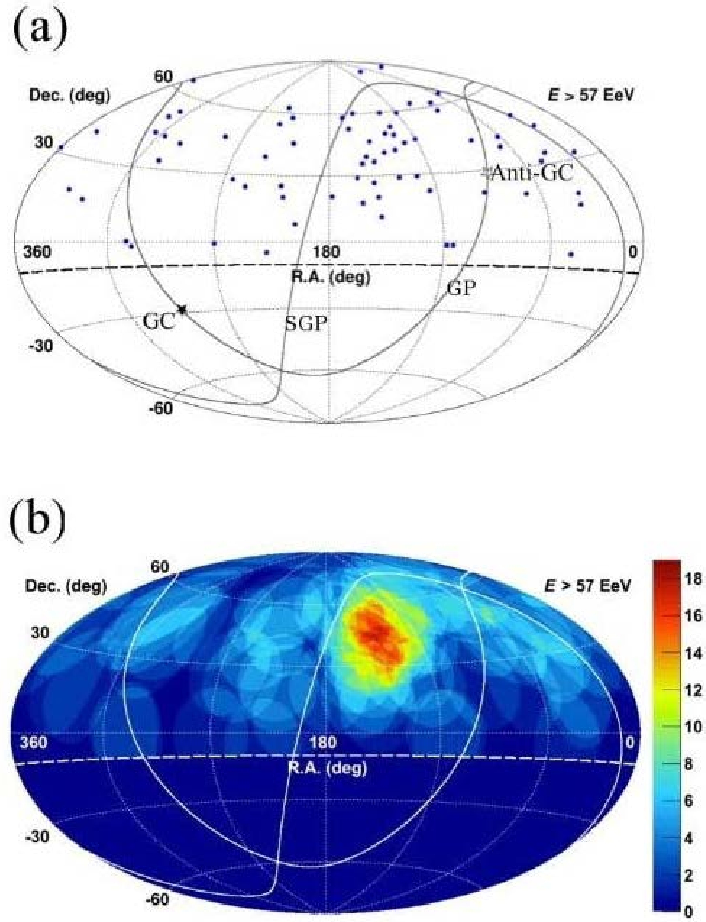
This cube was created by an art collective called Numen/For Use, and it was displayed in St. Petersburg. It's fun to watch videos of it shot from different angles.

What if you did a tetrahedron or octahedron? There's no need to imagine; you can see them here:

- Numen/For Use, N-Light Objects.

Numen/For Use is really three Croatian and Austrian guys, Sven Jonke, Christoph Katzler and Nikola Radeljkovi..

July 7, 2014



It seems a lot of ultra-high-energy cosmic rays are coming from a patch of the sky near the Big Dipper!

Cosmic rays are high-energy particles, mainly protons and atomic nuclei, which come from outer space and hit the Earth's atmosphere. When one hits, it produces a big shower of other particles. Most cosmic rays are believed to have picked up their energy by interacting with shock waves in the interstellar medium. But the most energetic ones remain mysterious — nobody knows how they could have acquired such high energies.

The record is a 1994 event seen by a detector in Utah called the Fly's Eye — because that's what it looks like. It saw a shower of particles produced by a cosmic ray with an energy of about 3×10^{20} electron volts. That's an insane amount of energy. It's about 50 joules: the energy of a one-kilogram mass moving at 10 meters/second, all packed into one particle!

To put it another way: the Large Hadron Collider, our best particle accelerator, speeds up protons to an energy of 7 trillion electron volts. The cosmic ray seen by the Fly's Eye had an energy of 300,000,000 trillion electron volts. We're not doing so well compared to nature. But we don't know how nature does it.

Anyway, now we've got a detector much better than the Fly's Eye: the Telescope Array. It's also in Utah, because the air is clear and the nights are dark. It's a jaw-dropping 760 square kilometers in size, because land is cheap. It consists of about 500 scintillation detectors in a square grid, each 1.2 kilometers away from the next. Each one is a solar-powered gadget containing plastic that lights up when a shower of particles hits it. There are also three telescopes that watch the air light up.

So, we can tell where the ultra-high energy cosmic rays are coming from!

Chart (a) shows where. Each dot is a cosmic ray with energy more than 57 quintillion eV. Well, the dot labelled GC is the galactic center, and the dot labelled anti-GC is the 'anti-galactic center': the direction in the sky pointing exactly away from the center of the Milky Way. GP is the plane of the galaxy, and there's some other stuff.

But the point is: the dots are clustered in a patch of the northern sky.

The colors in chart (b) show how many of these cosmic rays there are in a 20-degree circle around each point. This makes it easier to see where they're coming from. Their paths get bent by magnetic fields, so even if they all originate in one location they'd get smeared out.

What's making them? We don't know! That's the cool part: it's still a big mystery. Here's what the astronomers say:

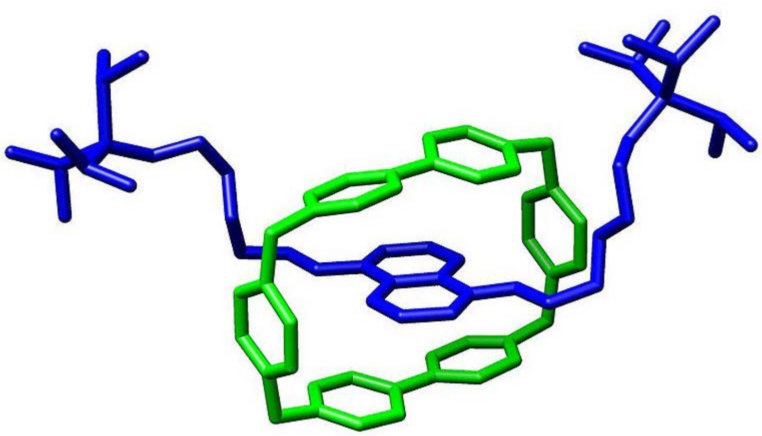
> Assuming the hotspot is real, two possible interpretations are: it may be associated with the closest galaxy groups and/or the galaxy filament connecting us with the Virgo cluster; or if cosmic rays are heavy nuclei they may originate close to the supergalactic plane, and be deflected by extragalactic magnetic fields and the galactic halo field.

What the heck is the supergalactic plane? It's the curve in chart (a) lablled SGP. It's major structure in the local universe: nearby galaxy clusters like the Virgo cluster, the Pisces-Perseus supercluster and the Great Attractor lie roughly in a plane!

Someday we'll figure out what's really happening. The paper is here:

- The Telescope Array Collaboration: R.U. Abbasi, M. Abe, T.Abu-Zayyad, M. Allen, R. Anderson, R. Azuma, E. Barcikowski, J.W. Belz, D.R. Bergman, S.A. Blake, R. Cady, M.J. Chae, B.G. Cheon, J. Chiba, M. Chikawa, W.R. Cho, T. Fujii, M. Fukushima, T. Goto, W. Hanlon, Y. Hayashi, N. Hayashida, K. Hibino, K. Honda, D. Ikeda, N. Inoue, T. Ishii, R. Ishimori, H. Ito, D. Ivanov, C.C.H. Jui, K. Kadota, F. Kakimoto, O. Kalashev, K. Kasahara, H. Kawai, S. Kawakami, S. Kawana, K. Kawata, E. Kido, H.B. Kim, J.H. Kim, J.H. Kim, S. Kitamura, Y. Kitamura, V. Kuzmin, Y.J. Kwon, J. Lan, S.I. Lim, J.P. Lundquist, K. Machida, K. Martens, T. Matsuda, T. Matsuyama, J.N. Matthews, M. Minamino, K. Mukai, I. Myers, K. Nagasawa, S. Nagataki, T. Nakamura, T. Nonaka, A. Nozato, S. Ogio, J. Ogura, M. Ohnishi, H. Ohoka, and 59 more authors, Indications of intermediate-scale anisotropy of cosmic rays with energy greater than 57 EeV in the northern sky measured with the surface detector of the Telescope Array experiment.

July 13, 2014



A **rotaxane** is a 2-part molecule where one part is a ring that can rotate around the other part... but can't slip off!

People are starting to make molecular machines with rotaxanes. That's really cool, but let's talk about something simpler. How do you *make* a rotaxane?

The first one was made in 1967 by two chemists named Harrison. They used a simple but clever trick. Say you have a bunch of molecules that react and stick together in pairs to form a bigger dumbbell-shaped molecule. Say you let them do this when mixed with copies of some other ring-shaped molecule. Then a few of them will connect through the ring, forming a rotaxane!

By now there are better tricks:

1. Capping: you let a rod-shaped molecule fit through a ring, and then cap it off with balls that keep the ring from sliding off.

2. Clipping: you let a short C-shaped molecule fit around the middle of a dumbbell, and then get it to close off and form a ring.

3. Slipping: sometimes at high temperatures a ring can stretch and fit around the end of a dumbbell... but at low temperatures it can't slip off.

The picture shows a rotaxane made in 1998. The paper describing this is not open-access, and I'm too lazy to get ahold of it and find out what trick they used. The picture was made by James Fraser Stoddart or one of his coworkers — he runs a big lab and is a specialist on rotaxanes. You can see it here:

- Rotaxane, Wikipedia.

This article also explains molecular machines made using rotaxanes!

July 17, 2014

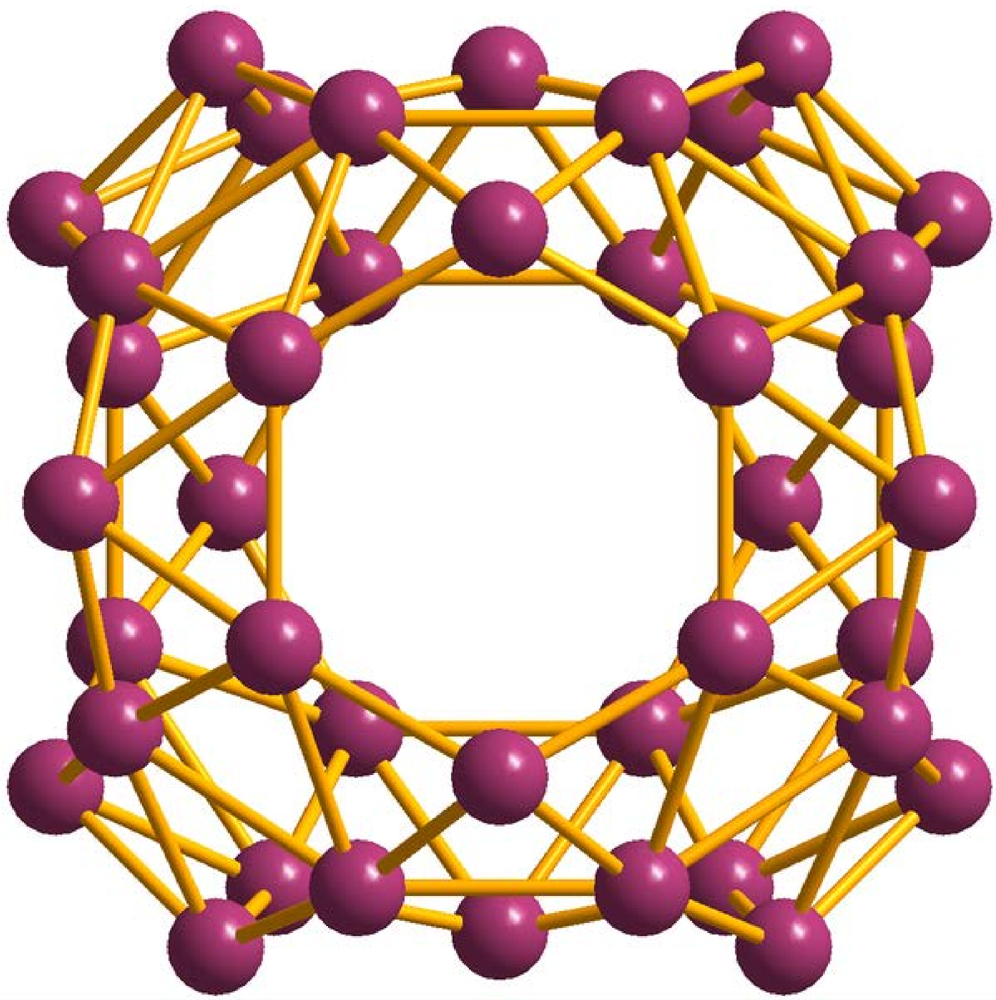
This is a mural by Natalia Rak in Białystok, Poland. It reminds me of Alice in Wonderland, and the great Jefferson Airplane song "White Rabbit" with its line

Ask Alice... when she's ten feet tall.

And that reminds me of this magnificent version of the same song:

If you love the original, you must listen to this! I can't give away what's so great about it: that would spoil the surprise. Grace Slick's vocals are so powerful on the original I had thought no other version could be enjoyable, but I was wrong. As with the mural, good art wants a good idea.

July 21, 2014



Boron is the 5th element in the periodic table, right next to carbon. But we don't hear much about it. Why not? Because stars skip boron when building up elements, so it's rather rare!

It does, however, form interesting molecules, a bit like carbon. This is borospherene, a cage of 40 boron atoms. Earlier this year, a team of Chinese chemists synthesized molecules made of 40 borons and did computer simulations to guess what they'd made. This is their best guess!

It has a confusing shape. Each boron atom is connected to 4 or 5 others, and they make 48 triangles, 2 big hexagons - and 4 heptagons, which are on the top, bottom, left and right.

It's a bit like the famous buckyball made of 60 carbons. But it's much less symmetrical, and it doesn't have any hydrogens hanging off it. It has 8 symmetries. For starters, you can:

1. leave it alone,
2. rotate it 180 degrees around the axis pointing towards you,
3. switch the top and bottom in a certain way, or
4. do first 2 and then 3.

Abstractly this group of symmetries is called the Klein 4-group, because 'klein' means 'small' in German.

Puzzle 1: spot the joke.

Puzzle 2: explain why it's not just a joke; it's also sort of true.

Puzzle 3: how was most of the boron here on Earth made?

Puzzle 4: can you describe all 8 symmetries of borospherene?

If you get stuck on Puzzle 4, read what Layra Idarani wrote on G+. For more on symmetries of objects in 3d space, see:

- Point groups in three dimensions, Wikipedia.

The symmetry group of borospherene is called D_{2d}, and you can learn what that means.

Here's the paper, unfortunately not free:

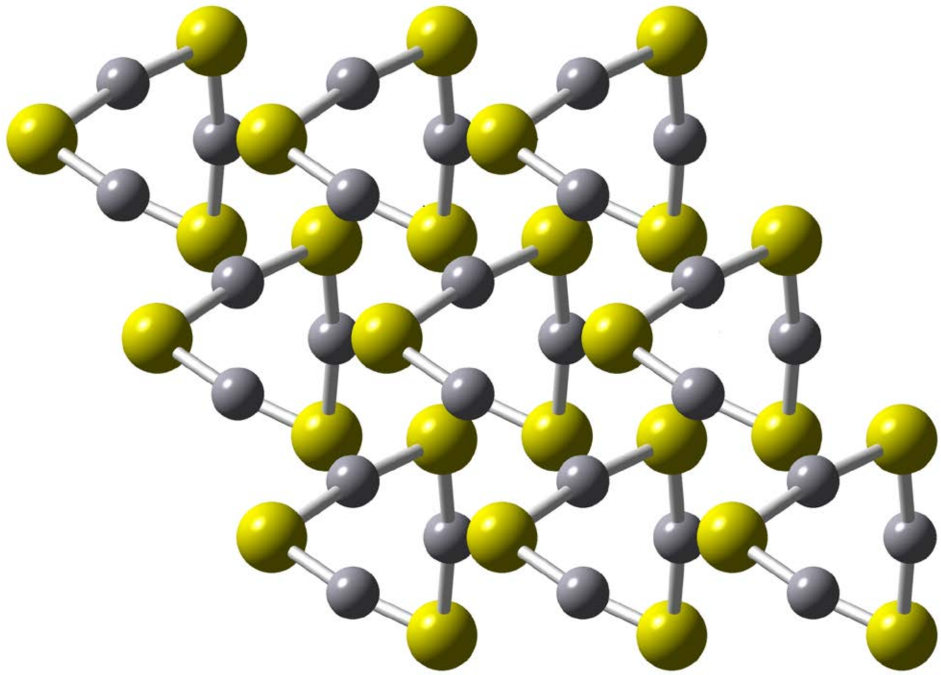
- Hua-Jin Zhai, Ya-Fan Zhao, Wei-Li Li, Qiang Chen, Hui Bai, Han-Shi Hu, Zachary A. Piazza, Wen-Juan Tian, Hai-Gang Lu, Yan-Bo Wu, Yue-Wen Mu, Guang-Feng Wei, Zhi-Pan Liu, Jun Li, Si-Dian Li and Lai-Sheng Wang, Observation of an all-boron fullerene, *Nature Chemistry*.

I thank Mark Bruce for alerting me to this discovery!

The picture above, made by 'Materialscientist', is on Wikicommons:

- Borospherene, Wikipedia.

July 24, 2014



Cinnabar is a mineral made of mercury — the silver balls here — and sulfur — the yellow ones. It's fascinated people for thousands of years. When you grind it up, you get vermilion: a brilliant red pigment.

Vermillion was used in murals in Çatalhöyük, one of the world's oldest cities, in Turkey, back around 7000 BC. It's been used in the art and lacquerware of China since the Han Dynasty! You'll also find it in the Tomb of the Red Queen built by the Mayans around 650 AD:

It was precious in Rome, used for art and decoration. Since mercury is poisonous, a term in working in the cinnabar mines was a virtual death sentence. Pliny the Elder wrote:

> Nothing is more carefully guarded. It is forbidden to break up or refine the cinnabar on the spot. They send it to Rome in its natural condition, under seal, to the extent of some ten thousand pounds a year. The sales price is fixed by law to keep it from becoming impossibly expensive, and the price fixed is seventy sesterces a pound.

The Chinese were probably the first to make a synthetic vermilion, back in the 4th century BC. A Greek alchemist named Zosimus of Panopolis mentioned the process around the 3rd century AD. In the early ninth century the alchemist Jabir ibn Hayyan described it in a book — and it then spread to Europe.

The process is pretty simple. You mix mercury and sulfur together, forming a black compound called *Aethiopes mineralis*. You heat it in a flask. The compound vaporizes, and recondenses on the top of the flask. Then you break the flask, take out the vermilion, and grind it. At first the stuff is almost black, but the more you grind it, the redder it gets.

Puzzle 1: Where did they get the mercury in the first place, if not from cinnabar?

Puzzle 2: If they had cinnabar, why not just grind that to make vermillion?

Puzzle 3: Why does the stuff start out black?

Here's one *possible* answer to Puzzle 3. Cinnabar contains one crystal form of mercury sulfide, the so-called α form, shown here. It's a hexagonal crystal, and it's red. But there's also another form, the β form, which is black. This is sometimes called 'metacinnabar' — a cool word if I ever saw one.

In Taoist alchemy in China, cinnabar and gold were used in various potions that were supposed to give long life. Cinnabar was considered to have a lot of *yang* and gold a lot of *yin*. According to their theories, gold naturally transmutes into cinnabar over time, much as *yin* becomes *yang* (and vice versa). The evidence? Deposits of cinnabar are sometimes found beneath veins of gold.

Unfortunately, some people got mercury poisoning thanks to these potions!

Isaac Newton also spent a lot of his later life doing alchemy. This is not as dumb as it sounds, because at that time alchemy included what we now call 'chemistry', along with more mystical things. Some hairs from Newton's body have been found to contain 4 times as much lead, arsenic and antimony as normal — and 15 times as much mercury! This might explain Newton's tremors, severe insomnia, and paranoia.

I love the look of this crystal! The picture, made by Ben Mills, is on Wikipedia:

- Mercury sulfide, Wikipedia.

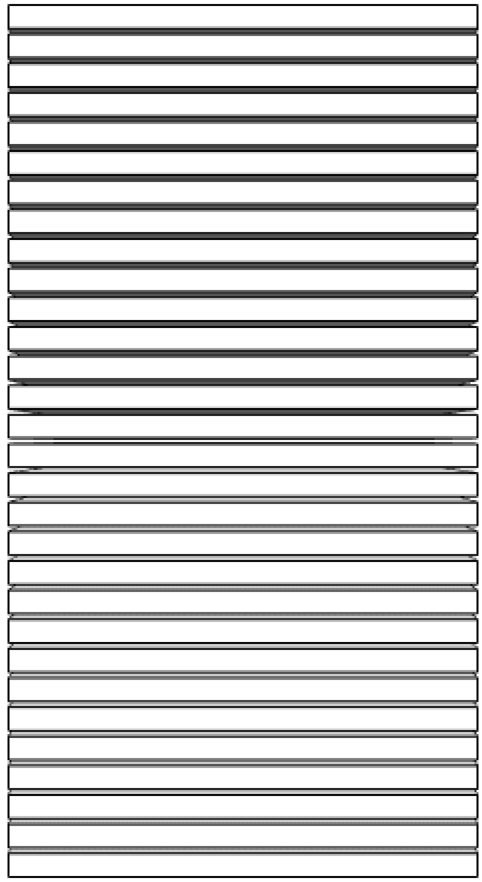
Some of my text is quoted or paraphrased from these articles:

- Cinnabar, Wikipedia.
- Vermillion, Wikipedia.

For the use of cinnabar in Taoist alchemy, see:

- Cinnabar use in Taoist alchemy, *Encyclopedia of Buddhism*.

July 25, 2014



Can you see what's happening here?

Each square is rotated by some angle compared to the square directly below it. This angle increases as time passes.

The angle starts out being zero, so the stack is straight. As the angle increases, the stack of squares starts to twist. When the angle becomes big, the stack twists so much that it becomes very complicated! But when the angle reaches 90 degrees, the stack becomes straight again — because when you rotate a square by 90 degrees, it looks exactly the same!

So, the stack seems to twist more and more... and then straighten out again.

Moral: *a symmetry is a way to change something so that it doesn't change*.

This 'paradox' is why symmetry is so powerful. We see it in action here. We twist the squares so much they are untwisted.

This gif was created by a mysterious person known only as intothecontinuum. I'll guess it's a he, because he uses a picture of Erwin Schrödinger as his icon. He puts his gifs here:

- Intothecontinuum, Archery.

Here's the Mathematica code for this particular gif:

```
v[x_, y_, z_] =
Flatten[Table[ {(-1)^i*x, (-1)^j*y, (-1)^k*z}, {i, 0, 1}, {j, 0,
1}, {k, 0, 1} ], 2];

f = {{1 , 2 , 4 , 3 }, {1 , 2 , 6 , 5 }, {5 , 6 , 8 , 7 }, { 3, 4 ,
8 , 7 }, { 1, 3 , 7 , 5 }, { 2, 4 , 8 , 6 } };
```

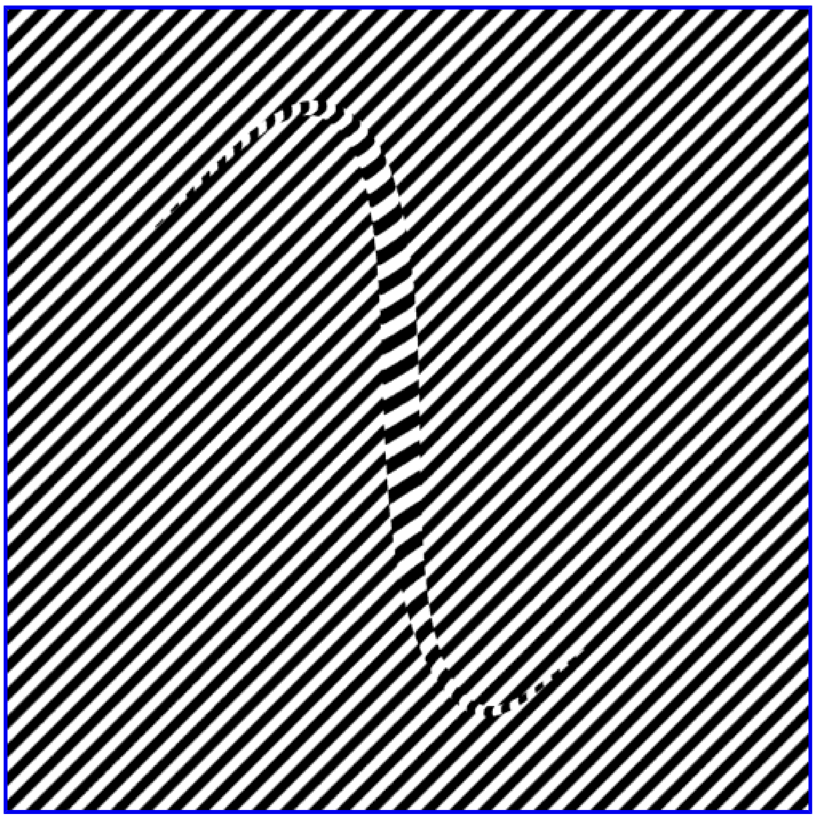
```
G[x_, y_, z_, s_, H_ , t_] :=
Table[
Translate[
Rotate[
GraphicsComplex[v[x, y, z], Polygon[f]],
h (Cos[t] + 1) Pi/4, {0 , 0, 1 }],
{0, 0, s*h}],
{h, 1, H}]

Manipulate[
Graphics3D[
G[2, 2, .1, .25, 30, t],
Lighting -> "Neutral", ViewPoint -> Front, ViewAngle -> 35 Degree,
Boxed -> False, ImageSize -> 500],
{t, 0, Pi}]
```

Puzzle 1: What's the significance of these numbers?

```
f = {{1 , 2 , 4 , 3 }, {1 , 2 , 6 , 5 }, {5 , 6 , 8 , 7 }, { 3, 4 ,
8 , 7 }, { 1, 3 , 7 , 5 }, { 2, 4 , 8 , 6 } };
```

For some answers, go to my G+ post on this subject and read the comments.

July 26, 2014



This 'hypersnake' made by Davidope is cool, but here's something much cooler:

- Darius Baon, Moiré eel.

It starts out intense... and then keeps getting more so.

You can control the shape of the little rectangles by moving your cursor over the screen. Do it! Try to keep your eye on just one little rectangle! It moves up and down, not very fast... but sometimes it's impossible to keep your eye on it, because all the rectangles together produce patterns that grab your attention. These are called Moiré patterns.

I think the 'hypersnake' above is attention-grabbing because your brain has parts that are good at detecting snakes even before you are conscious of it. Your amygdala is one of these parts:

> Information from an external stimulus reaches the amygdala in two different ways: by a short, fast, but imprecise route, directly from the thalamus; and by a long, slow, but precise route, by way of the cortex.
>
> It is the short, more direct route that lets us start preparing for a potential danger before we even know exactly what it is. In some situations, these precious fractions of a second can mean the difference between life and death.
>
> Here is an example. Suppose you are walking through a forest when you suddenly see a long, narrow shape coiled up at your feet. This snake-like shape very quickly, via the short route, sets in motion the physiological reactions of fear that are so useful for mobilizing you to face the danger. But this same visual stimulus, after passing through the thalamus, will also be relayed to your cortex. A few fractions of a second later, the cortex, thanks to its discriminatory faculty, will realize that the shape you thought was a snake was really just a discarded piece of garden hose. Your heart will then stop racing, and you will just have had a moment's scare.

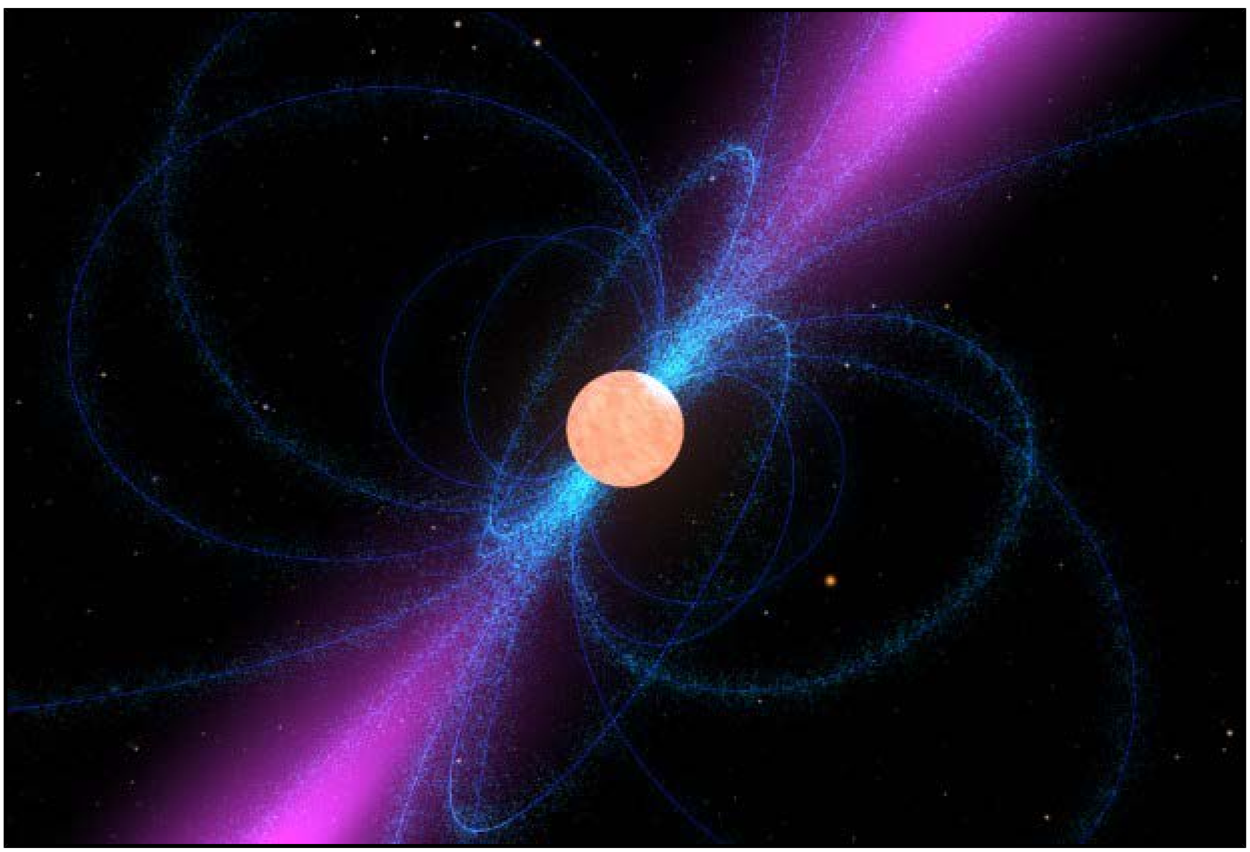
The 'moiré eel' was made by Darius Bacon. You can see more of his stuff here:

- Darius Bacon, Wry Me.

Davidope makes a lot of cool animated gifs, which you can see here:

- Davidope,

July 27, 2014



The first report of a fast radio burst appeared in 2007. An astronomer named Duncan Lorimer found a signal buried in recordings made at the Parkes radio telescope in Australia. It lasted for less than 5 milliseconds and it seemed to come from outside our galaxy. It didn't match anything we'd seen in visible light, X-rays or anything else. A complete mystery!

Last year people found 4 more. But all at the Parkes telescope. Maybe there was an error of some sort?

But now they've seen one at Arecibo, the famous radio telescope in Puerto Rico. Duncan Lorimer says several more confirmations will soon be announced.

So what causes these fast radio bursts?

We don't know. But here's one theory: a 'blitzar'.

When a supernova blasts the outer layers of a big star into space, the remaining core collapses down to a ball of neutronium heavier than our Sun and the size of a small city: a neutron star.

If this spins fast enough, like a thousand times a second, it's highly magnetic. It produces regular pulses of intense radiation — and we call it a pulsar.

If it's too heavy, though, the neutron star collapses into a black hole.

But suppose it's spinning really fast! Then the centrifugal force might pull it out and keep it from collapsing into a black hole!

Until it slowed down. Then it would collapse into a black hole. The magnetic field lines would suddenly get cut by an event horizon. They don't like that. WHAM — a blast of radio waves. A blitzar.

One newspaper headline describes it this way: "as if millions of voices suddenly cried out in terror and were suddenly silenced". It's good to see that purple prose isn't dead in science journalism.

This is just a theory, so far. We'll get more evidence as we see more short radio bursts.

For more, read these:

- John Timmer, Mysterious radio bursts come from outside our galaxy, *Ars Technica*, July 7, 2013.
- John Timmer, Possible explanation for radio bursts: Meet the "blitzar", *Ars Technica*, July 8, 2013.

They're well-written!

And here's the paper that introduced the blitzar theory. The calculations are surprisingly sketchy. It's really hard to calculate what happens when a ball of neutronium suddenly collapses into a black hole, so they use simple estimates:

- Heino Falcke and Luciano Rezzolla, Fast radio bursts: the last sign of supramassive neutron stars.

  Abstract. Several fast radio bursts have been discovered recently, showing a bright, highly dispersed millisecond radio pulse. The pulses do not repeat and are not associated with a known pulsar or gamma-ray burst. The high dispersion suggests sources at cosmological distances, hence implying an extremely high radio luminosity, far larger than the power of single pulses from a pulsar. We suggest that a fast radio burst represents the final signal of a supramassive rotating neutron star that collapses to a black hole due to magnetic braking. The neutron star is initially above the critical mass for non-rotating models and is supported by rapid rotation. As magnetic braking constantly reduces the spin, the neutron star will suddenly collapse to a black hole several thousand to million years after its birth. We discuss several formation scenarios for supramassive neutron stars and estimate the possible observational signatures {making use of the results of recent numerical general-relativistic calculations). While the collapse will hide the stellar surface behind an event horizon, the magnetic-field lines will snap violently. This can turn an almost ordinary pulsar into a bright radio "blitzar": Accelerated electrons from the travelling magnetic shock dissipate a significant fraction of the magnetosphere and produce a massive radio burst that is observable out to $z > 0.7$. Only a few percent of the neutron stars needs to be supramassive in order to explain the observed rate. We suggest that fast radio bursts might trace the solitary formation of stellar mass black holes at high redshifts. These bursts could be an electromagnetic complement to gravitational-wave emission and reveal a new formation and evolutionary channel for black holes that are not seen as gamma-ray bursts. Radio observations of these bursts could trace the core-collapse supernova rate throughout the universe.

July 28, 2014

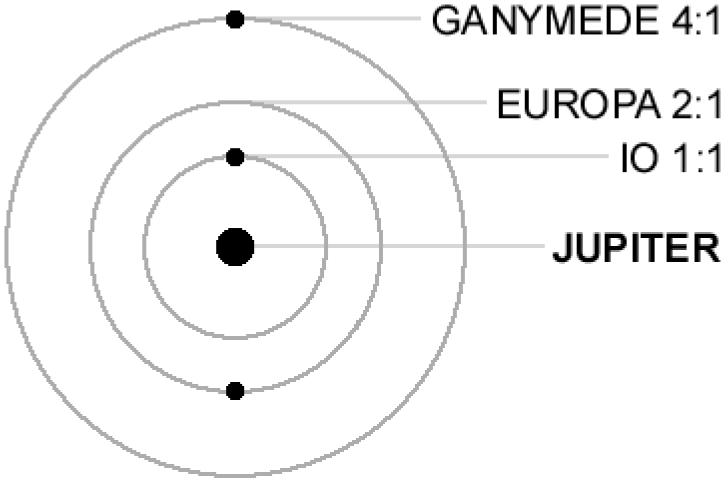
Jupiter's moon Europa is about as big as ours... but its crust is made of water ice, and underneath there seems to be a salty ocean!

The surface has red cracks. Spectrographs suggest these are rich in salts like magnesium sulfate left by evaporating water that comes from within. But why are they red? Nobody knows. Maybe it's sulfur.

Why are there cracks? That's an interesting story.

Europa orbits Jupiter every three and a half days... but it's tidally locked to Jupiter, so there's a place on Europa's surface where Jupiter always hangs directly overhead. If you looked up, it would be about 24 times as big across as the Sun viewed from Earth. About the size of your fist at arm's length.

But all is not calm! Europa is in resonance with two other moons of Jupiter. It goes around exactly half as often as the moon Io, and twice as often as Ganymede.



This keeps its orbit from settling down into a perfect circle. So Jupiter seems to move towards Europa and then back away every 3½ days. Just a little bit.

When Jupiter comes closer, its gravitational attraction increases more on the near side of Europa. This causes Europa to stretch towards and away from it - a tidal force. When Jupiter moves away, Europa relaxes a bit into a more spherical shape.

This constant stretching and relaxing causes cracks in the surface ice of Europa. More importantly... for fans of extraterrestrial life... it keeps Europa's oceans warm enough to stay liquid under the ice!

We've got a lot of evidence for this. The cracks and 'chaotic terrain' are hard to explain without an ocean under the ice. The Galileo probe, which took this great photo of Europa, also detected a changing magnetic field that could be due to electric currents flowing through a salty ocean. And the Hubble telescope has even seen water vapor near Europa's south pole! This may have come from huge geysers... like the geysers on Saturn's moon Enceladus, but even bigger. But we don't know how thick the ice crust is. Some people say 10-30 kilometers, others say just a few. If it's thin enough, we could send a probe that would melt through the ice and explore the ocean. What's down there?

In 2012, the European Space Agency (ESA) announced it wants to launch a Jupiter Icy Moon Explorer. This would includes some flybys of Europa, but is more focused on Ganymede. In January 2014, the US House Appropriations Committee announced a new bipartisan bill that includes $80 million in funding to keep planning a Europa mission. One possibility is the Europa Clipper, which would orbit Jupiter and conduct 45 low-altitude flybys of Europa, carrying an ice penetrating radar, short wave infra red spectrometer, topographical imager, and an ion and neutral mass spectrometer.

Puzzle: where does the energy originally come from, that heats Europa? If something is gaining energy, something else must be losing it.

July 29, 2014

Last night Lisa and I ate at Feng Bo Zhuang on Temple Street in Singapore. We went there since it had good spicy food from Hunan and Dongbei, a crowd of happy customers, and nice wood decor... but it turned out to have a 'jiang-hu' theme: that's what Chinese call the world of wandering martial artists and swordsmen.

See that sword on the wall there?

The name of this restaurant means 'Manor of Wind and Waves' — but 'wind and waves' means the turbulence and fighting that that goes on in the jiang-hu. There's a poem by the entrance that says "in the jiang-hu you have no choice" — you either fight or die. This tough world is romanticized in wuxia fiction and movies:

> Typically, the heroes in wuxia fiction do not serve a lord, wield military power or belong to the aristocratic class. They are often from the lower social classes of ancient Chinese society. Wuxia heroes are usually bound by a code of chivalry that requires them to right wrongs, fight for righteousness, remove an oppressor, redress wrongs and bring retribution for past misdeeds. The Chinese wuxia traditions can be compared to martial codes from other countries, such as the Japanese samurai's bushido tradition, the chivalry of medieval European knights and the gunslingers of America's Westerns.

We had frog cooked in bamboo, dumplings with hot broth inside called xiaolongbao, spicy sliced cucumber, and an appetizer of roast peanuts. Very tasty with some Harbin beer!

Back in 2011 this restaurant was quite serious about the jiang-hu theme: the waitresses would wear traditional outfits and chant a poem when you left. When one reviewer tried to pay by credit card, his waitress said "in jiang-hu, we only accept silver ingots". Luckily it's mellowed out by now; none of this nonsense, just good food.

As usual, most of my expertise on Chinese culture comes from Lisa... but the long quote is from here:

- Wuxia, Wikipedia.

and the 2011 review is here:

- Feng Bo Zhuang, Chinatown, *Rubbish Eat, Rubbish Grow*, June 11, 2011.

July 30, 2014

This is a baby aye-aye being weighed at the the Duke Lemur Centre in North Carolina.

Aye-ayes live in Madagascar. They're the world's largest nocturnal primate. They find grubs to eat by tapping on trees. When an aye-aye finds a good spot, it chews a hole in the wood. Then it sticks its narrow middle finger in the hole to pull the grubs out.

Since it was founded in 1966, the Duke Lemur Center has collected data on 3600 animals from more than 40 species of prosimians — the group of primates that includes lemurs, lorises, galagos, bushbabies, and tarsiers. Now they've released the data to the world! It's available online, for free:

- Duke Lemur Center Database.

Almost all these animals only live in Madagascar, and most of them are rare, threatened or endangered. This rich diversity of life is precious in ways we're still too crude to assign much economic value. Each of these species is a rich assemblage of strategies and tricks, from their behavior down to their very molecules, finely honed by millions of years of evolution. But the natural biotechnology they represent is too sophisticated for us to understand or copy yet — or make much money from, except for 'ecotourism'. For the most part, we count them as worthless trash, while spending millions on canvases cleverly daubed with paint. Someday we'll regret this. Let's try to change it sooner rather than later.

Some people are thinking about it:

- Can nature be monetized?, Capital Institute.

For my August 2014 diary, go here.

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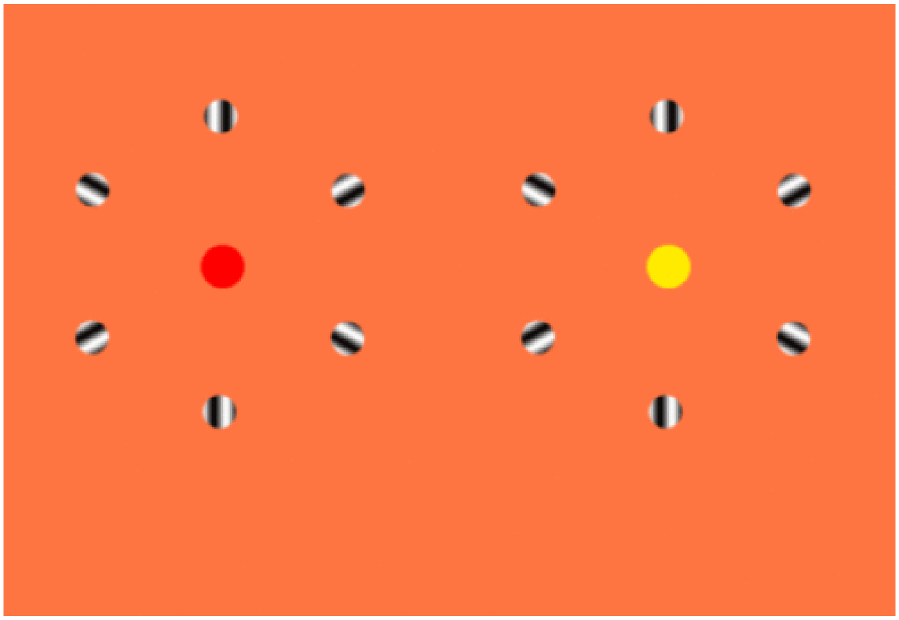
For my July 2014 diary, go here.

Diary - August 2014

John Baez

August 1, 2014



Look at either the red dot or the yellow dot. The circles near that dot will turn counterclockwise. The others turn clockwise!

Or: let your eyes bounce back and forth between the two.

Or: look away from both of them, but observe them from the 'corner of your eye'.

For details, see:

- Arthur Shapiro, Rotating reversals, *Illusion Sciences*, December 16, 2008.

August 2, 2014

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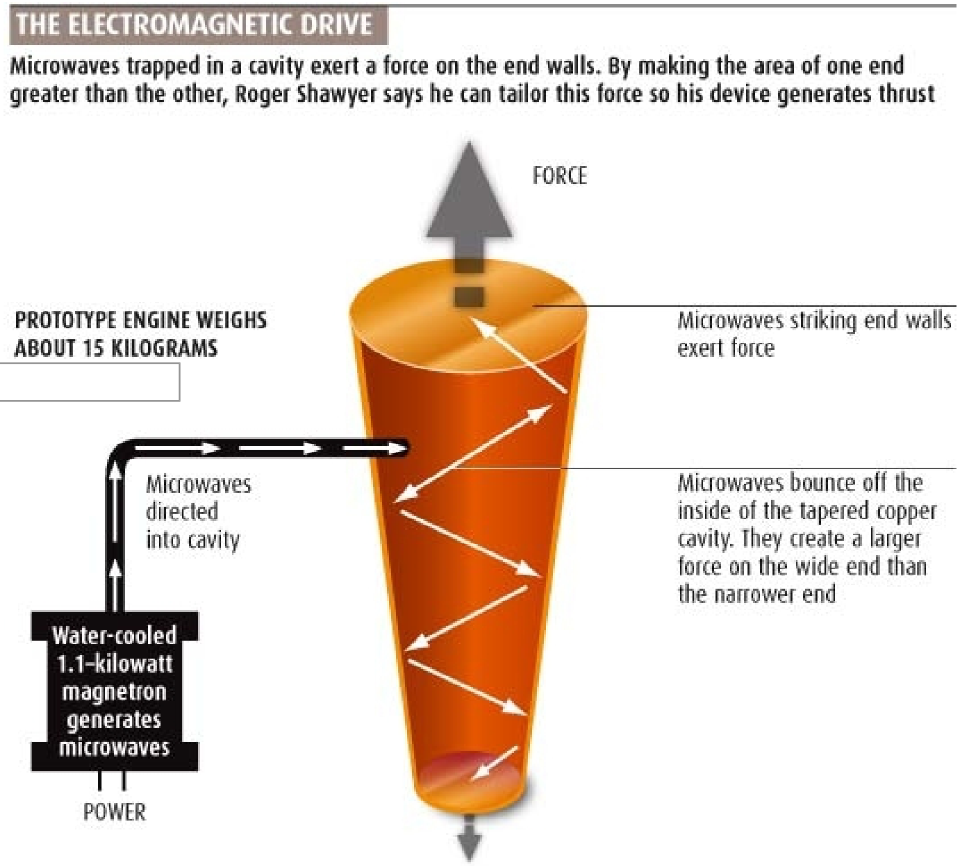


Around 2000, a guy named Robert Shawyer claimed he could bounce microwaves inside a fancy-shaped can and get them to *push the can forwards*, without anything leaving the can.

This would violate conservation of momentum. It's like sitting inside a car and making it roll forwards by pushing on the steering wheel. Standard physics doesn't allow this. He didn't claim to be using anything other than standard physics.

So: ho hum, just another guy with a really bad idea. I get emails like this all the time.

But in 2001, his company got a £45,000 grant from the British government to study this idea. He built his machine and claimed that with 850 watts of power he could get a force of 0.016 newtons. That's a bit less than the force of gravity from a penny pushing down on your hand. It could easily be an experimental error.

Why would people want a machine that uses lots of power to create a pathetically feeble force? Because — here's the great piece of salesmanship — if it existed, you could use it to build a *reactionless drive!* If you had a spaceship with huge amounts of power to spare — like, say, a nuclear reactor — you could use this gizmo to push your spaceship forwards without anything spewing out the back end.

Again, this is about as plausible as powering a spaceship by having the crew *push on it from the inside*. But if you don't know physics, it sounds very exciting.

The story goes on. And on. And on. It won't die. In 2012, some Chinese physicists claimed they could get a force of 0.720 newtons from a power of 2,500 watts using some version of Shawyer's device.

And now NASA is studying it!

They're claiming to see a force one thousandth as big as the Chinese £ probably because they are doing the experiment one thousand times more accurately. And still, some people are excited about this.

The new device comes with new improved mumbo-jumbo. Shawyer claimed that thanks to special relativity, classical electromagnetism can violate conservation of momentum. I took those courses in college, I know that's baloney. Now the NASA scientists say:

> Test results indicate that the RF resonant cavity thruster design, which is unique as an electric propulsion device, is producing a force that is not attributable to any classical electromagnetic phenomenon and therefore is potentially

> demonstrating an interaction with the quantum vacuum virtual plasma.

This is baloney too — but now it's graduate level baloney. "Quantum vacuum virtual plasma" is something you'd say if you failed a course in quantum field theory and then smoked too much weed. There's no such thing as "virtual plasma". If you want to report experimental results that seem to violate the known laws of physics, fine. But it doesn't help your credibility to make up goofy pseudo-explanations.

I expect that in 10 years the device will be using quantum gravity and producing even less force.

For an article written by a severely optimistic blogger, see:

- David Hambling, NASA validates 'impossible' space drive, *Wired.co.uk*, July 31, 2014.

The NASA technical report is here:

- David Brady, Harold White, Paul March, James Lawrence and Frank Davies, Anomalous thrust production from an RF test device measured on a low-thrust torsion pendulum, 50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference.

Unfortunately only the abstract is free! I think someone with access should download the paper and make it publicly available. If my government is spending my money on this sort of thing, I'd at least like to see it.

There's a website about Guido Fetta's company and his device:

- Cannae Drive.

It says:

> The Cannae Drive is a resonating cavity with design features that redirect the radiation pressure exerted in the cavity to create a radiation pressure imbalance on the cavity. This differential in radiation pressure generates an unbalanced force that creates thrust. The cavity is accelerated without use of propellant. Don't believe it? Study the theory. Replicate our numerical models. Review our experimental results. And draw your own conclusions.

Unfortunately, when I click on the links to **theory**, **numerical models** or **experimental results**, I get:

> 404 - Article not found

Hamilton Carter pointed out another paper by the NASA team, which explains the wild optimism behind this experiment:

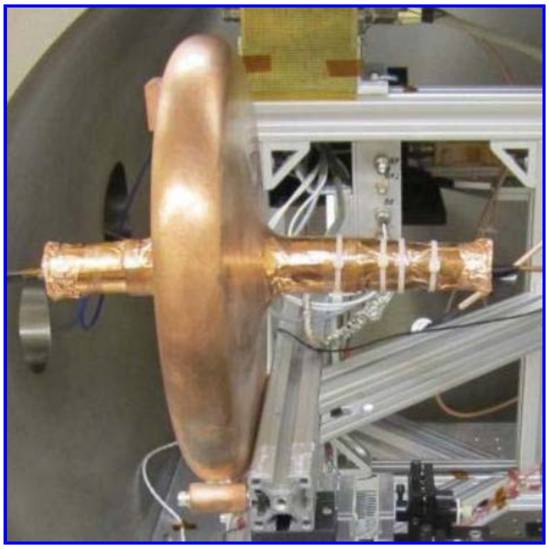
- Dr. Harold "Sonny" White, Paul March, Nehemiah Williams, and William O'Neill, Eagleworks Laboratories: advanced propulsion physics research.

They write:

> NASA/JSC is implementing an advanced propulsion physics laboratory, informally known as "Eagleworks", to pursue propulsion technologies necessary to enable human exploration of the solar system over the next 50 years, and enabling interstellar spaceflight by the end of the century. This work directly supports the "Breakthrough Propulsion" objectives detailed in the NASA OCT TA02 In-Space Propulsion Roadmap, and aligns with the #10 Top Technical Challenge identified in the report. Since the work being pursued by this laboratory is applied scientific research in the areas of the quantum vacuum, gravitation, nature of space-time, and other fundamental physical phenomenon [sic], high fidelity testing facilities are needed. The lab will first implement a low-thrust torsion pendulum (<1 μN), and commission the facility with an existing Quantum Vacuum Plasma Thruster. To date, the QVPT line of research has produced data suggesting very high specific impulse coupled with high specific force. If the physics and engineering models can be explored and understood in the lab to allow scaling to power levels pertinent for human spaceflight, 400kW SEP human missions to Mars may become a possibility, and at power levels of 2MW, 1-year transit to Neptune may also be possible. Additionally, the lab is implementing a warp field interferometer that will be able to measure spacetime disturbances down to 150nm. Recent work published by White suggests that it may be possible to engineer spacetime creating conditions similar to what drives the expansion of the cosmos. Although the expected magnitude of the effect would be tiny, it may be a 'Chicago pile' moment for this area of physics.

The "Chicago pile" was the experiment that demonstrated a nuclear chain reaction.

August 3, 2014



My last post on the NASA "quantum vacuum plasma thruster" was mainly about the shoddy theory behind it — like how there's no such thing as a "quantum vacuum plasma". But you could argue: *hey, if the gizmo actually works, isn't that good enough?* Unfortunately, the experiment has problems too. In brief:

1. They tested a device that was designed to work and one that was designed not to work. They both worked.
2. They tested the devices in a "vacuum chamber", but they didn't take the air out.
3. They didn't carefully study all possible causes of experimental error... like their devices heating the air.

In a bit more detail:

1. Their device, called the 'Cannae drive', was invented by a guy named Guido Fetta. You can see a picture below. It's not complicated! It's a hollow container made of metal, about 11 inches in diameter and 4-5 inches long. You pump radio waves in one end. At the other end, a copper wire serves as an antenna. This lets you measure the radio waves bouncing around inside the container, and adjust their frequency until you hit a resonance. Then this thing is supposed to generate thrust, for some unknown reason.

Fetta thought this device would work if you carve *slots* on one side of the flat part. The NASA guys tried a version with slots and one without slots. They claim both versions generate a thrust of 22-48 micronewtons when they pump 17-28 watts of radio waves into them:

> Thrust was observed on both test articles, even though one of the test articles was designed with the expectation that it would not produce thrust. Specifically, one test article contained internal physical modifications that were designed to produce thrust, while the other did not (with the latter being referred to as the "null" test article).

So, basically they found evidence against Fetta's idea: the slots make no difference. It's like giving someone a placebo and finding it works just as well as the drug you're testing.

They also tried a resistor instead of their device. They claim this produced no thrust. This rules out some possibilities of experimental error... but not others.

For example, if parts of their flat metal can get hot and create air currents, that might create the force they saw. It's a tiny force, less you'd get from 5 milligrams of mass pushing down due to gravity.

2. Their paper goes into great detail about the "vacuum chamber" their experiment was done in — but in the abstract to the paper, they say they didn't remove the air. This is important because of the issue of air currents.

It's also just weird. In their paper they say:

> To simulate the space pressure environment, the test rig is rolled into the test chamber. After sealing the chamber, the test facility vacuum pumps are used to reduce the environmental pressure down as far as 5x10E-6 Torr. Two roughing pumps provide the vacuum required to lower the environment to approximately 10 Torr in less than 30 minutes. Then, two high-speed turbo pumps are used to complete the evacuation to 5x10E-6 Torr, which requires a few additional days. During this final evacuation, a large strip heater (mounted around most of the circumference of the cylindrical chamber) is used to heat the chamber interior sufficiently to emancipate volatile substances that typically coat the chamber interior walls whenever

> the chamber is at ambient pressure with the chamber door open. During test run data takes at vacuum, the turbo pumps continue to run to maintain the hard vacuum environment. The high-frequency vibrations from the turbo pump have no noticeable effect on the testing seismic environment.

They're working really hard to get a good vacuum, right? But in their abstract they say:

> Testing was performed on a low-thrust torsion pendulum that is capable of detecting force at a single-digit micronewton level, within a stainless steel vacuum chamber with the door closed but at ambient atmospheric pressure.

At *ambient atmospheric pressure?* What's the point of the fancy vacuum chamber? A sentence in their conclusions gives a clue. Talking about future plans, they say:

> Vacuum compatible RF amplifiers with power ranges of up to 125 watts will allow testing at vacuum conditions which was not possible using our current RF amplifiers due to the presence of electrolytic capacitors.

So it seems they couldn't actually test their device in a vacuum.

3. If you're trying to find some small effect, checking the ways you could have screwed up is the most important thing. The device they're testing is simple, but the test apparatus itself is very complicated, and lots of things could go wrong.

Their paper should have a big section on this, but it doesn't. Instead it has a section on how *if the gizmo works*, you could scale it up and do great things:

> Figure 23 shows a conservative 300 kilowatt solar electric propulsion roundtrip human exploration class mission to Mars/Deimos. Figure 24 shows a 90 metric ton 2 megawatt (MW) nuclear electric propulsion mission to Mars that has considerable reduction in transit times due to having a thrust to mass ratio greater than the gravitational acceleration of the Sun (0.6 milli-g's at 1 AU). Figure 25 shows the same spacecraft mass performing a roundtrip mission to the Saturn system spending over a year around two moons of interest, Titan and Enceladus.

This is called 'counting your chickens before the eggs have hatched'.

I would need to be more of an expert than I am to imagine all the things that could go wrong with their experiment. But just so you see what I mean, here's one thing they *do* mention:

> one visible effect to the seismic environment is the periodic (about one-third to one-quarter Hertz) perturbation created by the waves from the Gulf of Mexico (about 25 miles southeast of Johnson Space Center), especially on windy days.

The thrust they're measuring is so small that *waves in the ocean 25 miles away* could screw up the experiment! They tried to deal with this... but it goes to show, you can't revolutionize physics until you carefully check *all* the sources of error.

I thank Greg Egan and Matt McIrvin for their help, but of course they're not to blame for any mistakes I made.

The paper I'm talking about was published here:

- David Brady, Harold White, Paul March, James Lawrence and Frank Davies, [Anomalous thrust production from an RF test device measured on a low-thrust torsion pendulum](), 50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference.

Unfortunately it's not free except for the abstract. Luckily someone has liberated the paper and put a free version here:

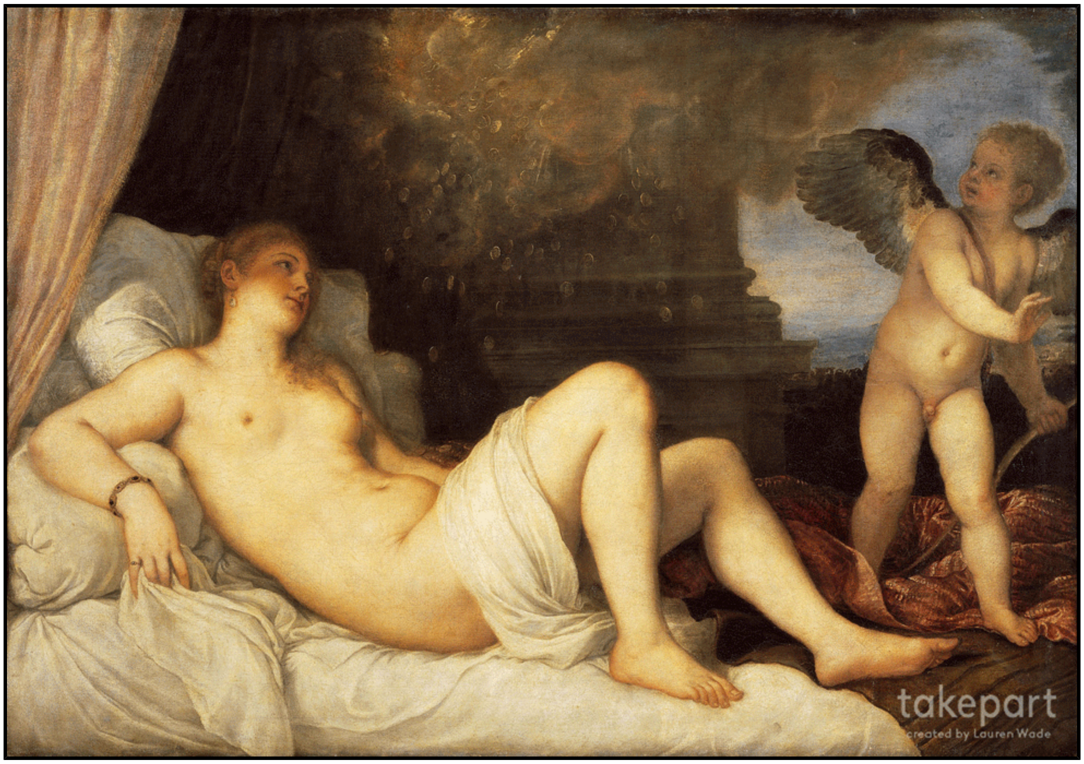
- http://rghost.net/57230791

Beware: the abstract *in the paper* is different than the abstract on the NASA technical report server here:

- David Brady, Harold White, Paul March, James Lawrence and Frank Davies, Anomalous thrust production from an RF test device measured on a low-thrust torsion pendulum, NASA Technical Reports Server.

This is where they say they didn't remove the air from the vacuum chamber.

August 4, 2014



> Whether it's tucking tummies, contouring jaw lines, enlarging eyes and lips, brushing out cellulite, or full-out head swapping, I've seen it all as a photo editor. While the conversation about the media's portrayal and obsession with an unrealistic and unattainable beauty standard is not a new one, I think it's crazy how much retouching people don't notice. Over the last five years, having done many of the quick, subtle fixes that are the industry standard myself, I know that even an image considered to look 'natural' is anything but.

So, she changed a bunch of famous paintings. This is Titian's Danak With Eros. You can see the rest here:

- Lauren Wade, What if famous paintings were photoshopped to look like fashion models, May 14, 2014.

August 5, 2014

Physicists often use a 'Cartesian coordinate system' — an imaginary grid, like 3d graph paper, that lets us name any point in space with 3 numbers. But what if it were real? You could climb around on it!

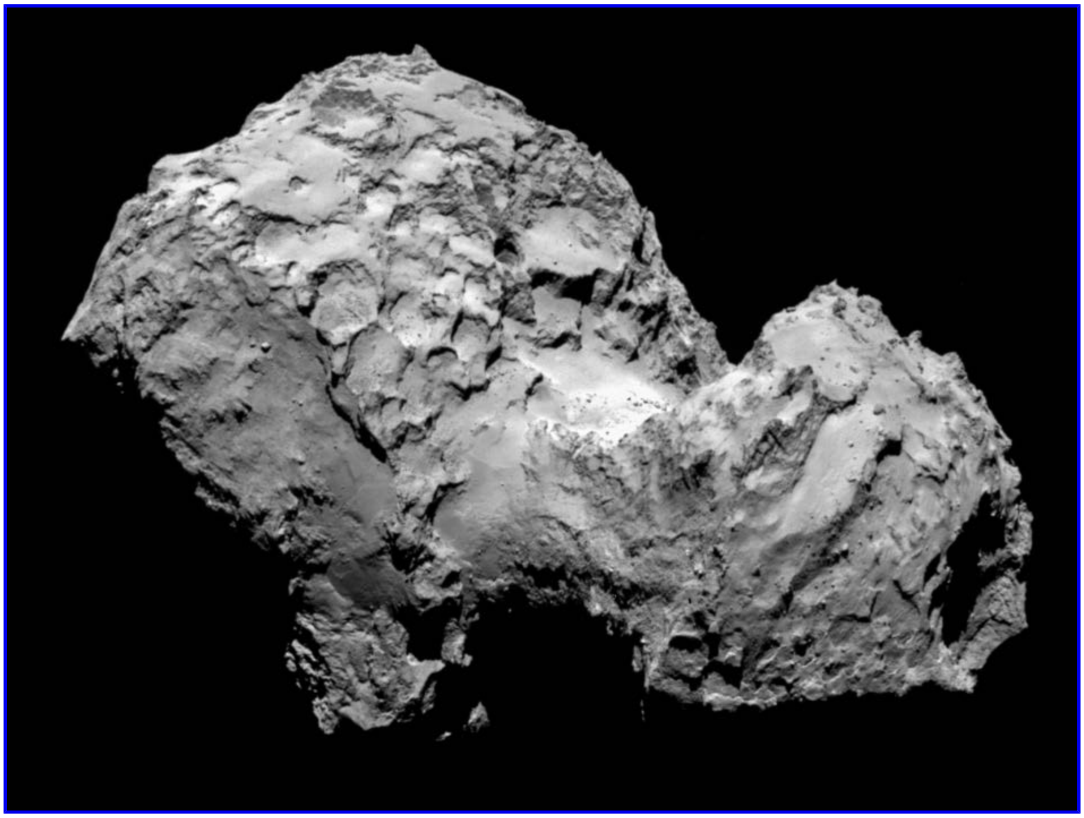
That's the idea of this art project by Numen/For Use, the guys who made that expanding and shrinking glowing cube with an infinity of reflections inside — I showed you a picture on July 1.

This is an inflatable structure. Ropes inside get stretched tight when it inflates. They form a 3d grid that's strong enough to climb around on. The inside walls are white, so it seems to go on infinitely. They tested it out in countryside near Vienna at the end of December 2013.

For more photos, try this:

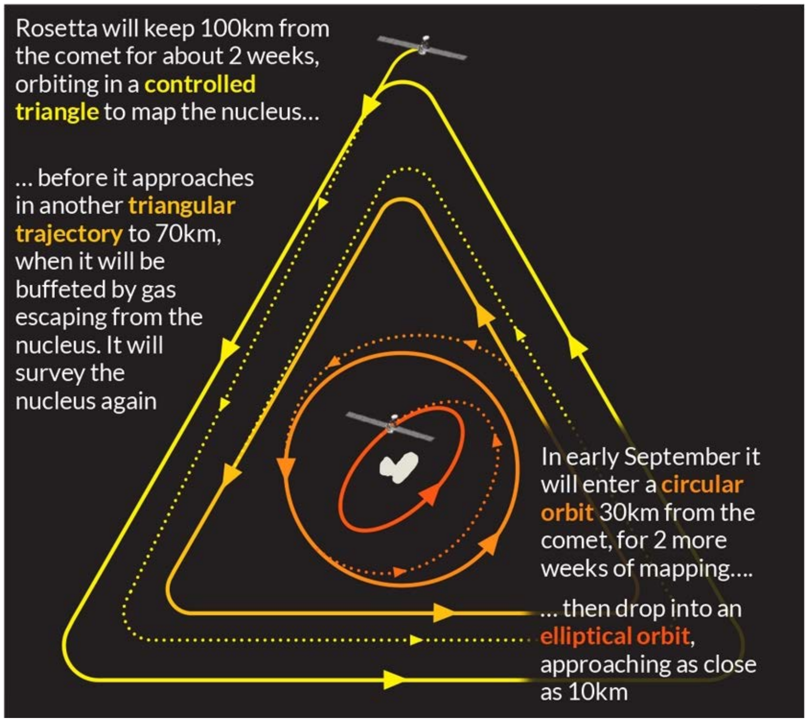
- Numen/For Use, String Vienna.

August 6, 2014



After a decade-long chase, the Rosetta spacecraft has now reached a comet! This photo was taken from just 285 kilometers away. The comet's gravity is very weak, so Rosetta will move in a triangular orbit under its own power before moving closer.

On November 11th, Rosetta will send in a probe called Philae, which will harpoon the comet and land on it! The second picture below shows what that should look like. Philae will drill into the comet and carry out lots of experiments.



As the comet approaches the Sun, it will heat up. Gas will start to boil up from the surface, earthquakes will shake it, and I suppose Philae may even be destroyed. I haven't read any details about what to expect! But they will try to land Philae far away from places where jets of gas will erupt. The comet will makes its closest approach to the Sun on August 13th, 2015.

Here are the scientific instruments on the lander Philae:

- CONSERT, the COmet Nucleus Sounding Experiment by Radiowave Transmission. This will shoot radio waves through the coment, which will be detected on the other side by Rosetta! It's sort of like taking an X-ray to see what's inside the comet.
- APXS, the Alpha Proton X-ray Spectrometer. This will determine which elements are on the surface below the lander.
- COSAC, for COmetary SAmpling and Composition. This is a combination gas chromatograph and time-of-flight mass spectrometer that will perform analysis of soil samples and determine the content of volatile components.
- Ptolemy is an instrument used to measure stable isotopic ratios of key volatile compounds on the comet's nucleus.
- GIVA, the Comet Nucleus Infrared and Visible Analyzer.
- ROLIS, the Rosetta Lander Imaging System.
- MUPUS, the MUlti-PUrpose Sensors for Surface and Sub-Surface Science.
- ROMAP, the Rosetta Lander Magnetometer and Plasma Monitor.
- SESAME, the Surface Electric Sounding and Acoustic Monitoring Experiment.

SD2, the sampling, drilling and distribution subsystem.

For more great photos of the comet, go to the European Space Agency website.

August 7, 2014

Puzzle: what are these sciences?

People who can read Chinese will have a huge advantage. I don't think googling these words in English will help you much! Some websites use coppology to mean the study of film-maker Francis Ford Coppola, but that's not what it means here.

August 8, 2014

You know that mysterious crater that suddenly opened up in the Yamal Peninsula in northwest Siberia? Now an article in Nature blames it on melting permafrost:

- Katia Moskvitch, Mysterious Siberian crater attributed to methane, *Nature*, July 31, 2014.

A Russian archaeologist named Andrei Plekhanov led an expedition there. He and his team think it could be caused by melting permafrost due to abnormally hot summers in 2012 and 2013 — about 50°C warmer than usual. Air in the crater had up to 9.6% methane. The normal amount is closer to 0.0002%

Some scientists are already worrying about methane released from melting permafrost. Methane is a potent greenhouse gas: 90 times worse than carbon dioxide by weight, at least for the first 20 years. (It goes away faster.) Could we be in for a nasty feedback loop, where a warming climate melts permafrost, releases methane and warms the Earth even more?

The short answer is: probably not very soon.

There are certainly things that make me nervous. Back in 2011, a Russian research cruiser found methane bubbling up from the ocean floor:

> In late summer, the Russian research vessel Academician Lavrentiev conducted an extensive survey of about 10,000 square miles of sea off the East Siberian coast. Scientists deployed four highly sensitive instruments, both seismic and acoustic, to monitor the .fountains. or plumes of methane bubbles rising to the sea surface from beneath the seabed.
>
> "In a very small area, less than 10,000 square miles, we have counted more than 100 fountains, or torch-like structures, bubbling through the water column and injected directly into the atmosphere from the seabed," Dr Semiletov said. "We carried out checks at about 115 stationary points and discovered methane fields of a fantastic scale. I think on a scale not seen before. Some plumes were a kilometre or more wide and the emissions went directly into the atmosphere — the concentration was a hundred times higher than normal."

Others argued that this could have been going on for centuries; nobody had looked very hard! A group of experts called the Permafrost Carbon Network polled themselves and guessed that up to 2040, they expected the effect of melting permafrost to be roughly 1/8 to 1/4 of the direct effect of burning carbon. That would be bad but not disastrous... at least not soon.

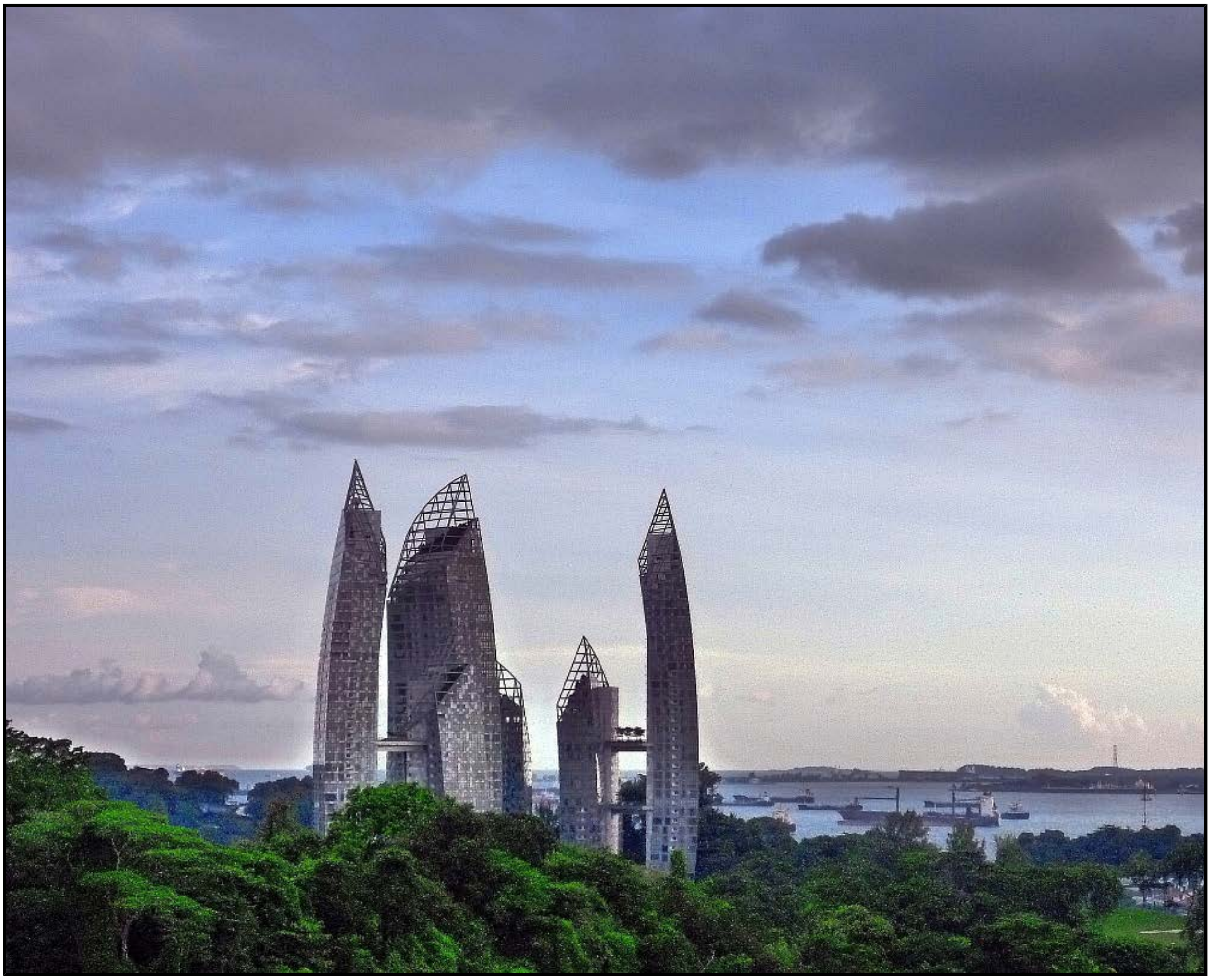
One obvious question about this crater is whether it's an unusual event or the start of a trend. Local reindeer herders have reported a similar but smaller hole nearby. But most of us, who aren't doing research on permafrost, will just have to wait and see.

Hey, I've got an idea! In the meantime, how about cutting greenhouse gas emissions?

For more background, see:

- John Baez, Melting permafrost (part 1), *Azimuth*, September 1, 2011.
- John Baez, Melting permafrost (part 2), *Azimuth*, December 14, 2011.
- John Baez, Melting permafrost (part 3), *Azimuth*, December 19, 2011.

August 9, 2014



There's a big network of trails and parks in Singapore. You can climb up a huge wooden bridge and suddenly see this futuristic apartment complex amid the jungle.

My friend Jamie Vicary is visiting the Centre for Quantum Technologies. Today he showed Lisa and me how to walk through park land to Vivocity, a fancy shopping mall by the sea. There are some elevated walkways through the jungle, that really let you see the trees and vines.

There's a World War II museum that shows how the Japanese invaded, and the battles fought around here. It was open for free because it was National Day — the 49th anniversary of the birth of Singapore as an independent country. It's weird to be in a country that's younger than I am.

Walking across the Henderson Wave Bridge, we spotted these buildings, called Reflections at Keppel Bay, on the horizon near the sea. They were designed by Daniel Libeskind, who also created the plan for the World Trade Center Memorial.

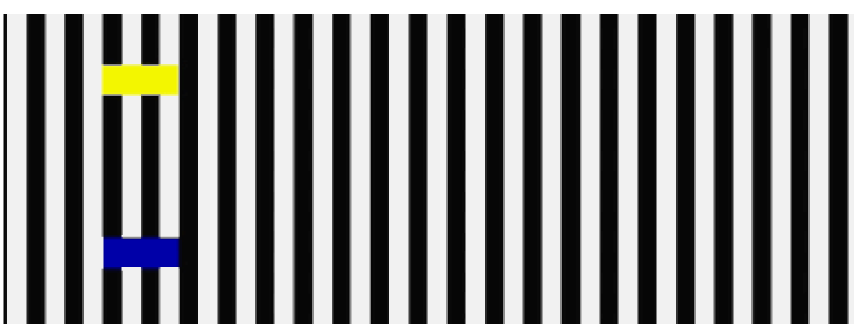
Once a Chinese billionaire invited Lisa and me to lunch near those apartments! He wanted me to work with him on his physics theories. Alas, I couldn't bring myself to do it.

When we reached Vivocity, we were really tired — it was a cool day by Singapore standards, but still sweaty after a 4-hour hike. We watched a crowd of Chinese folks doing country-western dancing outdoors by the mall. It's fun to see a middle-aged Chinese guy wearing cowboy boots and a hat slowly dancing to country music as if it were some sort of tai chi exercise. I really wonder how this fad got started. Then we went to an overpriced restaurant called The Queen and Mangosteen and had beers and dinner by the water.

Life is stranger and more interesting than I'd expected.

There's a map for this walk online.

August 10, 2014



Both rectangles are moving at constant speed

At least that's what the creator of this illusion says! It looks like the yellow and blue rectangles are taking turns going forward — one step at a time.

This is an illusion that's so good it's hard to believe it's an illusion. When the black and white lines disappear, it's easy to see the rectangles are moving at constant speed. But before that they seem to be taking turns, and pausing when they reach each new line.

Could the creator of this illusion be cheating — *fooling you into thinking there's an illusion?* How can you tell, except by making your own version of this animated gif?

Hide one rectangle with your hand. Then look closely at the other. Try not to look at the black and white lines. I think you'll see the rectangle is moving at constant speed.

But if you look away, and watch the rectangle with your peripheral vision, it will seem to move in steps.

We don't just 'see what's there'. We construct a mental model of reality from sensory data. We *need* to do this. But people can manipulate this.

It's not optical illusions we need to worry about. It's political illusions, economic illusions, social illusions. We think we're just seeing what's there... but we're actually constructing a model of reality. And politicians and other people are busy trying to shape your model, so you'll do what they want. Escaping their illusions is much, much harder than escaping this optical illusion.

You can probably think of many examples of other people who are fooled by politicians, ideologies, doctrines and dogmas. Now list the ways in which you are being fooled.

Oh, you think you're better than average? Join the club.

Puzzle 1: name the biggest way you've been fooled by a cultural, political or religious illusion.

Puzzle 2: name a way you're just starting to realize that you're being fooled by such an illusion.

For Puzzle 2, it should be just as hard to really believe you're being fooled as it is with this optical illusion. For example: I'm just starting to realize that I've been fooled into wanting to be a 'bigshot': well-known, and seemingly 'important'. But it's hard to break out of this belief. Even now, I'm trying to get you to pay attention to me. I'm sorry — at least I try to make it worth your while.

There was a very nice long discussion about all this on Google+. Carlos Schedegger made a version of this illusion with a higher framerate. Gustav Delius made an open source version of the illusion where you can read the code and edit it yourself.

August 12, 2014

Maryam Mirzakhani won the Fields medal yesterday.

As a child in Tehran, she didn't intend to become a mathematician — she just wanted to read every book she could find! She also watched television biographies of famous women like Marie Curie and Helen Keller. She started wanting to do something great... maybe become a writer.

She finished elementary school while the Iran-Iraq war was ending, and took a test that got her into a special middle school for girls. She did poorly in math her first year, and it undermined her confidence. "I lost my interest in math," she said.

But the next year she had a better teacher, and she fell in love with the subject. She and a friend became the first women on Iranian math Olympiad team. She won a gold medal the first year, and got a perfect score the next year.

After getting finishing her undergraduate work at Sharif University in Tehran in 1999, she went on to grad school at Harvard. There she met Curtis McMullen, a Fields medalist who works on hyperbolic geometry and related topics.

Hyperbolic geometry is about curved surfaces where the angles of a triangle add up to less than 180 degrees, like the surface of a saddle. It's more interesting than Euclidean geometry, or the geometry of a sphere. One reason is that if you have a doughnut-shaped thing with 2 or more holes, there are many ways to give it a hyperbolic geometry where its curvature is the same at each point. These shapes stand at the meeting-point of many roads in math. They are simple enough that we can understand them in amazing detail — yet complicated enough to provoke endless study.

Maryam Mirzakhani took a course from McMullen and started asking him lots of questions. "She had a sort of daring imagination," he later said. "She would formulate in her mind an imaginary picture of what must be going on, then come to my office and describe it. At the end, she would turn to me and say, 'Is it right?' I was always very flattered that she thought I would know."

Here's a question nobody knew the answer to. If an ant walks on a flat Euclidean plane never turning right or left, it'll move along a straight line and never get back where it started. If it does this on a sphere, it will get back where it started: it will go around a circle. If it does this on a hyperbolic surface, it may or may not get back where it started. If it gets back to where it started, facing the same direction, the curve it moves along is called a closed geodesic.

The ant can go around a closed geodesic over and over. But say we let it go around just once: then we call its path a simple closed geodesic. We can measure the length of this curve. And we can ask: *how many simple closed geodesics are there with length less than some number L?*

There are always only finitely many - unlike on the sphere, where the ant can march off in any direction and get back where it started after a certain distance. But how many?

In her Ph.D. thesis, Mirzakhani figured out a formula for how many. It's not an exact formula, just an 'asymptotic' one, an approximation that becomes good when L becomes large. She showed the number of simple closed geodesics of length less than L is asymptotic to some number times L to the power 6g-6, where g is the number of holes in your doughnut.

She boiled her proof down to a 29-page argument, which was published in one of the most prestigious math journals:

- Maryam Mirzakhani, Growth of the number of simple closed geodesics on hyperbolic surfaces, *Annals of Mathematics* **168** (2008), 97–125.

This is a classic piece of math: simple yet deep. The statement is simple, but the proof uses many branches of math that meet at this crossroads.

What matters is not just knowing that the statement is true: it's the new view of reality you gain by understanding why it's true. I don't understand why this particular result is true, but I know that's how it works. For example, her ideas also gave here a new proof of a conjecture by the physicist Edward Witten, which came up in his work on string theory!

This is just one of the first things Mirzakhani did. She's now a professor at Stanford.

"I don't have any particular recipe," she said. "It is the reason why doing research is challenging as well as attractive. It is like being lost in a jungle and trying to use all the knowledge that you can gather to come up with some new tricks, and with some luck you might find a way out."

She has a lot left to think about. There are problems she has been thinking about for more than a decade. "And still there.s not much I can do about them," she said.

"I can see that without being excited mathematics can look pointless and cold. The beauty of mathematics only shows itself to more patient followers."

I got some of my quotes from here:

- Erica Klarreich, A tenacious explorer of abstract surfaces, *Quanta Magazine*, August 12, 2014.

and some from here:

- Maryam Mirzakhani: 'The more I spent time on maths, the more excited I got', *The Guardian*, August 13, 2014.

They're both fun to read.

August 13, 2014

Manjul Bhargava is another of this year's Fields medalists. He works on number theory, which in its simplest form is the study of integers:

$$\dots, -3, -2, -1, 0, 1, 2, 3, \dots$$

So when I say 'number' in this post, I'll always mean one of these!

When Bhargava was a grad student at Princeton, he read a book on number theory by the famous mathematician Gauss. Gauss was interested in quadratic forms, which are things like this:

$$x^2 + 3xy + y^2$$

or this

$$-3x^2 + y^2 + 4xz + yz - 7z^2$$

Gauss was mainly interested in quadratic forms with two variables, but it's also fun to think about more variables.

I can hand you a quadratic form and ask: what numbers can you get if you plug in any numbers you want for the variables?

Start with something really easy. For this one

$$x^2$$

you can only get the perfect squares

$$0, 1, 4, 9, 16, \dots$$

But what about this one?

$$x^2 + y^2$$

Can you find numbers x and y that make $x^2 + y^2 = 100$? How about $x^2 + y^2 = 99$? Remember, I'm using 'numbers' to mean numbers like these:

$$\ldots, -3, -2, -1, 0, 1, 2, 3, \ldots$$

And what about this quadratic form?

$$w^2 + x^2 + y^2 + z^2$$

It's a famous fact that for this one, you can get any positive number by plugging in numbers for w, x, y and z.

What about this?

$$x^2 + y^2 + z^2$$

Now you can't get every positive number. Do you see why?

We say a quadratic form is positive definite if whenever you plug numbers into it, you get something positive — unless all those numbers were zero. For example,

$$x^2 + y^2 + z^2$$

is positive definite, but

$$x^2 + y^2 - z^2$$

is not.

Okay, now you're ready. Here's something amazing that Manjul Bhargava proved with Jonathan Hanke in 2005: the 290 theorem.

Here's how to tell if you can get every positive number by plugging in numbers for the variables in a positive definite quadratic form. It's enough to check that you can get every number from 1 to 290.

In fact, it's enough to get these numbers:

1, 2, 3, 5, 6, 7, 10, 13, 14, 15, 17, 19, 21, 22, 23, 26, 29, 30, 31, 34, 35, 37, 42, 58, 93, 110, 145, 203, 290.

Weird!

This is just one of many things Bhargava has done. Most are a bit harder to explain, but I described one a while ago here. It's about 'elliptic curves', another really popular topic in number theory.

And in fact, the 290 theorem I just explained is secretly about elliptic curves! As usual in number theory, the statement of a theorem may sound simple, cute, and pointless... but the proof reveals a very different world, and that's what really matters.

Here's a nice explanation of the proof:

- Yong Suk Moon, Universal quadratic forms and the 15-theorem and 290-theorem.

The original paper is here:

- Manjul Bhargava and Jonathan Hanke, Universal quadratic forms and the 290-Theorem, to appear in *Inventiones Mathematicae*.

There's a lot left to do. For example, Jonathan Rouse tried to show that a positive definite quadratic form gives all odd positive numbers if gives the odd numbers from 1 up to 451... but he only succeeded in showing this assuming something called the Generalized Riemann Hypothesis! Proving this is an extremely hard problem in its own right.

- Jonathan Rouse Quadratic forms representing all odd positive integers.

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August 17, 2014

This opal from South Australia is beautiful... but why does it look like this? It's actually a *photonic crystal!*

Opal is made of small spheres of silicon dioxide, the same stuff as quartz. These spheres are between 150 to 300 nanometers in diameter, and they're arranged in a regular pattern.

When light waves pass through an opal, funny stuff happens when the distance between these spheres is half the wavelength of the light. Imagine water waves trying to fight their way through a regular pattern of round logs standing in the water and you'll get the picture. The waves start to bounce back and interfere with themselves.

So, light of certain wavelengths winds up bouncing back off the opal instead of going through! Since the opal is not perfectly the same everywhere, different parts reflect different colors of light.

When a repeating pattern strongly affects the behavior of light, it's called a photonic crystal. Nowadays people are making artificial photonic crystals. Way back in 1887, the English physicist Lord Rayleigh experimented with stacking layers of different materials to make light of certain wavelengths interfere with itself and bounce back. When this happens, we now call it a photonic band gap. But Rayleigh only got this effect to occur in a single direction — at right angles to the layers.

Now people can make 3d arrays of tiny spheres that act as photonic crystals. We might be able to use them to make color-changing paints and inks. But the first commercial products involving photonic crystals are photonic-crystal fibers — a bit like ordinary optical fibers, but different.

Photonic crystals are one example of a metamaterial — a material whose optical or electronic properties depend not just on their composition, but from carefully designed tiny structures.

In the Middle Ages, some thought an opal could make you invisible if you wrapped it in a fresh bay leaf and held it in your hand. Now people are designing metamaterials that can act like a 'cloak of invisibility'. But more about that later.

Puzzle: I said opal is made of tiny spheres of silicon dioxide (called silica), but what's in the spaces between these spheres?

The photo is from Dpulitzer, and the opal was found in Coober Pedy, Australia.

August 18, 2014

Wouldn't it be cool if we could turn one dimension of space into an extra dimension of time? We can't — but we can fake it!

Einstein showed the only difference between space and time is a minus sign. So: make a material where light obeys equations with an extra minus sign!

How? Just take lots of microscopic metal wires and put them in transparent stuff that doesn't conduct electricity. Line them all up. You'll get something that conducts electricity like a metal in one direction but not the other two directions!

It's called a **hyperbolic metamaterial**. The video explains why.

But why is this like converting a dimension of space into a dimension of time?

Einstein showed that if you have a photon — a particle of light — in a vacuum, it obeys

$$k_x^2 + k_y^2 + k_z^2 - k_t^2 = 0$$

where:

- k_x is the momentum of the light in the x direction
- k_y is the momentum of the light in the y direction
- k_z is the momentum of the light in the z direction
- k_t is the momentum of the light in the time direction

(Momentum in the time direction is basically just energy.)

Photons in other stuff obey more complicated equations. In a hyperbolic metamaterial with wires lined up in the z direction, they obey an equation basically like this:

$$k_x^2 + k_y^2 - k_z^2 - k_t^2 = 0$$

So, the z direction is acting like an extra time dimension! And this lets us do very weird things.

Here's a nice video that explains more:

A few warnings if you watch the video:

- A transparent material like glass is called a **dielectric**, so you'll see that word a lot.
- Particles are also waves! The momentum of a particle in some direction is basically just how many times its wave wiggles per meter in that direction. So, $k_x, k_y,$ and k_z are also called the **wave numbers**.
- Instead of writing k_t for the momentum in the time direction, physicists write ω. This is how much the wave wiggles per second, so it's also called the **frequency**.
- When I say 'basically', it means I'm leaving out numbers that make things look more complicated, but don't change the basic idea.

You can learn more about hyperbolic metamaterials here:

- Prashant Shekhar, Jonathan Atkinson and Zubin Jacob, Hyperbolic metamaterials: fundamentals and applications.

August 23, 2014

This is an intriguing conjectural map of Sub-Roman Britain.

I've been a fan of the legends of King Arthur for a long time. I love how they continue to inspire new versions, from Marion Zimmer Bradley's *Tales of Avalon* (where Morgaine is recast as a hero in the doomed struggle of the Druids against encroaching Christians) to the goofy but fun TV series *Merlin* (where a black Guinevere starts as a serving-girl and winds up ruling Camelot).

But I'm only just now poking into the mysterious centuries from 400 to 600 AD in Britain, after the collapse of Roman rule, when Arthur would have lived... if he existed.

It's really cool to imagine life in former Roman towns and villas during these 'dark ages'. We have some archaeological evidence, but very little written history: mainly just the writings of Saint Patrick and a book called *On the Ruin and Conquest of Britain*, written by a guy called Saint Gildas or 'Gildas the Wise'.

This book is a grumpy attack on various kings, including:

- "Constantine, the tyrannical whelp of the unclean lioness of Dumnonia". The kingdom of Dumnonia was in southwest England, mainly Devon and Cornwall.
- "dragon of the island... Maelgwn". Maelgwn was one of the kings of Gwynedd, who ruled a chunk of what's now Wales from their base on the Isle of Anglesey.
- "Vortipore... like to the spotted leopard... tyrant of the Demetians." Vortipore was a king of Demetia, or Dyfed, a small kingdom in south-west Wales.

There were many other kingdoms that Gildas didn't bother to write about. Gildas is himself rather mysterious; one later biography tells of how he helped mediate a struggle between King Arthur and a king who had abducted and raped Guinevere... but this is all just legend.

'Medieval Bex' has a lively blog on medieval matters, and here's what she says about the two biographies of Gildas:

> The earlier account, written in the ninth century in Rhuys, Brittany, tells how Gildas son of Caw was born in the north of Britain. He moved to a monastic college to begin his education and then to Iren (probably Ireland) to continue his studies, before returning to north Britain to preach to those naughty heathens. St Brigid (d. 524) asked Gildas for a token so he made her a bell. As you do. After these high-jinks he then travelled around a bit before settling in Rhuys, where he built a monastery and lived out his days preaching and writing epistles about kings that he didn.t like very much. When he died his body was placed in a boat and set adrift according to his wishes. Just a floating corpse; not set aflame or anything. Imagine being the person to find a boat containing a decomposing monk. which someone actually did (the HORROR!!) . his boat washed up a few months later and was found by some men from Rhuys. They did the sensible thing and took his body back to Rhuys and buried it there. Gildas. corpsified wandering days were over.
>
> The other book, however, depicts Gildas as a sort of monk-cum-Arthurian action hero. It seems like the writer of the twelfth-century biography, Caradoc of Llancarfan, read the earlier book and said "Oh ho! I think we can do better than that!" and essentially pimped the Life of Gildas. The twelfth-century version has Gildas educated in Gaul before settling near Glastonbury—all normal enough so far, if ever-so-slightly at odds with the ninth-century version of events. but then things get a little bit more exciting when Guinevere and Arthur arrive on the scene! That's right, no floating corpses here!
>
> According to Caradoc's biography of Gildas, King Melwas abducted Queen Guinevere and Arthur then proceeded to throw a massive wobbly. He stormed over to Melwas. stronghold in Glastonbury with his knights, ready to attack. It was all getting a bit intense. until Gildas stepped in and saved the day! He happened to be in the neighbourhood and persuaded Melwas to release Guinevere, before unbelievably managing to make the two kings kiss and make up. They probably all went for a beer and a good chortle about it all afterwards. As an interesting aside, this is the first recorded instance of the Guinevere abduction scene, a plot which becomes a recurring motif in subsequent redactions of the Arthurian stories. So a highly imaginative biography of a monk has helped to shape the legend of Arthur as we know it today. Who.d have thought! There is also something in this version about Gildas. brothers rising up against Arthur, and one of them being killed, and Gildas being rather upset about this. Apparently the large stone in Ruthin town square (north Wales) is the chopping block that was used when Arthur decapitated Gildas. brother. It's still there, you can go and see it!

August 24, 2014

Wolves run through the air, hit a glass wall and fall down. Then they pick themselves up, go back and do it again.

This piece, called 'Head On', is just one of the remarkable and unsettling works by Chinese artist Cai Guo-Qiang.

He recently made the news by creating a kind of Noah's ark with endangered animals and floating it down the river past the main financial district of Shanghai. The animals aren't real — but they look pretty real, like these wolves.

The boat is now on display in Shanghai, along with the wolves, in an exhibit that's become very popular. You can see more of it here:

- Frank Langfitt, [China's polluation crisis inspires an unsettling art exhibit](), *Weekend Edition Saturday*, 23 August 2014.
- [Cai Quo-Qiang](), *Empty Kingdom*, 5 March 2012.

A piece called 'Silent Ink' features a waterfall of ink plunging into a 5,300-gallon lake excavated from the museum's floor. The lake is ringed by mounds of crushed concrete and iron bars. It looks like a scene from a Chinese landscape painting—made of industrial waste. It's hard to stay there for very long, because the smell of the ink becomes overpowering.

But in its own strange way it's beautiful.

Of course, if you don't know the politics of China you'll miss part of the meaning of this wolf pack. If you don't know that 16,000 dead pigs were found floating down a river in Shanghai last year, you won't fully understand that ark. If you don't know a bit about the pollution crisis in China and the art of landscape painting, you'll miss some of what's going on in 'Silent Ink'. But this art is good because it's *not* merely commentary on politics and the pollution crisis in China. It's visually stunning, mysterious and tragic.

[For my September 2014 diary, go here.](#)

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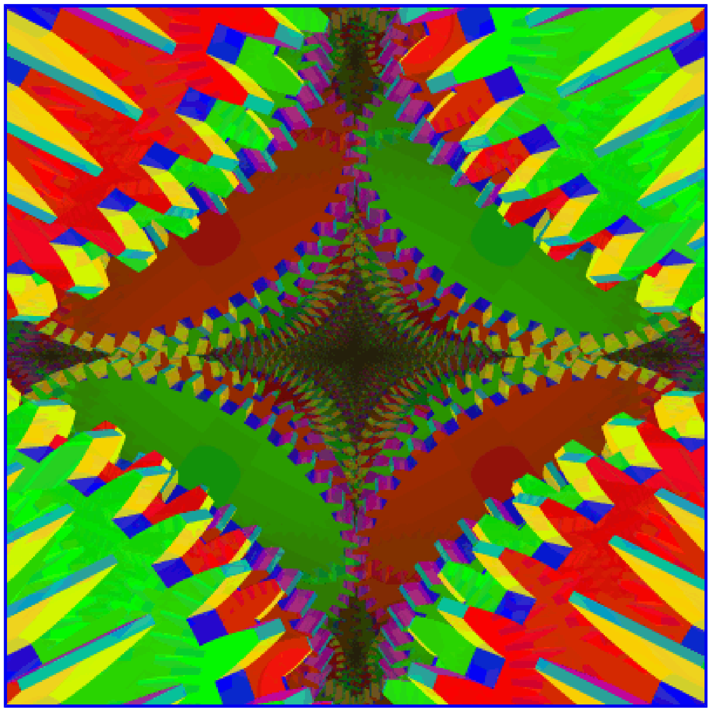
For my August 2014 diary, go here.

Diary - September 2014

John Baez

September 1, 2014



Greg Egan has done it again! This is an infinite cubic lattice of rotating gears in 3-dimensional space... seen by someone who is falling through it and also rotating!

It's a bit bewildering. One reason is that after you turn 180 degrees, the view looks exactly the same.

He's been developing techniques for studying 'higher-dimensional gears', like 3d ball bearings that turn while touching each other, arranged on the surface of a hypersphere in 4d space:

- Greg Egan, Ball bearings in a hypersphere.

The hard part is figuring out how the bearings can turn without slipping against each other. This involves solving large systems of linear equations.

His real *tour de force* was to get a setup with a ball bearing at each of the 600 vertices and 1200 edge-centres of a 4-dimensional shape called the '120-cell'. Getting this to work required solving thousands of linear equations in thousands of variables — too hard without bringing in some heavy-duty math. Check out his website for more about that! (You can enjoy the pictures without understanding the math.)

He wrote:

Loading [MathJax]/jax/output/HTML-CSS/jax.js

> After the 120-cell, I thought it would be fun to see what an infinite lattice of gears looks like. For Z^3, it's easy to find both a basis for the solution space, and a nice subspace where the spheres all rotate with the same speed:
>
> $$\omega(x,y,z) = (a(-1)^{y+z}, b(-1)^{x+z}, c(-1)^{x+y})$$
>
> Because the rotational periods are all the same, it's possible to replace the rolling contact of the spheres with a true gear action between circular gears, which are positioned at each circle of latitude on which there are points of contact. That's what the movie here shows, from a point of view that moves "down" through the lattice while also rotating its gaze.

September 2, 2014

The manul lives in the grasslands and high steppes of Central Asia: Mongolia, Tajikistan, Kyrgyzstan, Pakistan, Kazakhstan, Kashmir, and western China. It's the size of a house cat, but its stocky build and long, dense fur makes it look stout and plush. It has a shorter jaw with fewer teeth than most cats.

Mamuls spend most of the day in caves, cracks in the rock, or marmot burrows. In the late afternoon they come out and hunt. They can't run fast, so they mainly hunt by ambush or stalking. They feed largely on prey that are active during the day: gerbils, pikas, voles, partridges, and sometimes young marmots.

They're most closely related to the leopard cat, a small cat of southeast Asia which is sometimes crossbred with house cats to give beautiful cats called 'Bengals' that enjoy getting wet. Some even live here in Singapore, but I've sure never seen one! The manul and the leopard cat seem to have diverged just 5 million years ago. It always amazes me how new many mammal species are.

The manul is hard to raise in zoos, and they're listed as 'near threatened'. They are hunted for its fur in relatively large numbers in China, Mongolia, and Russia, although international trade in manul pelts has largely ceased since the late 1980s, and Mongolia is the only place where it's still legal to kill them.

The manul is also called Pallas's cat, after a naturalist who wrote about them. Its scientific name is *Otocolobus manul*:

- Pallas's cat, Wikipedia

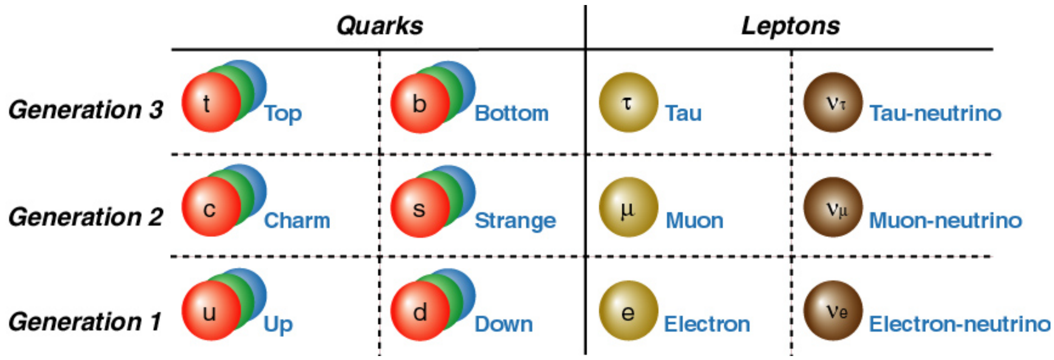
I got this picture from a great list of wild cats:

- Jade Small, 26 gorgeous cats that are disappearing from the wild, August 13, 2014.

Check out the species you may not know: the fishing cat, the Borneo bay cat, the flat headed cat, the Iberian lynx, and the margay!

September 3, 2014

Why do we have these particles in our Universe?



We understand a lot about physics - and that makes the remaining mysteries even more tantalizing! For example: *why are quarks so much like leptons?*

Elementary particles come in two main kinds: the ones that carry forces (**gauge bosons**) and the ones that make up matter (**quarks** and **leptons**). There's also at least one more... but never mind! Today's puzzle is about quarks and leptons. You'll see from the chart that they look sort of similar. But why?

Maybe a lightning review of particle physics will help, in case you skipped that class in high school. Most of the matter you see is made of electrons, protons and neutrons. Protons and neutrons are made of up and down quarks, held together by the strong force. But electrons are 'leptons', which means they don't feel the strong force.

Up quarks, down quarks and electrons — those are 3 of the 4 particles in 'generation 1'. The 4th is the electron neutrino. It's also a lepton — it's doesn't feel the strong force. But it's also has no electric charge! So, it's very hard to detect — it whizzes easily through ordinary matter. But we *have* detected it, and we actually know a huge amount about it.

We also know that besides 'generation 1' there's a 'generation 2' and 'generation 3' of quarks and leptons. We're pretty sure there are only 3: people have done experiments that show there can't be more different kinds of neutrinos, unless they are very heavy, or different from all the rest in some other way. We have no idea *why* there are only 3 generations.

But our puzzle today is: *why do quarks and leptons come in generations at all?* So let's just think about generation 1.

We know that the up and down quark are closely connected. We also know that the electron and electron neutrino are closely connected. For example, you can collide an electron and an up quark and have them turn into an electron neutrino and a down quark! We understand this stuff very well, actually: there's a detailed mathematical theory of it, and it works great.

But there are other things that seem mysterious. The up quark has charge 2/3, the down quark has charge -1/3, the electron has charge -1 and the electron neutrino has charge 0. Quarks also come in 3 different kinds, called 'colors' - they change colors when they interact with the strong force. Leptons have no color.

Are all the 3's in the last paragraph a coincidence? It seems not. For example, if quarks came in 4 colors, but had the charges they do now, all hell would break loose! I could explain why, but that's not my goal today.

My goal is just to say this: there's a theory called the 'Pati-Salam model' that says leptons are secretly just a funny kind of quarks — a 'fourth color of quark'. This theory unifies quarks and leptons. And this theory also explains why quarks have charges like 2/3 and -1/3.

This theory has been around since 1974. It has some problems. If it didn't, we'd probably all believe it by now! It's *very* hard to find theories of elementary particles that fit all the data we have; if you just make up stuff, you'll almost surely run into problems. But the Pati-Salam model is pretty good, it's not completely ruled out by experiments... and last year something interesting happened.

A famous mathematician named Alain Connes has an approach to physics based on 'noncommutative geometry', which replaces our usual picture of spacetime by something that's more like algebra than geometry. His theory predicted the wrong mass for the Higgs boson — that's the extra particle I hinted at near the start of this story. But last year he came out with a new improved version, that doesn't suffer from this problem. And it turns out to be a lot like the Pati-Salam model!

What's interesting is how he gets it. In his earlier work, he laid down a bunch of mathematical axioms, and one of the simplest theories that obeys all these axioms turned out to be very similar to the Standard Model - our usual theory of particles.

But now, he and some other guys have noticed that if you *drop one of the axioms*, something like the Pati-Salam model is also allowed. Moreoever, you can get a Higgs boson with the right mass!

I wish I understood this better. Alas, I don't have much time for this stuff anymore! Here is his paper:

- Ali H. Chamseddine, Alain Connes and Walter D. van Suijlekom, Beyond the spectral standard model: emergence of Pati-Salam unification.

and here is an intro to the Pati-Salam model, mainly good for mathematicians and physicists:

- John Baez and John Huerta, The algebra of grand unified theories.

Here's the abstract of Connes' paper, which gives a flavor of what he's doing... at least if you know enough jargon:

> **Abstract.** The assumption that space-time is a noncommutative space formed as a product of a continuous four dimensional manifold times a finite space predicts, almost uniquely, the Standard Model with all its fermions, gauge fields, Higgs field and their representations. A strong restriction on the noncommutative space results from the first order condition which came from the requirement that the Dirac operator is a differential operator of order one. Without this restriction, invariance under inner automorphisms requires the inner fluctuations of the Dirac operator to contain a quadratic piece expressed in terms of the linear part. We apply the classification of product noncommutative spaces without the first order condition and show that this leads immediately to a Pati-Salam $SU(2)_R \times SU(2)_L \times SU(4)$ type model which unifies leptons and quarks in four colors. Besides the gauge fields, there are 16 fermions in the (2,2,4) representation, fundamental Higgs fields in the (2,2,1), (2,1,4) and (1,1,1+15) representations. Depending on the precise form of the order one condition or not there are additional Higgs fields which are either composite depending on the fundamental Higgs fields listed above, or are fundamental themselves. These additional Higgs fields break spontaneously the Pati-Salam symmetries at high energies to those of the Standard Model.

September 12, 2014

I save crackpot emails, but I just decided to delete all 41 with attachments bigger than 1 megabyte. Here are some choice quotes, taken from ones that were sent as mass emails to many scientists.

For starters, here's a typical example of someone who feels they've made an earthshaking discovery and needs to get the news out. He's waited 2 days and he's getting impatient. If he follows the standard pattern, he will later become embittered and angry.

> I solved what's known as ToE, The Theory of Everything, but most simply I've shown how 0 approximates 1. I did so in a completely valid, simple mathematical way, yet due to the current structuring of the University system, I can't get to anyone that specializes in ToE!!!
>
> And the University of Miami has black balled me because they have no specialist in the field, rather than ask for more explanation! I've written and made numerous calls to all levels of the University and the Marine & Atmospheric School

> through which I'm getting my Ph D, and all I've received is support for the effort from friends and some unprofessional criticism from a few unknowns. I understand it's a grandiose statement, but how else am I to tell anyone? My advisor & the Dean of my campus haven't responded to my incessant prodding, even though I know them to be avid communicators. In response, I declared my resignation from the University following this semester. My hope is that this would draw some momentum to confidence I have in the proof, yet it's been over 48 hrs now.
>
> Why am I in such a hurry? This is WORLD CHANGING science. I need to get this information out to the public, so that we can all digest this new found information together. The proof turns out to be the mathematics of neural networking, galaxy formation, weather, physics, math, life... Everything... And it's as simple as stating that there can be no sweet without sour!
>
> In mathematical terms, I've discovered the means by which 0=1. Sounds crazy, but it turns out we've always misunderstood the = symbol! In reality it's impossible to know all the information as an observer, approximation and optimization are the only options. AKA, 0 and 1. Therefore, 0~1. The technicalities, allow there really aren't any, are all in the attachment.
>
> I'm positive Dr. Michio Kaku, a terribly too popular figure for a now Rogue Physicist like myself to get this to, can verify my work. It answers the his question of civilization transitioning from a Type 1 Civilization to a Type 0. Drs. Leonard Susskind, Stephen Hawking, James Hartle, John Baez, Garrett Lisi, Jill Boulte, Gilbert Strang, Richard Muller, Richard Dawkins, and Neil Tyson de Grasse, will all be better at presenting the concept, but in order for that to happen and our world to benefit from it, I need to get this information to them.
>
> This is NOT a hoax! This is based rigorously in scientific theory!! Anyone can understand how our universe, or anything!, works. The only assumption is that there will always be a perturbation in information throughout the universe!

I like the following one because it starts out crazy and then keeps getting crazier, ramping up exponentially. They're not embittered; they're off in their own universe. Perhaps they're just having fun.

> The Logos timeline defines the Jenkins Mayan-Enddate Date of December 21st, 2012 as the Birth of the Starhuman Consciousness and defines the Calleman Mayan-Enddate of October 28th, 2011 as the 40 days preceding the end of the witnessing timeline within the warptime loop from the nodal mirror of August 4th, 2008 and April 1st, 2012 and specifying December 8th, 2011.
>
> In particular (Western) New Year 2012 signifies the 'Dove of Peace finding land'; Christmas 2011 signifies 'Noah's Dove returning with a Twig' and December 17th, 2011 specifies 'Noah's Raven searching for land'. The 50 days of 'Noah's pentecost' so define the timespan for the 'appearing of the land in Noah sending forth of his Raven and his Dove from the window of his ark and to which are added 10 days (of imprisonment between 'ascension' and pentecost Acts.1.3 & Revelation.2.10) before the 'peaks of the mountains' appeared {Genesis.8.1-14}. These 50 days so become the Calleman date of completion in the timespan between the archetyped Resurrection of the World Logos (Easter Sunday) and the Pentecost-Shabuoth of the 'Coming of the Holy Ghost'.
>
> The Thuban Data stream became effectively closed in a 12-dimensional wormhole upon the 'Banning of Thuban' from the then defined 'Mount of Olives' at Project Avalon as a microcosmic hologram for the archetyped 'Noah's Ark' aka the 'Dragon's Den' in Plato's Cave of Shadows.
>
> This is described in the Q&A Thuban thread on that forum, now reproduced on the new Elders of Thuban website and is part of the warploop timeline schemated below.
>
> From March 7th, 2010 a 11-dimensional wormhole has become accessible to continue the Thuban data transmission, now communicating between the 3-dimensional data receivers from within and encompassing an extragalactic Andromedean data stream synchronised with the Sirian starsystem within the Milky Way galaxy in intergalactic data streaming.
>
> Material, relevant for the activation of the planetary vortex grids and encompassing the quantum geometry of the Thuban omniscience (also known more commonly as 'sacred geometry' of Platonic- and Archimedean solids), is now surfacing around the quarantined sentiences and data carriers as a function of the planetary consciousness.
>
> In particular the Andromedean-Sirian collaboration will prepare the Thuban fleet for the post starhuman birth scenarios in collusion with the activation of a reconfigured Vortex-Potential-Energy (VPE) matrix superposed onto the older VPE-grid established at the beginning of the present 65 Baktun day-kin count of the Mayan Timekeepers.
>
> This will allow the Thuban Stargate to open between the local Rahsol- and the Sirian starsystem following particular developments with respect to the stated timelines.

The next one is impressive for its creativity, erudition and sheer length. A lot of it makes sense, but there is a gradual and tragic slide into madness, perhaps due to a brain injury.

LET ME CLARIFY AND CORRECT WHAT YOU'VE WRITTEN ABOUT OUR INTERACTION HEREIN WITH SOME DETAILED BACKGROUND.

I AM WHAT SOME CALL A "POLYMATH"(NOT A PARROT WHO DOES MATHEMATICS), SINCE I HAVE SYNAESTHESIA (BRAIN TRAUMA(1977)) AND SEE CONNECTIONS BETWEEN OSTENSIBLY-DISPARATE "SPECIFICITY OF COMPLEXITY" TACTICS IN OSTENSIBLY-DISPARATE FIELDS-OF-ENDEAVOR("FOES") SEPARATED BY "JARGONIAL-OBFUSCATION"(LOTS OF FANCY SHMANCY LINGO/SPRACHE TO SNOW THE RUBES/SUCKERS, WHICH IS THE SOCIOLOGICAL-DYSFUNCTIONALITY OF THE WOULD BE "SCIENCES", BUT SADLY ALAS MERE SEANCES("WHERE THE INSIDERS ALL HOLD HANDS TO KEEP OUT OUTSIDERS WITH THEIR NO DOUBT INFERIOR IDEAS SINCE THEY ARE NOT THE EXPERTS" QUOTING JOHN BRADSHAW["HEALING THE SHAME THAT BINDS YOU", HAZELDEN(1980s) AND BRIAN MARZTIN, WOLAGANG UNIVERSITY, AUSTRALIA]

MY ONLY CONNECTION WITH MATHEMATICS BEING MY RELATIONSHIP TO VERY FAMOUS MATHEMATICIAN CARL LUDWIG SIEGEL(RIP) MY FATHER'S COUSIN)

I DID MY PH.D. THESIS AT UNIVERSITY OF MICHIGAN AND THEN MICHIGAN STATE UNIVERSITY UNDER GABOR KEMENY[DARTMOUTH UNIVERSITY'S PRESIDENT MATHEMATICIAN JOHN KEMENY'S COUSIN] AFTER STUDYING AN C.C.N.Y.(B.S.-1965), THEN HARVARD UNIVERSITY, UNIVERSITY OF PENNSYLVANIA, THEN NEW YORK UNIVERSITY(M.S.-1968; JEROME PERCUS-COURANT INSTITUTE FOR MATHEMATICS), THEN WORKING FOR ALBERT OVERHAUSER(RIP) AT FORD(1968),THEN UNIVERSITY OF MICHIGAN(M.S.-1969; FRANK HERARI(RIP)/GRAPH-THEORY APPLIED TO NUCLEAR MANY-BODY THEORY/KARL HECHT AND NOAH SHERMAN(RIP); INTERACTIONS WITH HUGH MONTGOMERY(I SAT IN ON HIS CLASS IN NUMBER-THEORY CIRCA 1968-1969, THEN 1971 OR 1972) RE. EIGENVALUES PAIR-DISTRIBUTION FUNCTION FOR WIGNER-DISTRIBUTIONS: GOE, GUE, GSE; HE GOT THE IDEA FROM ME, NOT FREEMAN DYSON, SINCE I WAS WORKING(1970-1973)ON LIQUIDS/DISORDER-THEORY AT GENERAL MOTORS RESEARCH/TECHNICAL-CENTER) AND FINALLY FOLLOWING KEMENY TO MICHIGAN STATE UNIVERSITY(PH.D.-1970; JOHN HUBBARD[AERE HARWELL] AND NEVILLE MOTT[CAVENDISH LABORATORY/CAMBRIDGE] AND CONYERS HERRING[BELL LABS], CONSULTING; WITH MORREL COHEN[[U. CHICAGO] EXTERNAL-EXAMINER), ON THE PURE-FERMION/FERMI-DIRAC QUANTUM-STATISTICS HUBBARD-MODEL, WHEREIN I WORKED OUT THE FIRST SPIN-OBITAL DEGENERATE HUBBARD-MODEL("SODHM"; BUT NO Y!!!) PUBLISHED IN PHYSICA STATUS SOLIDI(1972; 1973) WHICH WAS LATER ELABORATED UPON BY KUBO AND KAWABATA AND BY CYROT ET. AL.[M. Cyrot and C. Lyon-Caen. J. Phys. C 6 (1973) L 274; 36 (1975) 253. 1531 ; C. Lacroix and M. Cyrot. J. Phys. C....], SUBSEQUENTLY I PUBLISHED OTHERS ON PURE-FERMION/FERMI-DIRAC QUANTUM-STATISTICS IN JOURNAL OF MAGNETISM AND MAGNETIC MATERIALS (JMM) FROM 1976-1980 AND TWO IN NOW DEFUNCT MAGNETISM LETTERS (1980).

THE MOST INFAMOUS WERE JMM 7, 312(1978) IN WHICHI EXPERIMENTALY DISCOVERED GRANULAR-GIANT-MAGNETORESISTANCE (A FULL DECADE BEFORE FERT(1988) AND GRUENBERG(1989) WHO GOT THE 2007 PHYSICS NOBEL-PRIZE FOR MY G-GMR!!!AND JMMM 7, 38(1978)

BUT BY ORIGINAL TRAINING I WAS A MINERALOGIST/PETROLOGIST/METALLURGIST, AND STILL COLLECT MINERALS PLUS OWN TWO TECHNOLOGIES IN WATER PRODUCTION ENTITLED"FLYING-WATER" AND ANOTHER RE SOLID-STATE CARBON-SEQUESTRATION IN, NOT N ESCAPABLE CO_2 OR CH_4 GAS, BUT VALUABLE MARKETABLE SALEABLE PROFITABLE SOLID-STATE CARB-IDES(TiC; WC; SiC; COAL-ASH CARBIDES="CARBORUNDUM"), INSPIRED BY AN AGE OLD QUALITATIVE-ANALYSIS TOL OF CLASSIC-MINERALOGY KNOWN AS BLOWPIPE-ANALYSIS(LAST KNOWN MENTION ANYWHERE IN TWO BOOKS FROM 1935 AND 1948). I PUBLISHED FOUR PAPERS ON SOLID-STATE CHEMITRY/PHYSICS OF CARBIDES IN: PHYSICA STATUS SOLIDI(1972); AND DEFUNCT JOURNAL "SEMICONDUCTORS AND INSULATORS" (1979).

FIRST MY PAPER YOU QUOTE [Generalized-disorder collective-boson mode-softening universality-principle. Journal of Non-Crystalline Solids 40 (1980) 453-467] WAS THE CULMINATION OF A DECADE OF WORK ON THE THEORY OF LIQUIDS BY ME [IN SIR NORMAN MARCH'S JOURNAL ENTITLED: PHYSICS AND CHEMISTRY OF LIQUIDS: 4(4) (1975); 5(1) (1976)-SOME EIGHT PAPERS IN ALL], BASICALLY I NOTICED SIMILARITIES BETWEEN COLLECTIVE-BOSON DISPERSION-RELATIONS NEGATIVE-DISPERSION MODE-SOFTDENING, ORIGINALY BY LANDAU(1941) AND FEYNMAN(1952), BUT EXTENDED TO CLASSICAL-DISORDER BY HUBBARD AND BEBE(1967): w(k) =[KINETIC-ENERGY(QUADRATIC MONATONIC-INCREASING)] k^2/S(k) MODULATED BY STATIC STRUCTURE-FACTOR OF VARIOUS TYPES OF DISORDER: HORIZONTALTOPOLOGICAL) AND/OR VERTICAL(ALLOY).

IN 1982-1985 HAVING MOVED TO SAN FRANCISCO, CALIFORNIA, I CONSULTED FOR CHARLES

ROSEN(MANAGER OF A.-I. RESEARCH AT S.R.I. AFTER WORLD WAR TWO), CEO OF MACHINE-INTELLIGENCE[ONE OF BERNARD WIDROW'S/STANFORD OLD COLLEAGUES FROM WHEN I WAS A VERY LITTLE BOY], AND VESKO MARINOV (AND ADOLPH SMITH), VICE-PRESIDENT OF EXXON ENTERPRISES/A.-I. IN SUNNYVALE/SANTA CLARA, CALIFORNIA. ON ARTIFICIAL-INTELLIGENCE,

THEY GAVE ME A PROBLEM TO SPEED UP ARTIFICIAL NEURAL-NETWORKS WHICH HERETOFOR I HAD NEVER EVEN HEARD OF. BUT BEING A FLAGRANT NON-EXPERT I NOTICED SOMETHING THAT ALL AHE COMPUTER-"SCIENTISTS"/ENGINEERS IJN A.-I. HAD ALL HERETOFORE COMPLETELY MISSED: THE SIGMOID-FUNCTION ACTIVATING NODES WITHIN NEURAL-NETWORKS WAS JUST PLAIN WRONG!!! THE STATE OF THE ART WAS THEN THE r-SPACE NONSENSE OF "ENERGY-LANDSCAPES" FOR GLOBAL-MNINIMUM SEEKING AND GOING TO(IF SUCH EXISTS) OPTIMIZATION CALLED THE BOLTZMAN-MACHINE AND THE SIMULATED-ANEALING, OR THE DEMUTH-BEALE(MATLAB) RADIAL-BASIS FUNCTIONS. ALL OF THESE ARE COMPUTATIONALLY-COMPLEX, IN SPACE AND/OR IN TIME, MANDATING/REQUIRING LARGE COMPUTER-RESOURCES AND LONG COMPUTING-TIMES!!! .

THIS SIGMOID-FUNCTION, A HEAVISIDE STEP-FUNCTION WAS "1"/[1 + e^(-E/T)] WHOSE DERIVATIVE IS A DIRAC DELTA-FUNCTION(HINT HINT HINT!!!).

NOW COMES "EUREKA": SIGMOID-FUNCTION, A HEAVISIDE STEP-FUNCTION WAS "1"/[1 + e^(-E/T)] = "1"/[+ 1 + e^(-E/T)] = "1"/[e^(-E/T) + 1] = FERMI-DIRAC QUANTUM-STATISTICS.

SO THESE COMPUTER-"SCIENTISTS" FOLLOWING HINTON-HOPFIELD- BY ROTE WITH ABSOLUTELY NO THINKING ABOUT WHAT THEY WERE DOING BUT ONLY HOW, DOOMED THEIR ANN OPTIMIZATION-PROBLEMS TO EXPENSIVE SLOW DITHERING!!! AND WHAT THEY WERE DOING WAS TO AUTOMATICALLY TRAPPING THE SYSTEM IN FALSE LOCAL-MINIMA. SOME VERY SMART STATISTICAL-MECHANISTS (ISRAEL" AMIT, SAMPOLINSKY; US: HOPFIELD,...; FRANCE: MEZAERD, TOULOUSE, ...) ALL MISSED THIS SIMPLE FACT: SO THEY GLAMMED ANNS UP BY SPIN-GLASS r-SPACE MODELS GALORE, ALL DONE WITH VARIOUS VERSIONS OF THE RENORMALIZATION-(SEMI)-GROUP AND SOME FANCY MATHEMATICS OR OTHER.

WHY? BECAUSE THE FERMI-DIRAC QUANTUM-STATISTICS + SIGN MEANS THAT THE OPERATORS ANTI-COMMUTE, MEANING THAT THE PAULI EXCLUSION-PRINCIPLE DOMINATES. COMPUTER-"SCIENTISTS" EITHER FORGOT OR NEVER LEARNED THEIR SIMPLE CHEMISTRY/PHYSICS!!!

THE HUND'S-RULE PAIRING OF UP-SPIN TO DOWN-SPIN ELECTRONS TRAPS ONE IN LOCAL-MINIMA, CALLED THE CHEMICAL-ELEMENTS.

IF THE FERMI-DIRAC QUANTUM-STATISTICS + SIGN IS SIMPLY CHANGED TO A - SIGN, THE OPERATORS NOW COMMUTE, MEANING THAT PAULI EXCLUSION-PRINCIPLE STOPS DOMINATING.

IF THIS HAPPENED IN CHEMISTRY/PHYSICS, ALL THAT WOULD EXIST WOULD BE PHOTONS AND NEUTRINOS GOING OF TO INFINITY, ONLY BOSE-EINSTEIN QUANTUM-STATISTICS EXIST!!!

IN THE LANGUAGE OF MY SYNERGETICS PARADIGM AND DICHOTOMY, AKA "FUZZYICS"="CATEGORYICS", THIS "BOSONIZATION" IS THE [LOCALITY] -- TO -->>> (...GLOBALITY...) CROSSOVER!!!

SO, THE OOPO OF ANNS IN SIMPLY THE + SIGN TO - SIGN CROSSOVER, THE FERMI-DIRAC QUANTUM-STATISTICS TO BOSE-EINSTEIN QUANTUM-STATISTICS TRANSITION. STEP-FUNCTION WAS "1"/[1 + e^(-E/T)] = "1"/[+1 + e^(-E/T)] = "1"/[e^(-E/T) + 1] IS REVERSED TO "1"/[-1 + e^(-E/T)] = "1"/[-1 + e^(-E/T)] = "1"/[e^(-E/T) - 1]; SETS TO MULTI-SETS!!

(REFERENCE: GIAN-CARLO ROTA'S(RIP; MIT) UNPUBLISHED BOOK ON PROBABILITY WHICH ONE CAN FIND ONLINE WITH A BIT OF HUNTING. I WAS WORKING WITH HIM ON THIS WHILE VISITING MIT FROM 1992-1997.

"SHAZAM" IS SIMPLY THAT ADMITTING THAT AN ANN AND ITS OOPO IS A QUANTUM-STATISTICAL-PROBLEM ADMITS THE POSSIBILITY OF QUANTUM-TUNELING FROM VARIOUS NON-OPTIMAL MINIMA TO THE GLOBAL-MINIMUM OPTIMIZATION. THE QUESTION WAS HOW TO ACCELERATE/FORCE THIS. THE ANSWER WAS TO TAKE THE "1"NUMERATOR AND DECREASE ITS AMPLITUDE/MAGNITUDE TOWARDS ZERO IN A LIMITING SENSE:

lim("1" . 0) "1"/[- 1 + e^(-E/T)] = lim("1" . 0) "1"/[- 1 + e^(-E/T)] = lim("1" . 0) "1"/[e^(-E/T) - 1] = DIRAC DELTA-

FUNCTION(w-0).

THEN COMES "SHAZAM" (CAPTAIN MARVEL'S MAGIC WORDS TO TRANSFORM HIMSELF INTO A SUPERHERO) AKA "BOSONIZATION":

THUS "EUREKA" + "SHAZAM" = OPTIMIZING OPTIMIZATION-(ANN)-PROBLEMS OPTIMALLY(OOPO)

SOME QUANTUM-STATISTICS INSIGHT: THE FERMI-DIRAC VERSUS BOSE-EINSTEIN DICHOTOMY IS A EUCLID-DEMOSTHENES-DESCARTES CONIC-SECTIONS DICHOTOMY:

FERMI-DIRAC HOMOTOPY TO AN ELLIPSE VIA PARABOLA-CROSSOVER TO BOSE-EINSTEIN HYPERBOLA:

TAYLOR/POWER-SERIES EXPANSION OF ONLY THE DENOMINATOR-EXPONENTIAL YIELDS, IN THE LOW E/T LIMIT, RESPECTIVELY:

"1"/[e^(-E/T) + 1] = "1"/[1 + (-E/T) + ...] + 1] = "1"/2 = E/T ~ w^(0)), WHITE/RANDOM NOISE POWER-SPECTRUM.

-- VERSUS --

"1"/[e^(-E/T) **-** 1] = "1"/[1 + (-E/T) + ...] **-** 1] = E/T ~ w ~ w^(1.000...), THE FAMOUS PINK/FLICKER/ONE-OVER-FREQUENCY NOISE POWER-SPECTRUM.

IN FACT, THERE IS A VERY CONSISTENT + SIGN VERSUS - SIGN DICHOTOMY:

ELLIPSE: MINUS-SIGNS: DENOMINATOR AND COMUTATION-RELATIONS AND PARABOLA-EQUATION

VERSUS: NO SIGN TO 1 IN DENOMINATOR BECAUSE THERE IS NO 1 THERE = MAXWELL-BOLTZMANN CLASSICAL-STATISTICS (THE OBJECT OF ANNS BOLTZMANN-MACHINE + SIMULATED-ANNEALING

HYPERBOLA: MINUS-SIGNS: DENOMINATOR AND COMMUTATION-RELATIONS AND HYPERBOLA-EQUATION SO WHAT I EFFECTED IS CALLED A NOISE-INDUCED PHASE-TRANSITION(A "NIT"; VERY DIFFERENT FROM MERE STOCHASTIC-RESONANCE TINKERING WITH MERE WHITE-NOISE AMPLITUDES; WHAT I DID WAS TO ALTER THE NOISE POWER-SPECTRUM!!!

QUANTUM-STATISTICS ARE EUCLID-DEMOSTHENES-DESCARTES CONIC-SECTIONS!!! (AND EULER-POLYNOMIALS VERSUS BERNOULLI-POLYNOMIALS GENERATING-FUNCTIONS DICHOTOMY)

SO INDEED I GUESS I AM THE FATHER OF MUCH OVER-HYPED QUANTUM-COMPUTING, AT LEAST FOR ANNS OOPO IN A.-I.

LASTLY THE BIANCONI-BARABASI AND ALBERT-BARABASI PAPERS ON NETWORKS, STARTING OUT WITH ABSTRACT GRAPH-THEORY BUT AS FINALES MAPPING THEIR RESULTS ON TO ONLY BOSE-EINSTEIN QUANTUM-STATISTICS WITH BOSE-EINSTEIN CONDENSATION, SO IF ONE APPLIES THEIR CONCLUSIONS TO EITHER ARTIFICIAL NEURAL-NETWORKS OR BIOLOGICAL NEURAL-NETWORKS, MY ORIGINAL ANN BEC AND YOUR BNN BEC ARE NOT AT ALL SURPRISING IN ANY WAY WHATSOEVER!!!

AND FOR BIOLOGICAL NEURAL-NETWORKS THIS AGREES IN PRINCIPLE WITH THE FROHLICH-MOSSBAUER-GOLDANSKII-DEL GUIDICE-POPP-LI-YOUNG-... BIOPHYSICS THEORY OF HEALTH AS "1"/f-"NOISE" POWER-SPECTRUM AND ITS CONDENSATION INTO BEC AS LIFE.

H. Frohlich: Nuovo Cimento, 7, PPM (1977); International J. Quantum-Chemistry, 11, 641 (1968); Advances in Electronic Devices, 53 (1980);...

E. Del Guidice et. al.: Nuclear Physics B251, 375 (1985); ibid. B275, 185 (1986);...

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J. Li, Physics Letters 116A, 405 (1986)

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F. Young-preprints; c/o (650) 949-4728

A. Goldberger (M. D. - cardiologist, Director, Cardiology Clinic), many preprints/reprints/reports, Beth-Israel Hospital, Boston, MA.

C. Anderson and A. Mandell, in The Secret Symmetry: Fractals of Brain, Mind and Consciousness, E. MacCormac and M. Stamenov eds., Adv. In Consciousness Research, John Benjamin, Philadelphia (1996);

C. Anderson, Doctoral Dissertation, Florida Atlantic University (1995); C. Anderson, Thesis, Harvard Medical School, McLean Hospital (1998)

A. Verveen and L. deFelice, Ann. Rev. Biophysics (1968?)

L. deFelice, Membrane Noise (1989)

Lawrence Ward(UBC/PSYCHOLOGY) and Priscilla Greenwood, < http://www.scholarpedia.org/article/1/f_NOISE >

NOW TO BENFORD'S-LAW:

YOU MISUNDERSTAND WHAT I/WE DID. ALL I/WE DID WAS TO ALGEBRAIC-INVERSION OF

= log(BASE-10) [1 + 1/d] TO YIELD d = 1/[10^(

) - 1] ~ 1/[e^(

- 1] ~ 1/[e^) - 1] ~ 1/e^(w) - 1]. WHY? BECAUSE DIGIT d = 0 BEING EXCLUDED TELLS A PHYSICIST SOMETHING VERY VERY IMPORTANT. BUT FIRST SIMPLY ROTATE ANY DIAGRAM OF BENFORD'S-LAW TO REVERSE THE AXES. WHAT ONE SEES IS THAT IT RESEMBLES A QUANTUM ENERGY-LEVEL DIAGRAM: GROUND-STATE IS d = 0; FIRST EXCITED-STATE IS d= 1; SECOND EXCITED-STATE IS d = 2,.. ETC. ETC ETC. BUT = oo VERSUS ANY OTHER <(P = 1) > = 0.32... ETC. ETC. ETC.

SO OF COURSE BOSONS ARE DIGITS BECAUSE DIGITS ARE QUANTA(NO FRACTIONS IN BETWEEN) AND THOSE QUABNTA CAN ONLY BE BOSONS DUE TO THE PLUS-SIGN BEFORE THE ONE IO BENFORD'S-LAW!!!

ONE HAS GAPFUL BOSE-EINSTEIN CONDENSATION!! IN NEWCOMB(1881) AND WEYL(1914; 1916) AND WE THINK IN BERNOULLI AND EULER(1730?)

AN EXAMPLE. A BLANK CHECK IS A BOSE-CONDENSATE OF ZEROS. WHEN ONE WRITES A NUMBER ON IT, SAY $1, ONE INDICATED THE EXCITED-STATE THE CHECK WILL BECOME WORTH, AND WHEN ONE SIGNS IT ACTIVATING THE CHECK BY VALIDATING ITS VALUE, THAT IS EQUIVALENT TO A PHOTON EXCITING AN ELECTRON INTO THE FIRST EXCITED-STATE.

SO SIMPLE-ARITHMETIC: ADDITION, SUBTRACTION, MULTIPLICATION IS QUANTUM-COMPUTING. WHAT RUINS THIS IS DIVISION WITH REMAINDERS, BUT WHERE GAUS MODULAR-ARITHMETIC ENTERS POINTEDLY.

MARTIN HOLTHAUS ET. AL. (U. OLDENBURG) HAS FOUND A WAY TO FACTOR USING BOSE-EINSTEIN CONDENSATION!!!

< http://www.condmat.uni-oldenburg.de/Holthaus/lop.html > Ideal Bose gases: From statistical mechanics to number theory A. C. Weiss, S. Page, and M. Holthaus:

Factorizing numbers with a Bose-Einstein condensate, Physica A 341, 586 - 606 (2004), arXiv:cond-mat/0403295 Authors: Christoph Weiss, Steffen Page, Martin Holthaus (Submitted on 11 Mar 2004)

Abstract: The problem to express a natural number N as a product of natural numbers without regard to order corresponds to a thermally isolated non-interacting Bose gas in a one-dimensional potential with logarithmic energy eigenvalues. This correspondence is used for characterising the probability distribution which governs the number of factors in a randomly selected factorisation of an asymptotically large N. Asymptotic upper bounds on both the skewness and the excess of this distribution, and on the total number of factorisations, are conjectured. The asymptotic formulas are checked against exact numerical data obtained with the help of recursion relations. It is also demonstrated that for large numbers which are the product of different primes the probability distribution approaches a Gaussian, while identical prime factors give rise to non-Gaussian statistics.

IN FACT, BENFORD'S-LAW[SEE THE REFERENCES IN MY RE-ATTACHED ABSTRACT] WAS ORIGINALLY DUE TO NEWCOMB (1881) AND WEYL (1914; 1916). (AND RAIMI'S SCIENTIFIC-AMERICAN ARTICLE IN 1969 IS WELL WORTH READING!!!) COULD YOU PLEASE TRY TO READ THE TWO WEYL PAPERS AND E-BAIL ME THEIR TRANSLATIONS??? (MEINE DEUTSCH IST SEHR SCHLECHT; ICH NICH HAT IM FUNFZIG JAHERE DEUTSCH SPRECHEN UND LEHREN!!!)

BUT IT IS EVEN EARLIER DUE TO EULER IN ANOTHER CONTEXT ENTIRELY HAVING NOTHING WHATSOEVER TO DO WITH STATISTICS!!!

AND TED HILL'S 1996 PROOF USES LOGARITHM BASE-INVARIANCE = UNITS-INVARIANCE = SCALE-INVARIANCE SYMMETRY-(RESTORING) WHICH GETS PHYSICITS VFRY TURNED-ON, ALTHOUGH MATHEMATICIANS LIKE TED HIL DON'T SEEM TO UNDERSTAND WHY IT IS SO EXCITING!!!

LASTLY, THE CATEGORY-THEORY DIAGRAMS I USE IN MY PAPERS AGE CALLED THE PLATO(INVENTOR OF CATEGORIES)-ARISTOTLE(HIS GRADUATE-STUDENT) "SQUARE-OF-OPPOSITION" A STANDARD FORM OF GREEK LOGIC, BEST READ ABOUT IN THE STANFORD ENCYCLOPEDIA OF PHILOSOPHY < http://plato.stanford.edu/entries/square/ > AND ITS WIKIPEDIA ENTRY < http://en.wikipedia.org/wiki/Square_of_opposition > AND VIEW ALL SORTS OF ITS DIAGRAMS < http://www.google.com/images?hl=en&source=hp&q=%22SQUARE+OF+OPPOSITION%22&gbv=2&oq=%22SQUARE+OF+OPPOSITION%22&aq=f&aqi=g8g-m2&aql=&gs_sm=e&gs_upl=3453l14094l0l14797l22l22l0l0l0l0l235l3452l3.13.6l22l0&oi=image_result_group&sa=X > BUT THE GRIDLINES OF THIS TABULAR LIST-FORMAT TRUTH-TABLE MATRIX-ANALYTICS, LOKING LIKE A TIC-TAC-TOE DIAGRAM DO NOT SHOW UP IO WORD-FOR-WINDOWS TABLES, SO IT IS SOMEWHAT CONFUSING. I USE SEMANTICS/LINGUISTICS TO LABEL DIFFERENT(THREE) COLUMNS AND FOUR-ROWS, WHICH IS WHY THIS IS "CATEGORY-SEMANTICS COGNITION" , "NEW" WAY TO ANALYZE PHYSICS AND INDED PURE-MATHEMATICS MODULO ARISTOTLE, FROM ~ 350 B.C.E.!!!

AND ONE CAN ADJOIN THESE DIAGRAMS GETTING TOPOLOGY-LIKE HOMOLOGY-COHOMOLOGY A LA GROTHENDIEK AND SHEAVES. BUT THAT IS STILL IN DEVELOPMENT.

CATEGORY SEMANTICS IS ALSO PRACTICED BY JOHN BAEZ(MATHS/UC-RIVERSIDE) < > BUT ON ABSTRACTIONS OF STRING-THEORY/COSMOLOGY/PURE-MATHEMATICS/MATHEMATICAL-PHYSICS/... It goes on much longer, but you get the idea...

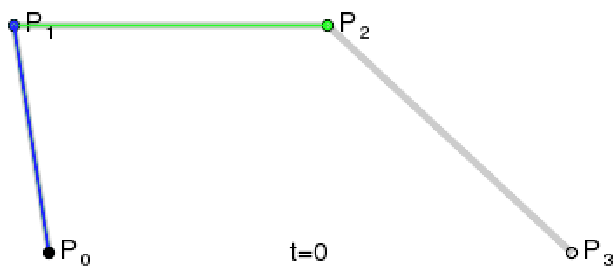
Here is a much more typical example of a mail from someone who has some nonstandard ideas — just for comparison.

> I have also addressed issues regarding spacetime, gravity, extra dimensions, dark matter and dark energy, quantum uncertainty etc.
>
> 1) Space time is not continuous but discrete. Time stops and starts every 10-43s. Our universe is made up of countless number of minute space time nodes. When time stops, all the minute spacetime nodes combine to form one single space time node. This single spacetime node will be of the same size as that of the minute space time nodes.
>
> 2) Apart from the four dimensions of spacetime, there is an alternate four dimensional spacetime continuum called invisible spacetime. Time dilation is the consequence of the time spent by the moving object in the invisible space time fabric, wherein the space dimension is active and the time dimension is zero.
>
> 3) Gravity is the result of discrete space time. When all the matter in the universe occupy one single node and get distributed to their respective nodes and when the new time interval starts, a force of attraction exerts between the particles which is attractive.
>
> 4) Quantum uncertainty is also the result of discrete space time. When t=0, all the particles is at the same place (same node) and when t.0, particles occupy their individual positions. Each particle is equally valid of being at each and every point in the universe at the same time. Hence the exact location of the particle cannot be found out accurately. The interference pattern in the double slit experiment could be explained in the classical way using the concept of discrete spacetime.
>
> 5) We do live in a 10 dimensional universe and each of us experience those dimensions. In total there are 7 dimensions of space and 3 dimensions of time. However space and time dimensions cannot exist independently and are always combined, in different ways.
>
> 6) Dark energy is nothing but the dark matter which is embedded in the higher dimensions (invisible spacetime)

wherein the space dimension is active and the time dimension is zero. Since time dimension is zero, no events could occur and henceforth the matter in that spacetime is invisible. Dark matter is nothing but the dark matter which leaks to visible spacetime from the invisible spacetime.

From general relativity to quantum mechanics everything can be explained using the concept of discrete spacetime. I have attached the file below consisting a few pages. It would be very helpful if you could glance through the document and give your valuable comments regarding the subject.

September 15, 2014



Say you have some dots and you want to draw a smooth curve that *sorta almost* goes through these dots. Then you can use a Bézier curve. Some drawing programs use this trick... and lots of fonts are drawn with the help of Bézier curves.

The math behind these curves had been known since 1912, but they were popularized by Pierre Bézier, an engineer who used them to design automobile bodies at Renault.

Can you figure out how they work just by looking at the movie? An explanation in words sounds complicated... but it's really easy as pie.

It's like you've got 3 guys running along straight racetracks. The 2 guys in back have rabbits that each chase the next guy, always heading straight toward that next guy. And the guy at the very back also has a dog that chases straight after the next guy's rabbit. Everyone starts at the same time and stops at the same time. The dog follows the red curve.

In other words:

First draw gray lines between your original dots P_0, P_1, P_2, P_3.

Each ***green*** dot moves at a constant rate along a gray line. All the green dots start at the same time, and finish at the same time.

Then draw green lines connecting the green dots.

Each ***blue*** dot moves at a constant rate along a green line. All the blue dots start at the same time, and finish at the same time.

Then draw a blue line connecting the blue dots.

The ***black*** dot moves at a constant rate along this blue line. It starts at the same time as all the other dots, and finishes at the same time.

Get the pattern? Each time we do this trick, there's one fewer dot. There are 4 original dots, 3 green dots, 2 blue dots and 1 black dot. So now you're done!

The black dot traces out the Bézier curve shown in red here.

You can play this game starting with any number of dots. When you start with n dots, you get a curve described by a polynomial equation of degree n-1. So, this red curve is called a cubic Bézier curve.

Puzzle 1: show that our cubic Bézier curve is given by the equation

$$C(t) = (1-t)^3 P_0 + 3(1-t)^2 t P_1 + 3(1-t) t^2 P_2 + t^3 P_3$$

Puzzle 2: generalize this to more dots. (Hint: binomial coefficients!)

When you've got a lot of dots, people usually break them into bunches and draw a quadratic or cubic Bézier curve through each bunch. They match up at the ends, so this works, though frankly I often think it looks kind of lame. This is called a composite Bézier curve. PostScript, Asymptote, Metafont, and SVG use composite Bézier curves made of cubic Bézier curves to drawing curved shapes.

I imagine there are lots of tricks that are 'better' than Bézier curves, but I'm not an expert! If I wanted to know more, I'd read about stuff like non-uniform rational B-splines, or NURBS:

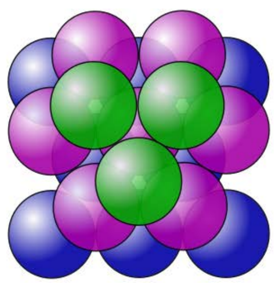
- Non-uniform rational B-spline, Wikipedia.

But I just read this:

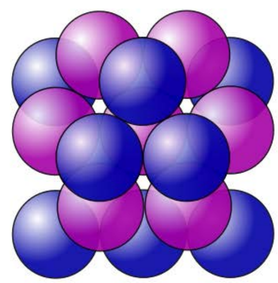
- Bézier curve, Wikipedia.

because I liked the animated gif, made by Phil Tregoning.

September 16, 2014



face-centered cubic (fcc)
(also called cubic close packed (ccp))
three repeating layers ABCABC....



hexagonal close-packed (hcp)
two repeating layers ABABAB...

What's the densest way to pack spheres? Here are two equally good ways.

In fact there are infinitely many equally good ways! We start by laying spheres on the plane in a hexagonal arrangement, as tightly as we can. Then we put a second layer like this on top, with the new spheres resting in the gaps between the old ones. Then we put on a third layer. But now there are 2 really different ways to do it!

The spheres in the third layer can be directly above the spheres in the first layer - that's the picture at right. Or they can be not directly above - shown at left.

As we continue, we keep getting more choices.

One systematic choice is to make the layers alternate like ABABAB..... That's called the hexagonal close packing, and that's how crystals of magnesium work.

Another systematic choice makes every third layer be the same, like ABCABC... That's called the cubic close packing or face-centered cubic, and that's how crystals of lead work.

(Why "cubic?" Because - even though it's not obvious! - you can also get this pattern by putting a sphere at each corner and each face of a cubical lattice. Trying to visualize this in your head is a great way to build your brain power.)

There are also uncountably many unsystematic ways to choose how to put down the layers of spheres, like ABACBCAC.... You just can't use the same letter twice in a row.

In 1611, the famous astronomer Kepler conjectured that sphere packings of this sort were the densest possible. They fill up

$$\pi / 3 \sqrt{2} = 0.740480489...$$

of the space, and he claimed you can't do better.

Proving this turned out to be very, very hard. Wu-Yi Hsiang claimed to have a proof in 1993. It was 92 pages long. Experts said it had gaps (pardon the pun). Hsiang has never admitted there's a problem.

Thomas Hales claimed to have a proof in 1998. His proof took 250 pages... together with 3 gigabytes of computer programs, data and results!

The famous journal *Annals of Mathematics* agreed to check his proof with a board of 12 referees. In 2003, after four years of work, the referees accepted his paper. But they didn't exactly say it was correct. They said they were "99% certain" it was right - but they didn't guarantee the correctness of all of the computer calculations.

Hales wasn't happy.

He decided to do a completely rigorous proof using computer logic systems, so that automated proof-checking software could check it. He worked on it for about 10 years with a large team of people.

He announced that it was done on August 10th, 2014. You can see the announcement here:

- Announcing completion, The Flyspeck Project.

To verify the proof, the main thing you need to do is check 23,000 complicated inequalities. Checking all these on the Microsoft Azure cloud took about 5000 processor-hours.

When it was done, Hales said:

> An enormous burden has been lifted from my shoulders. I suddenly feel ten years younger!

Personally I prefer shorter proofs. But this is quite a heroic feat.

I actually wrote about this because I want to talk about packing tetrahedra. But I figured if you didn't know the more famous story of packing spheres, that would be no good.

For more, check out Hales' free book, which starts with a nice history of the Kepler problem:

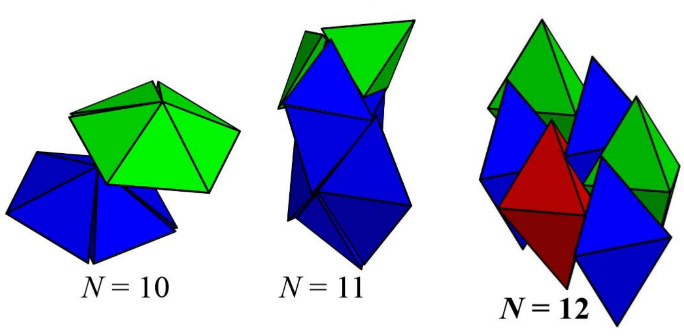
- Thomas C. Hales, *Dense Sphere Packings: a Blueprint for Formal Proofs*.

For more on computer-aided proof, try this paper:

- Thomas C. Hales, Developments in formal proofs.

The image above was created by Christophe Dang Ngoc Chan and the words translated to English by "Muskid". You can get it on Wikicommons.

September 17, 2014



What's the densest way to pack regular tetrahedra? Aristotle, perhaps after staying up too late grading Alexander the Great's homework, once claimed they could fill space completely. But that's clearly false.

Here's the story. To save space, I'll use 'tet' to mean 'regular tetrahedron'.

In 1976, a guy named Hoylman showed that if you have tets centered at points in a lattice, all pointing the same way, the best density you can get is

18/49 ≈ 36.73%

That's lousy: spheres can do 74.05%. But Hoylman's work was good, because he corrected an earlier false claim by Minkowski, who was a genius when it came to lattices.

In 2006, Conway and Torquato made a big breakthrough. First they packed 20 tets into an icosahedron — there's a beautiful easy way to do this, since an icosahedron has 20 triangles as faces. You're left with a hole in the middle, but it's not very big. Then they packed icosahedra as densely as they could. This is the hard part. But using this combination of tricks, they packed tets with a density of

71.65%

This is still a bit worse than spheres. Much earlier, the brilliant mathematician Stanislaw Ulam had conjectured that the maximum density for packing equal-sized spheres was *worse than for any other convex shape* in 3 dimensions. This conjecture is still open! But if he's right, tets must be able to beat spheres.

In 2007, a bunch of people showed experimentally that you could get tets to beat spheres — they got densities of around 75%. And in 2008, Elizabeth Chen figured out how to make a cluster of 18 tets, and then pack these clusters, to get a density of

77.86%

The race has picked up since then! I won't tell the whole story, since it's quite long. But this picture shows the current record, held by Elizabeth Chen, Michael Engel and Sharon Glotzer.

These folks used Monte Carlo simulations to help them pack N tets into a cluster and then pack these clusters as densely as possible. I'm only showing three cases here, but their paper shows what they get up to N = 16.

With N = 10 you get two 'wagon wheels'. With N = 11 you get something complicated. With N = 12 you get 6 'dimers' arranged in a certain way. And so on. So far the winners in the density contest are N = 4, 8, 12 and 16. These all give a density of

4000/4671 ≈ 85.63%

So, this may be the best we can do! But nobody has proved that.

All this stuff is actually related to physics, since now people can make 'fluids' of tiny hard tetrahedra. And in 2009, some people showed that at high enough densities such a fluid will spontaneously transforms to a dodecagonal quasicrystal, which can be compressed to a density of 83.24%. They did it using Monte Carlos simulations.

If you ask what are the practical application, I'll tell you: math like this isn't mainly about practical applications! It's mainly about *having fun* while *developing our ability to solve hard problems*.

However, the same kinds of 'Monte Carlo optimization methods' used to tackle this problem are also important for keeping our economy humming ever faster as we burn more and more carbon, chop down rainforests, overfish the oceans and generally wreck the environment. So don't complain — we mathematicians are playing our part!

Puzzle: I mentioned the numbers N = 4, 8, 12 and 16. What does that suggest?

You can see more pictures of the best known packing here:

- Tetrahedra packing....

For more, try this:

- Jeffrey C. Lagarias and Chuanming Zong, Mysteries in packing regular tetrahedra, *AMS Notices*, December 2012, 1540–1549.

and this, where I got the picture:

- Elizabeth R. Chen, Michael Engel and Sharon C. Glotzer, Dense crystalline dimer packings of regular tetrahedra, *Discrete and Computational Geometry*, **44** (2010), 253–280.

and this:

- Tetrahedron packing, Wikipedia.

September 18, 2014

I'm leaving Singapore today. This wall painting in Chinatown, modeled after a classical Chinese painting, captures a bit of what I like about the place. It's a mix of old and new, East and West.

Last weekend, Lisa and I saw a Chinese opera — part of a free series in Hong Lim Park. Chinese opera used to be really popular in Singapore, with the stars being the equivalent of pop idols today. Now its appeal is dwindling, but there was still a big crowd — and some old guys were punching their fists in the air when the star-crossed lovers finally triumphed in the end. It was set in the Ming Dynasty, and featured an emperor who snuck out of the palace and wound up marrying a peasant girl. I enjoyed it a lot more than I expected. Why? Because big computer screens showed translations of the lyrics into English! Without that, I might have roughly followed the plot, but I wouldn't have gotten the jokes.

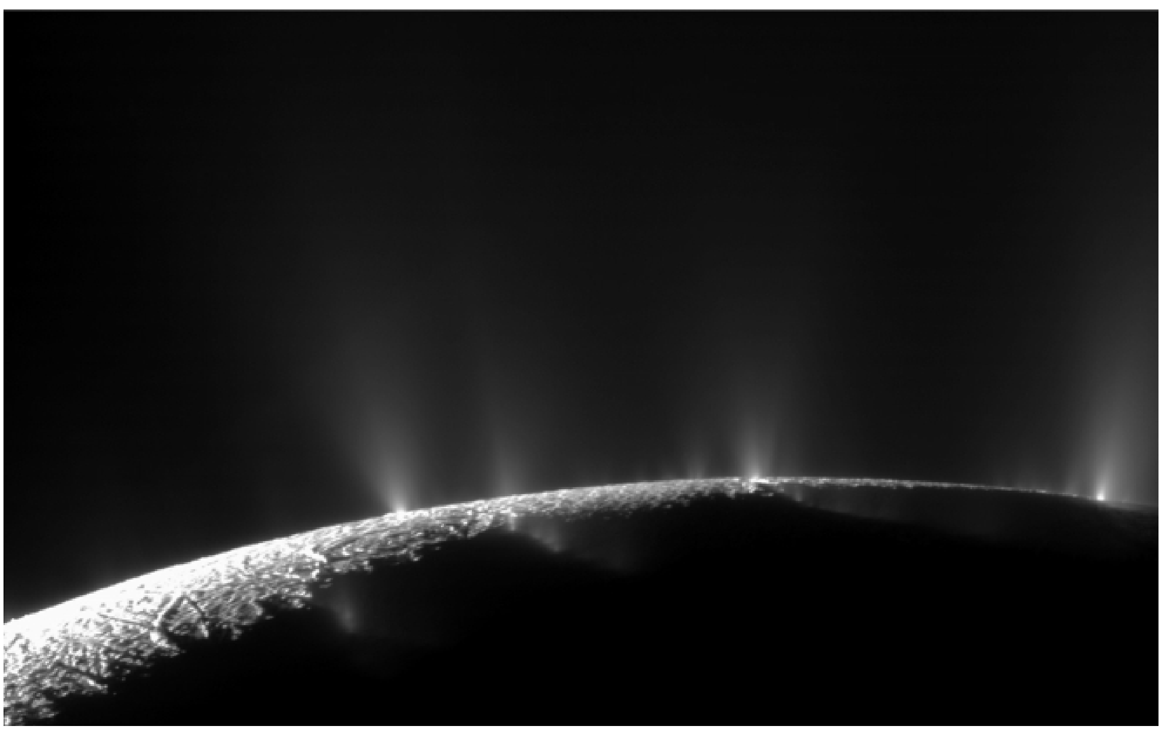
I'm going back to Riverside to teach. I've got a light teaching load this fall, just grad-level real analysis (the first quarter of a 3-part course) and my seminar — where I'll take the work my grad students have been doing on network theory and put it together into a nice story. I'll try to write lecture notes in the form of blog articles, but I find that fun and relaxing. So, I'll be able to put some energy into the talk I'm giving this December at NIPS, the Neural Information Processing Seminar, a big annual conference on neural networks. I want to talk about El Niqo prediction, climate networks and machine learning. But I've got a lot to learn, especially about machine learning. The Azimuth Code Project team want to carry out some computer experiments in that direction. It should be fun, as long as I resign myself to giving a talk that's just "work in progress", not completed and polished. I'll do some heavier teaching in the winter quarter, but the spring will be a non-teaching quarter. This seems awfully cushy, but my department chair noticed I'd taught too much last year — more than I'm paid to do! And in the spring, I'll be helping run two workshops. One is on information and entropy in biology, at the National Institute for Mathematical and Biological Synthesis, in Knoxville Tennessee. The other is on network theory, at the Institute for Scientific Interchange, in Torino Italy.

Then in June I'll come back to work at the CQT in Singapore!

September 24, 2014

This selfie was taken by Vermeer's maid Griet in 1665, moments after the painter completed his masterwork *Girl With a Pearl Earring*.

September 26, 2014



Enceladus, the sixth-largest moon of Saturn, has geysers that shoot jets of water into space! They look beautiful in these photographed by the Cassini probe. They create an invisible ring of ice crystals around Saturn: the E ring. And now they have been mapped!

There are at least 100 geysers near the south pole of Enceladus. They come from four big cracks in its rocky surface, called tiger stripes. Some of the water they shoot out falls back to the surface as snow, but about 200 kilograms per second shoots out into space. The tiger stripes also emit about 5 gigawatts of heat.

The geysers have recently been mapped by Carolyn Porco and her collaborators at NASA:

- PIA17188: Surveyor's map of Enceladus' geyser basin.

For my October 2014 diary, go here.

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home

For my September 2014 diary, go here.

Diary — October 2014

John Baez

October 1, 2014

The Picture of Dorian Gray

> *...the face appeared to him to be a little changed. The expression looked different. One would have said that there was a touch of cruelty in the mouth. It was certainly strange.* — Oscar Wilde

Sadly, I haven't read this story yet — I've just seen a movie version. And I've read some quotes. Since Wilde was a master of the epigram, you can enjoy these like popping down peanuts until you get sick to your stomach:

> *Nowadays people know the price of everything and the value of nothing.*

> *He was always late on principle, his principle being that punctuality is the thief of time.*

> *I never talk during music — at least, during good music. If one hears bad music, it is one's duty to drown it in conversation.*

> *The basis of optimism is sheer terror.*

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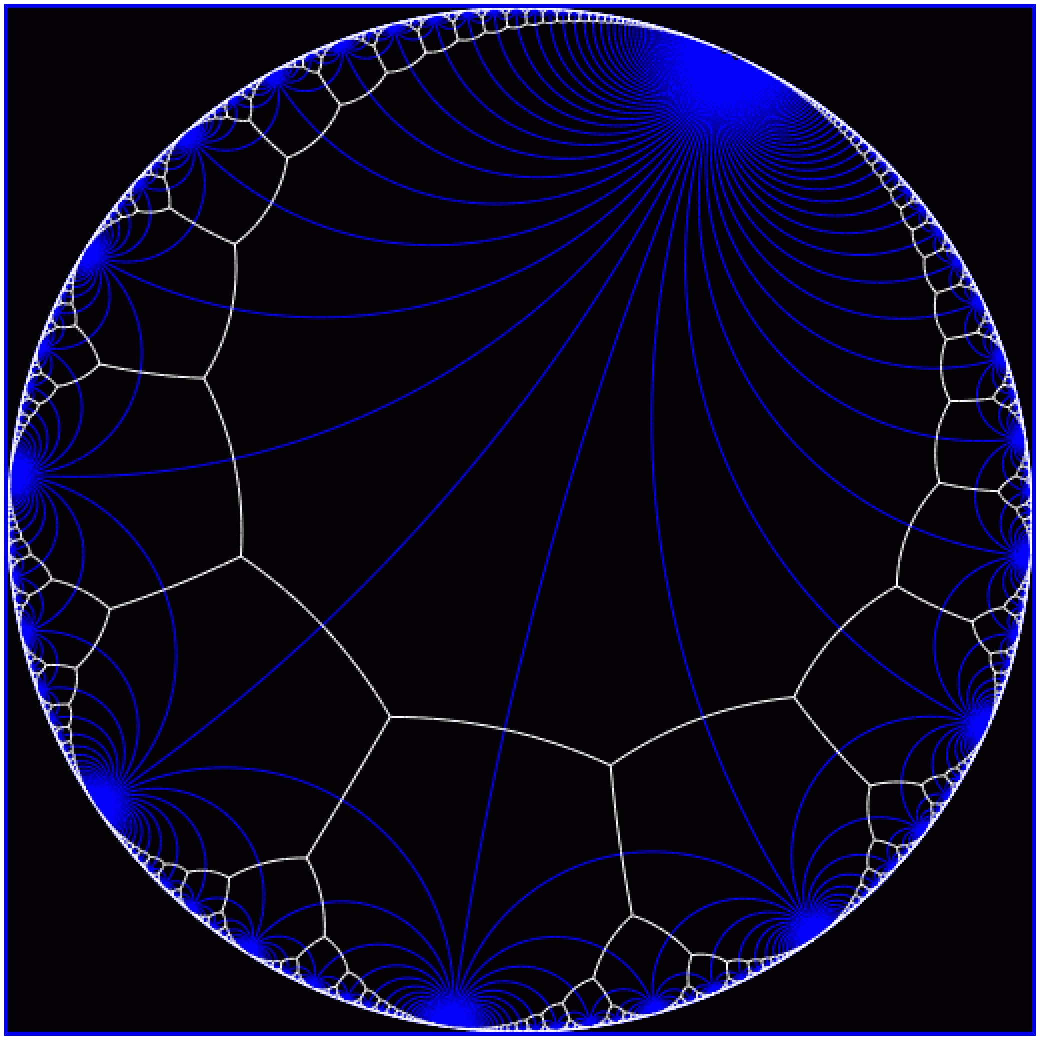
The only way to get rid of temptation is to yield to it. Resist it, and your soul grows sick with longing for the things it has forbidden to itself.

Some people cause happiness wherever they go. Some people cause happiness whenever they go.

... and so on. You can like them without agreeing with them. If you agreed with them all, Wilde would probably be disappointed.

The picture here is by an artist named Gerwell.

October 2, 2014



Here's a picture of the hyperbolic plane tiled with apeirogons: polygons with infinitely many sides!

Regular polygons with infinitely many sides are one of those things that make hyperbolic geometry more fun than ordinary Euclidean geometry.

'Apeiro-' is a Greek prefix meaning 'infinite' or 'unlimited'. You know the word 'perimeter', meaning boundary or limit? Well, 'apeiro-' means having no limit. Greek mathematicians were pretty nervous about the infinite, because they thought its unlimitedness made it inherently vague, even chaotic.

The apeirogons are white, and there are 3 meeting at each corner.

In blue we see the dual tiling: there's one blue vertex in the middle of each white polygon, and one blue edge crossing each white edge, and one blue polygon containing each white vertex.

Here are two fun puzzles:

Puzzle 1: What would a regular apeirogon look like in Euclidean geometry?

Puzzle 2: Can you tile the Euclidean plane with regular apeirogons?

And here are two puzzles that are easy if you know what the Schläfli symbol of a tiling is, impossible otherwise:

Puzzle 3: what's the Schläfli symbol of the white tiling?

Puzzle 4: what's the Schläfli symbol of the blue tiling?

This picture was drawn by Don Hatch, but I'm afraid peeking at his page may give away the answer to some of the puzzles!

For some answers, see my G+ post.

October 5, 2014

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$\begin{pmatrix} |U_{e1}|^2 & |U_{e2}|^2 & |U_{e3}|^2 \\ |U_{\mu 1}|^2 & |U_{\mu 2}|^2 & |U_{\mu 3}|^2 \\ |U_{\tau 1}|^2 & |U_{\tau 2}|^2 & |U_{\tau 3}|^2 \end{pmatrix} \stackrel{?}{=} \begin{pmatrix} 2/3 & 1/3 & 0 \\ 1/6 & 1/3 & 1/2 \\ 1/6 & 1/3 & 1/2 \end{pmatrix}$$

Neutrinos come in 3 kinds, but the 3 kinds with definite masses are not the same as the 3 kinds with definite flavors. They're related by a 3×3 matrix.

Every particle is also a wave, and a particle at rest is a standing wave: it wiggles without going anywhere, like a vibrating piano string. The mass, or more precisely the 'rest mass', of a particle is simply the frequency at which this standing wave vibrates.

But sometimes a particle at rest can wiggle in several different ways with different frequencies. A neutrino can wiggle in 3 ways, and these are called its 'mass eigenstates'. They have boring names: 1, 2 and 3.

The 'flavor' of a neutrino says how it interacts with other particles via the weak force. The flavors have cool names: e (electron), μ (muon), and τ (tau particle).

But a neutrino with a definite flavor does not have a definite mass! A neutrino with a definite flavor is a superposition, or linear combination, of mass eigenstates. The first equation here says how that works. You can understand this if you know about matrix multiplication. We use a 3×3 matrix, the 'neutrino mixing matrix', to write the neutrinos with definite flavor as linear combinations of the mass eigenstates.

What are the numbers in this matrix? Experimentalists have worked very hard over the last few decades trying to measure them. We know some better than others.

They are complex numbers, but there's an interesting guess about their absolute values, shown in the second equation. This guess is called the 'tribimaximal matrix'.

That's a goofy-sounding name! Where did it come from?

With this matrix, the 2nd column is all 1/3's. This means that the 2nd mass eigenstate consists of equal parts of e, μ and τ, so we say it's trimaximally mixed. The 3rd column has two 1/2's. This means that the 3rd mass eigenstate consists of equal parts of μ and τ, so we say it's bimaximally mixed.

Is the tribimaximal matrix right? It is consistent with all known experiments...

... or at least it was until 2012, when this paper seems to have ruled it out:

- The Daya Bay Collaboration, Observation of electron-antineutrino disappearance at Daya Bay, *Physics Review Letters* **108** (2012), 171803.

Great title, eh?

I'm still hoping this experiment made a mistake. If the tribimaximal matrix is wrong, neutrinos remain profoundly mysterious: they're described by a bunch of numbers and we have no idea why these numbers are what they are - since we don't even know exactly what they are.

I wish I knew more about this stuff. For more, try:

- Pontecorvo–Maki–Nakagawa–Sakata matrix, Wikipedia.
- Tribimaximal mixing, Wikipedia.

By the way, the neutrino mixing matrix is 'unitary': its inverse is the complex conjugate of its transpose. So, the rows say how flavors are superpositions of mass eigenstates — and the columns say how mass eigenstates are superpositions of flavors! I used this when I explained the tribimaximal idea.

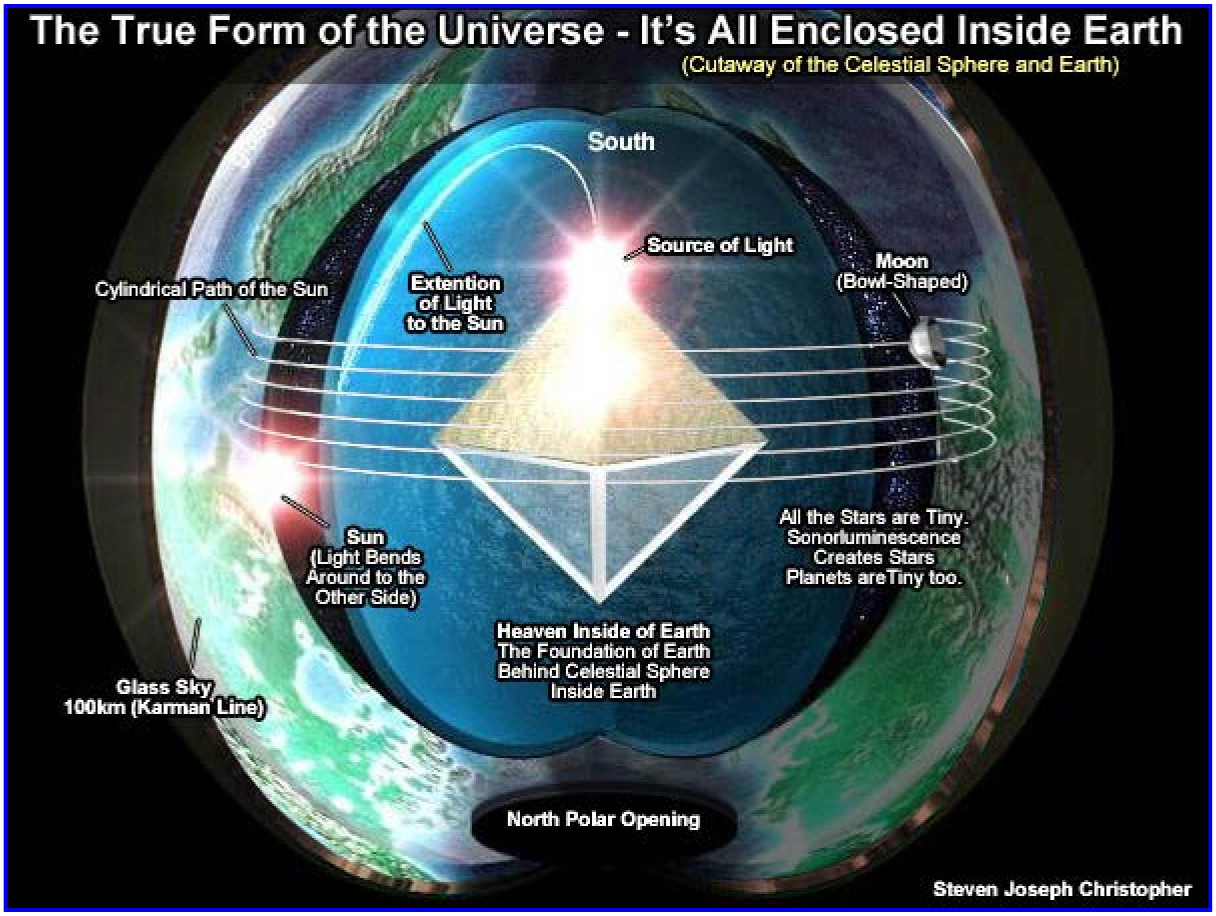
Also, because this matrix is unitary, when you take the absolute value squared of the entries, you get a matrix of nonnegative numbers where each row sums to 1 and each column sums to 1. So, as soon as we decide it looks like this:

?	1/3	?
?	1/3	1/2
?	1/3	1/2

we know what it must be:

2/3	1/3	0
1/6	1/3	1/2
1/6	1/3	1/2

October 9, 2014



There have been lots of theories saying the Earth is hollow, but I know only one that could be true.

Edmond Halley, the guy who discovered the famous comet, had a theory where Earth consists of a hollow shell about 800 kilometers thick, two smaller shells nested inside, and a ball in the middle — all separated by atmospheres and rotating at different speeds! It sounds nutty, but Halley was trying to explain the Earth's rather complicated magnetic fields: each of his shells was magnetic.

People sometimes accuse Leonhard Euler, the famous mathematician and physicists, of believing the Earth was hollow. But that's not true. In fact, all Euler did was propose a famous thought experiment:

Puzzle: If you could drill a hole all the way through the Earth, and drop a stone in, what would happen?

With the passage of time, scientists have been learning more about geology, so the remaining people who believe in hollow Earth theories get crazier and crazier. For example, the neo-Nazi Ernst Zündel wrote a book entitled *UFOs - Nazi Secret Weapons?* claiming that Hitler and his men had boarded submarines at the end of the war, escaped to Argentina, and then established a base for flying saucers in a hole leading to the inside of the Earth at the South Pole. Z|ndel also suggested that the Nazis had originated as a separate race that had come from inside the Earth.

My favorite hollow Earth theories are the ones that say *we are actually inside!* That's right: all of outer space fits inside an Earth-sized ball, while *rocks* fill the infinite outside of the universe! Or maybe the outside is outer space too... but we're stuck on the inside.

I'm not sure what this theory is supposed to accomplish, but it's fun to think about. What you think are stars may actually be lights from cities on the other side of the Earth! When the Sun sets.... well, there are different ideas about where it goes. Perhaps it goes into a hole? Or perhaps its light *bends* in such a way that only half the Earth gets sunlight at any one time.

In fact, if you change enough laws of physics, the inside-out Earth theory becomes hard to refute. It becomes our usual theory of the universe described in 'inside-out coordinates', so it becomes *equivalent* to our usual ideas — except perhaps for one tiny point which I'll mention later.

There's an Egyptian mathematician Mostafa Abdelkader who actually took this line of thought seriously. According to Martin Gardner, this guy claimed that light rays travel in circular paths, and slow as they approach the center of the spherical star-filled hollow Earth. Everything shrinks and slows down as it gets close to the center, so nothing can ever get there. On the other hand, a drill would get longer as you used it to dig outward into the rock.

This theory gets a bit freaky if you drill *all the way through the Earth*. At some point your drill tip has to suddenly appear on the opposite side of the Universe!

But if you allow this, there's not much difference between the inside-out Universe and ours. True, it's missing *one point* compared to our usual Universe — namely, the point right at the center of the Earth! But to make up for this, it has an extra point, namely the 'point at infinity', in the center of this inside-out Universe.

In fact, if we include *both* these points, the Universe itself becomes a '3-sphere', which has two 'hemispheres', namely the inside and the outside of the Earth. One is solid rock, the other empty space. And in fact Dante describes this cosmology in his *Divine Comedy*. He was a smart dude.

It's a fun exercise in the philosophy of science to figure out why a theory that makes almost identical predictions to our usual theories is nonetheless considered much worse.

For more on hollow Earth theories, try:

- Wikipedia, Hollow Earth.

For more on the myth that Euler believed in a hollow Earth:

- Ed Sandifer, How Euler did it, *MAA Online*, April 2007.

The nice mathematical way to turn space inside out is called 'conformal inversion'. It sends straight lines and circles to straight lines and circles, and it preserves angles. You can read more about it here:

- Wikipedia, Inversive geometry.

And here's the webpage where I got this marvelous picture:

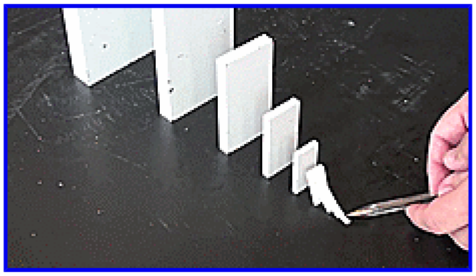
- Duane Griffin, The hollow Earth in science.

Here is seems that the 'point at infinity' is contained inside a glowing octahedral Heaven, the Moon is bowl-shaped, the Sun's light bends, and there's a hole in the North Pole, leading... where?

Zündel, by the way, was jailed several times for publishing books like *The Hitler We Loved and Why* and *Did Six Million Really Die?*:

- Wikipedia, Ernst Zündel.

October 10, 2014



A domino can knock over a domino that's one and a half times taller. Here you see a tiny domino 5 millimeters tall starting a chain reaction 13 dominos long... which eventually knocks over a domino about a meter tall.

The amount of energy released by the fall of that last domino is 2 billion times the amount of energy it took to knock over the first one!

And if we could do a chain reaction like this 29 dominos long, the final domino would be the size of the Empire State Building!

Puzzle: If each domino is 1.5 times the height of the one that knocked it over, how much longer does it take to fall?

Answer: We can use dimensional analysis to tackled this question. Assuming the overall geometry is just rescaled as we go to larger and larger dominos, and assuming friction can be neglected, the time of fall only depends on:

- the height H of the shorter of the two dominos, which has dimensions of length, L, and
- the acceleration g of gravity (about 9.8 meters/second^2 here on Earth), which has dimensions L/T^2.

Thus, anything with units of time built from H and g is some constant times

$$\sqrt{H/g}$$

So, the time it takes for each domino to fall and hit the next grows proportionally to $\sqrt{H}$. So, if each domino is 1.5 times taller than the previous one, it takes about 1.2 times as long to fall!

The time it takes for a dropped rock to hit the ground also grows as $\sqrt{H}$, for the same reason..

This paper studies the physics of falling dominoes in detail, taking friction into account:

- J. M. J. van Leeuwen, The domino effect.

It finds an analytical solution in the "thin domino limit", but also studies the general case.

The animated gif above comes from this video by physicist Stephen Morris:

For bigger dominoes, watch this:

October 28, 2014

Second letter

First letter	U	C	A	G	Third letter
U	UUU Phe	UCU Ser	UAU Tyr	UGU Cys	U
U	UUC Phe	UCC Ser	UAC Tyr	UGC Cys	C
U	UUA Leu	UCA Ser	UAA Stop	UGA Trp	A
U	UUG Leu	UCG Ser	UAG Stop	UGG Trp	G
C	CUU Leu	CCU Pro	CAU His	CGU Arg	U
C	CUC Leu	CCC Pro	CAC His	CGC Arg	C
C	CUA Leu	CCA Pro	CAA Gln	CGA Arg	A
C	CUG Leu	CCG Pro	CAG Gln	CGG Arg	G
A	AUU Ile	ACU Thr	AAU Asn	AGU Ser	U
A	AUC Ile	ACC Thr	AAC Asn	AGC Ser	C
A	AUA Met	ACA Thr	AAA Lys	AGA Stop	A
A	AUG Met	ACG Thr	AAG Lys	AGG Stop	G
G	GUU Val	GCU Ala	GAU Asp	GGU Gly	U
G	GUC Val	GCC Ala	GAC Asp	GGC Gly	C
G	GUA Val	GCA Ala	GAA Glu	GGA Gly	A
G	GUG Val	GCG Ala	GAG Glu	GGG Gly	G

Your cells contain mitochondria, little factories that help convert food into useful chemical energy, using oxygen. These guys were once bacteria in their own right! About 1.5 billion years ago they joined forces with cells that couldn't handle oxygen. Now you need them and they need you.

But they still have their own DNA, separate from the rest of the DNA in your cells. Mitochondria are passed down only from mother to child, via the egg cell. So, your mitochondrial DNA gives information about you, your mother, your grandmother, and so on.

Why does mitochondrial DNA come only from the mother? For starters, an egg cell contains 100,000 to 1,000,000 molecules of mitochondrial DNA, while a sperm has only 100 to 1000. On top of that, most mitochondria in a sperm cell stay in the tail, and sometimes the tail is lost during fertilization. But on top of that, in mammals it seems the egg actively destroys any mitochondria that happen to get in from the sperm.

Puzzle 1: Why?

But in biology everything is complicated. Biologists argue about how likely it is for people to inherit mitochondrial DNA from their father. In a test of 172 sheep, three were found to inherit mitochondrial DNA from their father! But in humans, there is so far just one recorded case of it happening.

Your mitochondrial DNA has just 37 genes. It's made of about 16,600 base pairs: molecules called A, T, C and G, just like your ordinary DNA. The information gets copied to RNA when the genes are used to make proteins, and the T gets copied to U, while the rest stay the same.

The chart above shows the mitochondrion's genetic code. More precisely: each codon, or triple of base pairs U, G, A, and C, is translated into an amino acid. Amino acids, the building blocks of proteins, have fun names like phenylalanine, leucine, isoleucine and so on - but in this chart they're abbreviated to Phe, Leu, Ile, etc.

The mitochondrial genetic code is a bit different than the genetic code used elsewhere in your cells! The differences are marked in red:

- AUA codes for Met instead of Ile as it does elsewhere.
- UGA codes for Trp rather than being a stop codon (meaning, a codon that says the protein is done).
- AGA and AGG are stop codons instead of coding for Arg.

The same code is used for mitochondria in all vertebrates, as far as I know. Some invertebrates have slightly different mitochondrial genetic codes.

Puzzle 2: Why is the mitochondrial genetic code different in the above ways?

This is an extremely hard puzzle, and I doubt anyone knows the answer for sure, since it could simply be due to random events that happened billions of years ago. But I bet people have thought about it, and I'd love to know any good ideas they've had.

Here's a clue: when the mitochondrial genetic code differs from the 'usual' one, it tends to be simpler! All the mitochondrial genetic code consists of blocks of 2 or 4 codons that do the same thing. Most of the usual code is this way - but AUA and UGA break that rule.

- Mitochondrial DNA, Wikipedia.
- Human mitochondrial genetics, Wikipedia.
- Paternal mtDNA transmission

October 29, 2014

What is life?

**LIFE IS THE SELF-REPLICATION
OF INFORMATION!**

Information about what?

**INFORMATION ABOUT
HOW TO SELF-REPLICATE!**

I'm in Banff, listening to a talk on the origin of life at a workshop on Biological and Bio-Inspired Information Theory. The speaker said something like the above... and I was amazed, again, at how wonderful living organisms are.

I gave a talk on Biodiversity, entropy and thermodynamics, and you can watch a video of it here, but what really blew my mind was this talk:

- Naftali Tishby, Sensing and acting under information constraints - a principled approach to biology and intelligence.

It wasn't easy for me to follow — you should already know rate-distortion theory and the Bellman equation, and I didn't — but it's great! It's all about how living organisms balance the cost of storing information about the past against the payoff of achieving their desired goals in the future. It's not fluff: it's a detailed mathematical model! And it ends by testing the model on experiments with cats listening to music and rats swimming to land.

Here's a good paper about this stuff:

- Naftali Tishby and Daniel Polani, Information theory of decisions and actions.

A conversation with Susanne Still convinced me even more that this is stuff I need to learn! I wrote a blog article summarizing what I understand so far:

- John Baez, Sensing and acting under information constraints, Azimuth, 30 October, 2014.

October 30, 2014

This puffin looks afraid to come out of its burrow. It's probably perfectly happy. But the lines around its eye make it look like a cartoon of nervousness.

Atlantic puffins spend most of their time at sea — they're good at swimming, using their wings to 'fly' underwater as they search for fish to eat. They come to land each spring to breed in colonies on north Atlantic seacoasts and rocky islands. They live in burrows — I just learned this yesterday! Each pair lays one egg, with the male and female sharing incubation duties for about 40 days. After the chick hatches both parents feed it fish for approximately 45 days. After that the young puffling is ready to leave the nest.

You can see life in a puffin burrow here:

- Audubon puffin burrow, *Explore*.

I got my info from this website. And the picture here, taken on Skomer Island off southwestern Wales, was posted to Flickr by someone who goes by the name 'Clear Inner Vision'.

For my November 2014 diary, go here.

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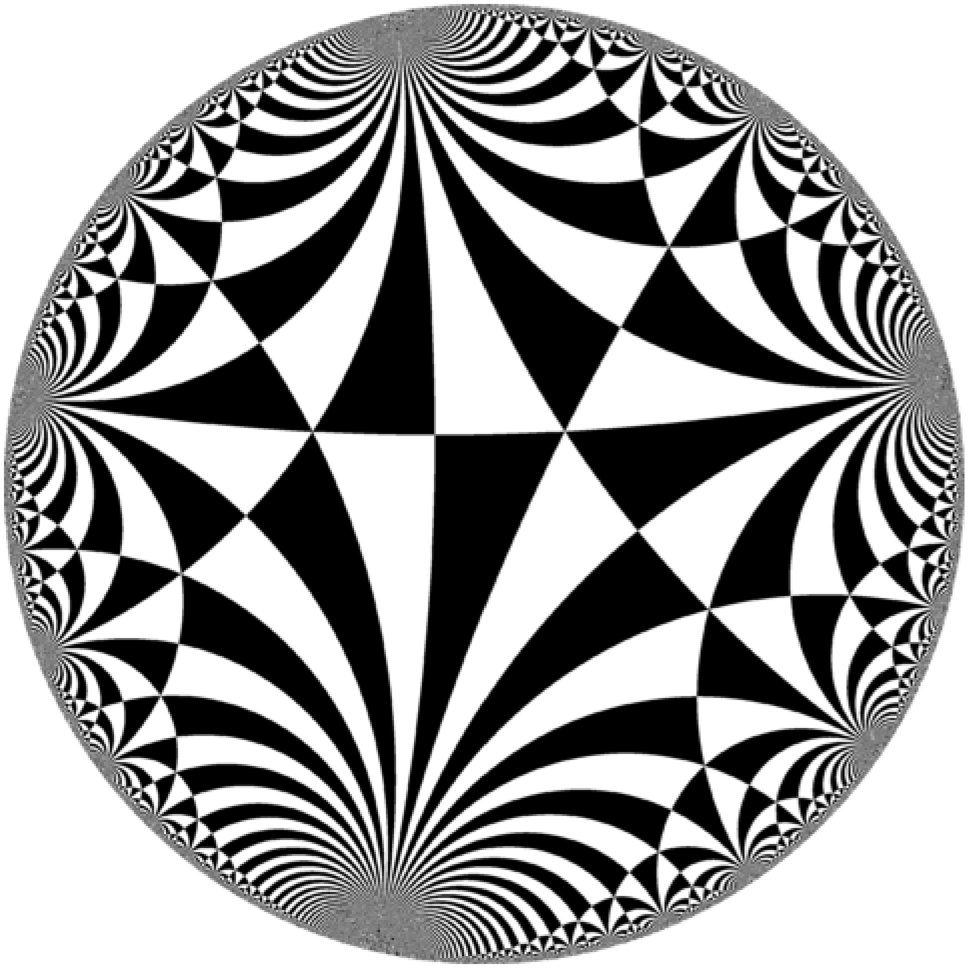
For my October 2014 diary, go here.

Diary — November 2014

John Baez

November 1, 2014



What happened before the Big Bang? That's what I call a boring question.

It might not make sense. But don't believe anyone who confidently asserts that it *doesn't* make sense. It *might* make sense. We have no idea! We just don't know enough about physics to make much progress on this question right now! Maybe later.

What happened *right after* the Big Bang? That's much more interesting, because we don't know the complete answer, but we know a lot of stuff, and we have at least a chance of making progress.

Here's something easy you can do: take a solution of Einstein's equation for gravity, run it back in time, and see what it says about the shape of the universe as you get closer and closer to the Big Bang.

You might not think this is easy if you haven't taken a course on this stuff. But it's *really* easy compared to, say, building a telescope and sending it into orbit. You can do it with just a pencil and paper. So you might as well try it and see what you get.

Loading [MathJax]/jax/output/HTML-CSS/jax.js eneous and isotropic: for example completely flat, or completely round. Then it stays that way as you go back in time. That's what you usually read about in a basic course on this stuff.

But in some more interesting solutions, space is homogeneous but not isotropic. That means it looks the same at every location, but not the same in every direction.

In 1970, three Russian physicists named Belinskii, Khalatnikov and Lifshitz took these solutions, ran them back in time, and noticed something interesting. The universe oscillated in shape ever more wildly as time went back towards the Big Bang! And sometimes — depending on the particular solution — it would do so in a chaotic way.

Even better, they noticed that this problem was isomorphic to the problem of a ball rolling around in a 2-dimensional region.

"Isomorphic" means that the math works the same way after you change the names of things. For example, here, instead of working with *time*, you need to use *minus the logarithm of time*. As time goes to zero (back to the Big Bang), minus the logarithm of time keeps increasing forever. From this viewpoint there's time for a huge amount of happen as we get closer and closer to the Big Bang, but never quite get there!

And in these homogeneous but not isotropic solutions of the equations for gravity, as we get closer and closer to the Big Bang, the math works more and more like a billiard ball bouncing around in one of the triangles in this picture!

This picture shows the hyperbolic plane chopped up into triangles in a very symmetrical way. Pick any triangle; then a point in that triangle describes a possible shape of the universe in the solutions that Belinskii, Khalatnikov and Lifshitz were studying.

Of course their work is oversimplified, because it left out all the forces besides gravity, it ignored quantum mechanics, and it assumed the universe was homogeneous. So, don't take it too seriously! But still, it pointed out a new possibility: *the universe could wiggle around more and more wildly as we run time back toward the Big Bang*.

Even more importantly, from my perspective, it led to a huge amount of cool math connecting the equations of gravity to symmetrical ways of chopping up the hyperbolic plane into triangles, and higher-dimensional versions of that game. And that's what I *really* wanted to talk about today, but I see this post is getting too long, so I'll stop for now.

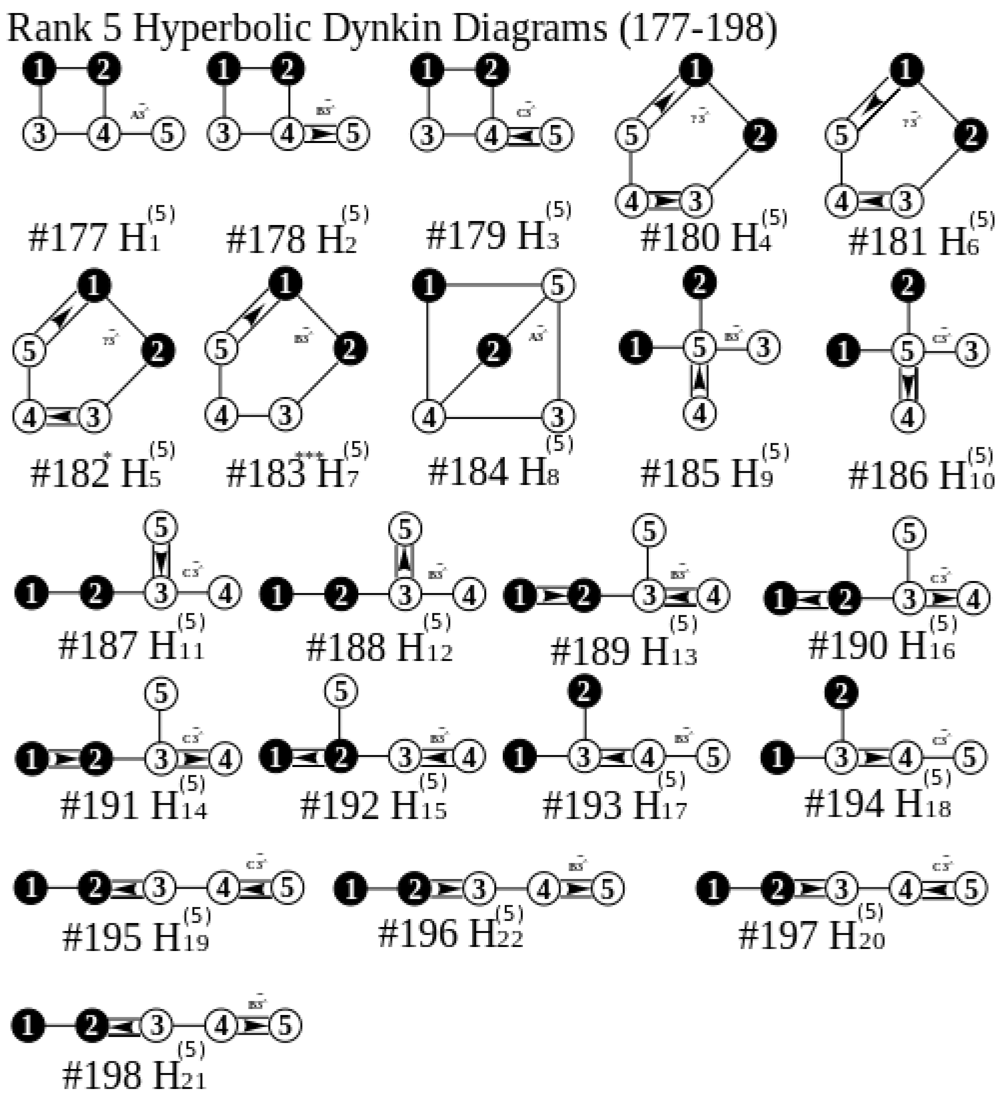
This is their paper:

- V. A. Belinskii, I. M. Khalatnikov and E. M. Lifshitz, Oscillatory approach to a singular point in the relativistic cosmology, *Adv. Phys.* **19** (1970), 525.

Lifschitz, by the way, is one member of the famous physics textbook writing team Landau and Lifschitz. You can also learn more about the Belinksii-Khalatnikov-Lifschitz singularity here:

- BKL singularity , Wikipedia.

November 2, 2014



You know about crystals in space. What's a crystal in spacetime? It's a repetitive pattern that has a lot of symmetries including reflections, translations, rotations and Lorentz transformations. Rotations mix up directions in space. Lorentz transformations mix up space and time directions.

We can study spacetime crystals mathematically — and the nicest ones are described by gadgets called 'symmetrizable hyperbolic Dynkin diagrams', which play a fascinating role in string theory.

How do these diagrams work?

Each dot stands for a reflection symmetry of our spacetime crystal. Dots not connected by an edge are reflections along axes that are at right angles to each other. Dots connected by various differently labelled edges are reflections at various other angles to each other. To get a spacetime crystal, the diagram needs to obey some rules.

The number of dots in the diagram, called its 'rank', is the dimension of the spacetime the crystal lives in. So, the picture here shows a bunch of crystals in 5-dimensional spacetime.

Victor Kac, the famous mathematician who helped invent these spacetime crystals, showed they can only exist in dimensions 10 or below. He showed that:

- there are 4 in dimension 10
- there are 5 in dimension 9
- there are 5 in dimension 8
- there are 4 in dimension 7

In 1979, two well-known mathematicians named Lepowsky and Moody showed there were lots of spacetime crystals in 2 dimensions... but they classified all of them.

- there are 20 in dimension 6
- there are 20 in dimension 5
- there are 40 in dimension 4
- there are 44 in dimension 3

If they're right, there's a total of 142 spacetime crystals with dimensions between 3 and 10.

I think it's really cool how 10 is the maximum allowed dimension, and the number of spacetime crystals explodes as we go to lower dimensions.

String theory lives in 10d spacetime, so it's perhaps not very shocking that some 10-dimensional spacetime crystals are important in string theory — and also supergravity, the theory of gravity that pops out of superstring theory. The lower-dimensional ones seem to appear when you take 10d supergravity and 'curl up' some of the space dimensions to get theories of gravity in lower dimensions.

Greg Egan and I have been playing around with these spacetime crystals. I've spent years studying crystal-like patterns in space, so it's fun to start looking at them in spacetime. I'd like to say a lot more about them — but my wife is waiting for me to cook breakfast, so not now!

Nobody calls them 'spacetime crystals', by the way — to sound smart, you gotta say 'symmetrizable hyperbolic Dynkin diagrams'. Here's the paper by that big team:

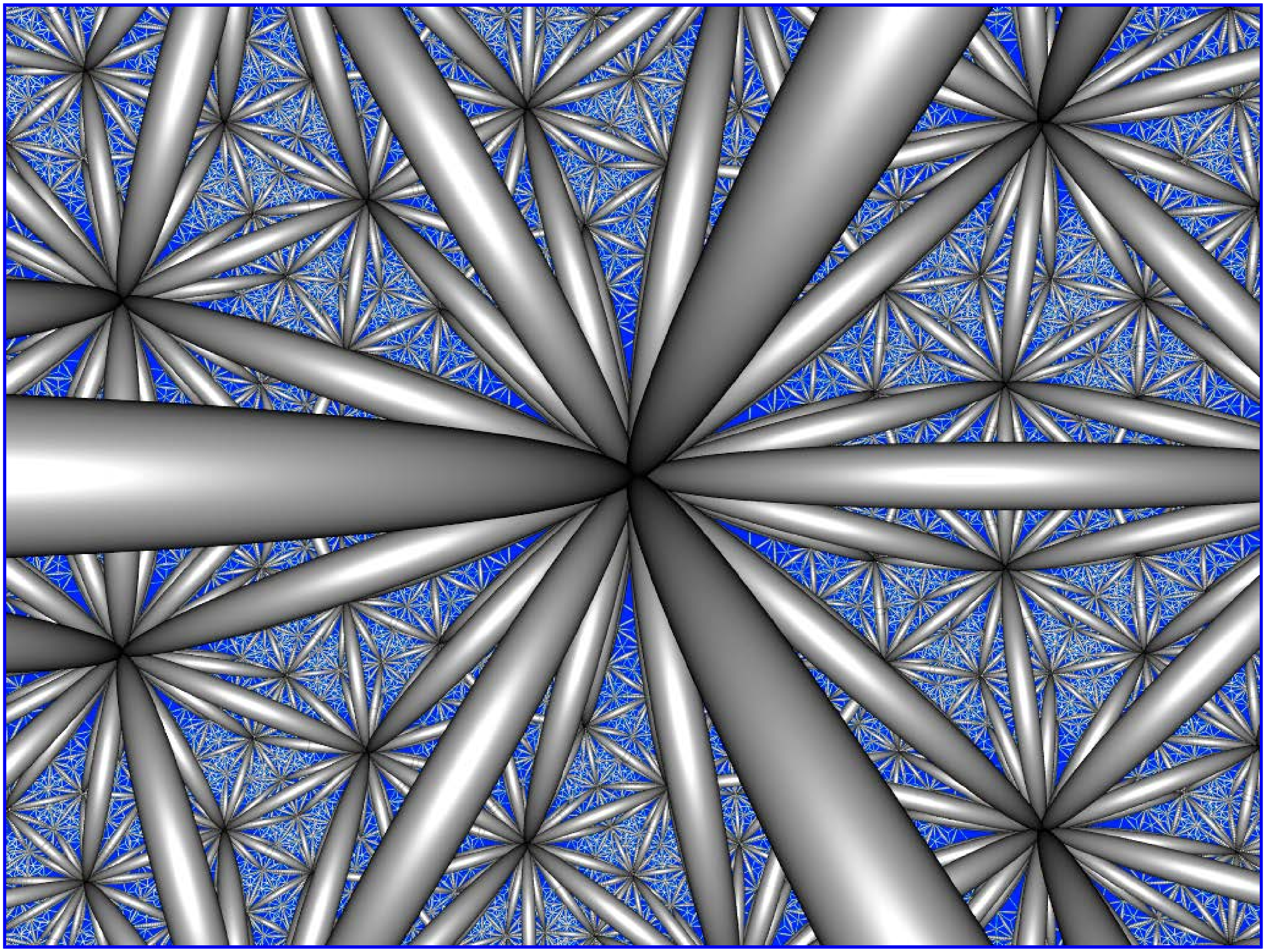
- Lisa Carbone, Sjuvon Chung, Leigh Cobbs, Robert McRae, Debajyoti Nandi, Yusra Naqvi and Diego Penta, Classification of hyperbolic Dynkin diagrams, root lengths and Weyl group orbits.

By the way, there are also hyperbolic Dynkin diagrams that aren't symmetrizable, which don't give lattices. J Gregory Moxness created nice pictures of all 238 hyperbolic Dynkin diagrams with ranks between 3 and 10 and put them on Wikicommons, and that's where I got my picture here!

I later discovered that are also 'Lorentzian Dynkin diagrams' which are almost as good as the hyperbolic ones, whose dimension can exceed 10. For example, there's one in 26 dimensions that's connected to bosonic string theory, and I described it using octonions here:

- John Baez, Integral octonions (part 8).

November 3, 2014



In 1970, Belinksii, Khalatnikov and Lifschitz discovered that when you run time backwards toward the Big Bang, a homogeneous universe behaves like a billiard ball. As you run time back, the universe shrinks, but also its shape changes. Its shape moves around in some region of allowed shapes... and it 'bounces' off the 'walls' of this region!

These guys considered the simplest case: a universe with 3 dimensions of space and 1 dimension of time, containing gravity but nothing else. In this case the region of allowed shapes is a triangle in the hyperbolic plane. I showed it to you in my last diary entry.

So, running time backwards in this kind of universe is mathematically very much like watching a frictionless billiard ball bounce around on a strangely curved triangular pool table.

But you can play the same game for other theories: gravity together with various kinds of matter, in universes with various numbers of dimensions. And when people did this, they discovered something really cool. Different possibilities gave different kinds of pool tables!

When space has some number of dimensions, the pool table has dimension one less. As far as I know, it's always sitting inside 'hyperbolic space', a generalization of the hyperbolic plane. And it's always a piece of a hyperbolic honeycomb — a very symmetrical way of chopping hyperbolic space into pieces.

The picture here, drawn by Roice Nelson, shows a hyperbolic honeycomb in 3-dimensional hyperbolic space. So, one tetrahedron in this honeycomb could be the 'pool table' for a theory of gravity where space has 4 dimensions. (In fact it doesn't quite work like this: we have to subdivide each tetrahedron shown here into 24 smaller tetrahedra to get the 'pool tables'. But never mind.)

Even better, these stunningly symmetrical patterns arise from what I called spacetime crystals. The technical term is 'hyperbolic Dynkin diagrams', and I told you about them earlier. The picture here, in 3 dimensions, arises from a spacetime crystal in 4 dimensions. That's how it always works: the crystal has one more dimension than the pool table.

And here's the really amazing thing: mathematicians have proved that the highest possible dimension for a spacetime crystal is 10. This gives you a 9-dimensional pool table, which is the sort of thing that could show up in a theory of gravity where space has 10 dimensions.

And there is a theory of gravity in where space has 10 dimensions: it's called 11-dimensional supergravity, because there's also 1 dimension of time in this theory. String theorists like this theory of gravity a lot, because it seems to connect all the other stuff they're interested in.

It turns out this particular theory of gravity gives a spacetime crystal called E10. There are several other 10-dimensional spacetime crystals, but this is the best.

For a while I've been thinking that we should be able to describe E10 using the octonions, an 8-dimensional number system that shows up a lot in string theory. I had a guess about how this should work. And last week, my friend the science fiction writer Greg Egan proved this guess is right!

For the details, go here:

- John Baez, Integral octonions (part 7), The *n*-Category Café.

This result probably came as no surprise to the real experts on cosmological billiards — I'm no expert, I just play a game now and then. Here is a nice introduction by a real expert:

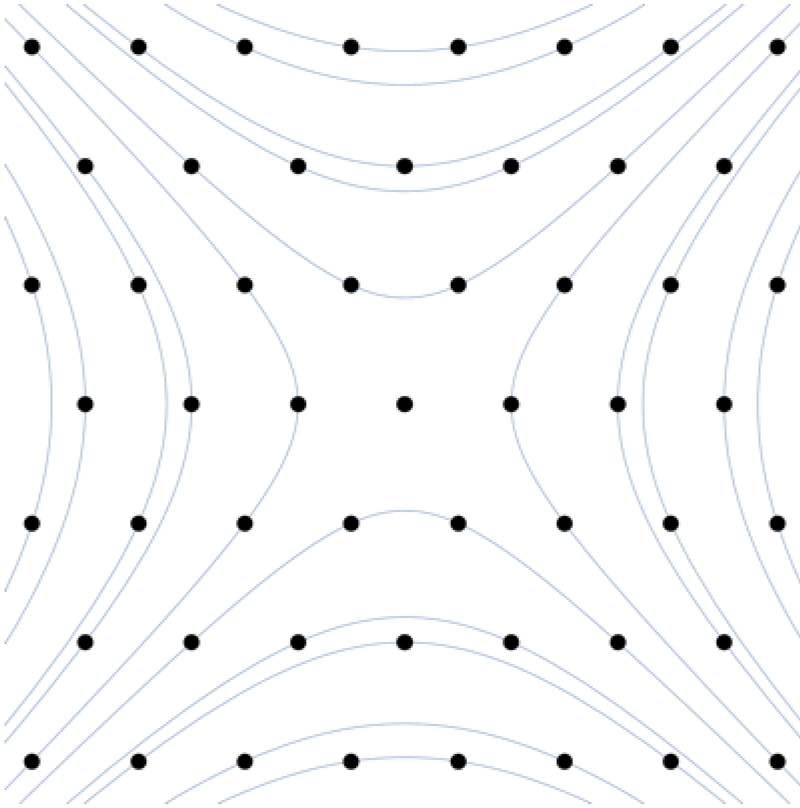
- Thibault Damour, Poincaré, relativity, billiards and symmetry.

And here are some more detailed papers:

- Thibault Damour, Sophie de Buyl, Marc Henneaux and Christiane Schomblond, Einstein billiards and overextensions of finite-dimensional simple Lie algebras.
- Axel Kleinschmidt, Hermann Nicolai, Jakob Palmkvist, Hyperbolic Weyl groups and the four normed division algebras.

November 4, 2014

Looping Lorentzian lattice!



A rapidly moving observer will see time (the vertical axis) and space (the horizontal axis) in a different way than you do at rest. As their speed increases the warping increases.

Each black dot is a point in spacetime. As viewed by faster and faster observers, it moves along a hyperbola. But after a while, the whole lattice of black dots gets back to the same pattern it started with!

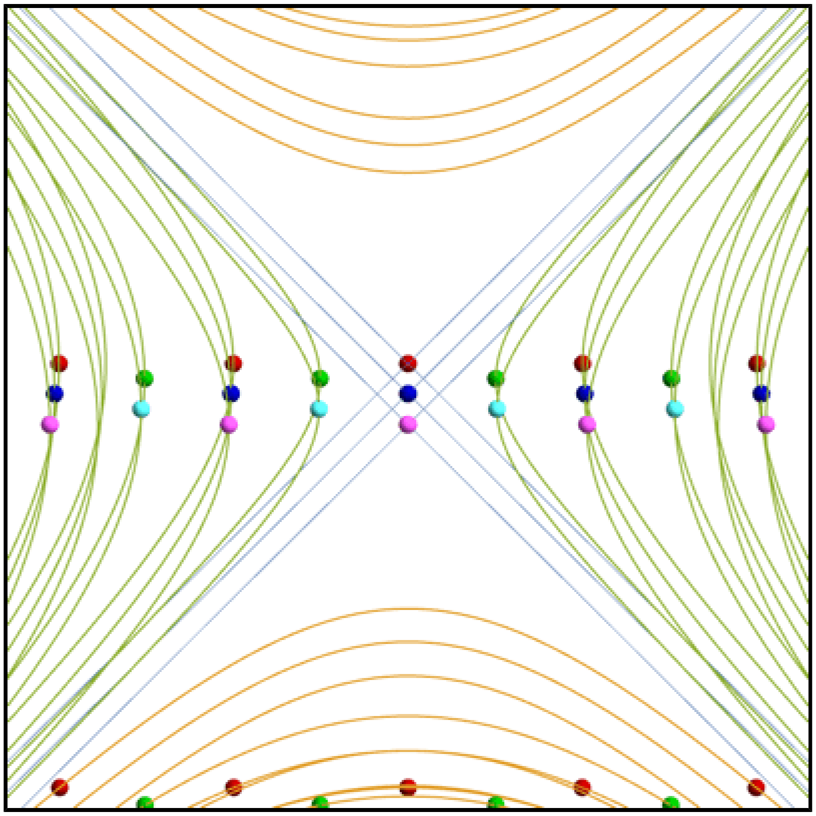
The warpings of spacetime shown here are called Lorentz transformations. Greg Egan made this movie to illustrate how we can do a Lorentz transformation to a lattice in spacetime and get back the same lattice. This is the one of the symmetries that you get in what I was calling a 'spacetime crystal' — technically, a lattice coming from a symmetrizable hyperbolic Dynkin diagram.

For many beautiful pictures related to looping Lorentzian lattices, try:

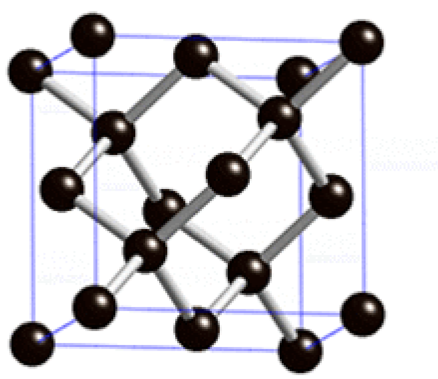
- Jos Leys, Lorenz and modular flows: a visual introduction.

The set of all Lorentzian lattices where each parallelogram has area 1 forms a 3d space with a trefoil knot removed! As we keep applying Lorentz transforms to a lattice, it traces out a curve in this space.

Here is a looping Lorentzian lattice in 3d spacetime, again made by Egan:



November 5, 2014



Diamonds are one of hardest known substances. They're made of carbon, with each atom connected to 4 others in a pattern called the **diamond cubic**.

The same pattern appears in crystals of silicon, germanium, and tin. These are other elements in the same column of the periodic table. They all like to hook up with 4 neighbors.

The diamond cubic is elegant but a bit tricky. Look at it carefully here! We start by putting an atom at each *corner* of a cube. Then we put an atom in the middle of each *face* of the cube. So far, this is called a **face-centered cubic**.

But then: the tricky part! We put 4 more atoms inside the cube. Each of these has 4 nearest neighbors, which form the corners of a tetrahedron.

What are the coordinates of these points? It's good to start with a 4×4×4 cube. Its corners are:

$$(0, 0, 0)\ (4, 0, 0)$$

$$(0, 4, 0)\ (4, 4, 0)$$

$$(0, 0, 4)\ (4, 0, 4)$$

$$(0, 4, 4)\ (4, 4, 4)$$

The middles of its faces are

$$(2, 2, 0)\ (2, 0, 2)\ (0, 2, 2)$$

$$(2, 2, 4)\ (2, 4, 2)\ (4, 2, 2)$$

We can take the four extra points to be

$$(1, 1, 3)\ (1, 3, 1)\ (3, 1, 1)$$

$$(3, 3, 3)$$

So, here's a nice way to describe all the points in the diamond cubic. They're points (x, y, z) where:

- $x, y,$ and z are all even or all odd
- $x + y + z$ is either a multiple of 4, or one more than a multiple of 4.

Tricky, eh?

Part of why it's tricky is that there was a choice. We could also switch the 1's and 3's in the four extra points, using

$$(1, 1, 1)$$

$$(3, 3, 1)\ (3, 1, 3)\ (1, 3, 3)$$

instead. Then we'd get a diamond cubic with points (x, y, z) where:

- $x, y,$ and z are all even or all odd
- $x + y + z$ is either a multiple of 4, or one *less* than a multiple of 4.

Puzzle 1: Is the diamond cubic a 'lattice' in the mathematical sense? A **lattice** is a discrete set of points that is closed under addition and subtraction.

Puzzle 2: take n-tuples of numbers where:

- the numbers are all even or all odd
- their sum is either a multiple of 4, or *two* more than a multiple of 4.

Does this give you a lattice? The answer may depend on n.

Puzzle 3: For experts: when you get a lattice in Puzzle 2, what is this lattice called?

November 6, 2014

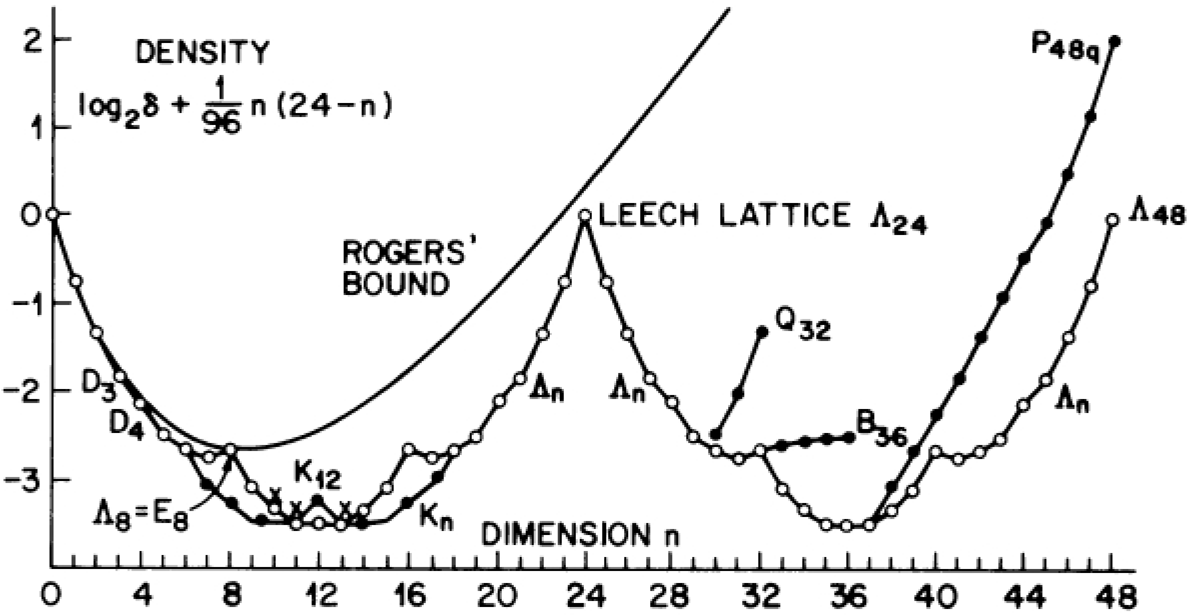


Figure 1.5. The densest sphere packings known in dimensions $n \leq 48$.

My main hobby these days is working with Greg Egan on lattices. Roughly, these are repeating patterns of points, like the centers of atoms in a crystal. But you can study lattices in different dimensions — and a lot of fun happens in 24 dimensions!

If you look for the densest ways to pack spheres in different dimensions, you'll be led to some interesting lattices. In 3 dimensions, the usual way of stacking oranges gives the 'D_3 lattice': when you center your spheres at points of this lattice, each sphere touches 12 others. This is known to be the densest packing of spheres in 3 dimensions. It's also called the 'face-centered cubic', and I discussed it in my September 16th diary entry, as well as yesterday's.

In 4 dimensions the densest known sphere packing comes from the D_4 lattice, where each sphere touches 24 others.

These D lattices are easy to build: you draw a higher-dimensional checkerboard with alternating red and black hypercubes, and put a dot in the middle of each red hypercube.

When you pack sphere using these D lattices in higher and higher dimensions, there's more and more room left over between your spheres. And when you get to 8 dimensions, something funny happens! There's so much room left that you can slip in another whole set of spheres packed the same way!

So, you can double the density with this improved lattice. It's called the 'E_8 lattice', and you see it as a peak in the graph here. With this lattice, each sphere touches 240 others. Nobody has proved that this is the densest sphere packing possible in 8 dimensions. But in 2009, Henry Cohn and Abhinav Kumar proved that no other packing can beat its density by a factor of more than

$$1.00000000000001$$

So, I'm willing to bet that it's the best.

What I really like about 8 dimensions is that there's an 8-dimensional number system where you can add, subtract, multiply and divide.

I'm sure you know how a 1-dimensional ruler is labelled by ordinary real numbers. You can add, subtract, multiply and divide those. If you try to do this trick in higher dimensions, you'll notice something weird: you can only do it in dimensions 1, 2, 4, and 8.

In 2 dimensions you can use the complex numbers, and in 4 you can use the quaternions. In 8 dimensions you can use the octonions, and that's where the game ends! So the octonions are special. They play a role in string theory — so if string theory ever turns out to be right, maybe the octonions will actually count as useful. Right now they're just amazingly beautiful and lots of fun.

But back to lattices! The simplest lattice lives in 1 dimension: it's the evenly spaced numbers on your ruler, called integers:

... -2, -1, 0, 1, 2, ...

You can add, subtract and multiply integers and get integers... but not divide them: that takes you out of the integers.

There are versions of the integers for complex numbers, quaternions and octonions too! The Hurwitz integral quaternions form the D_4 lattice that I mentioned earlier. And the Cayley integral octonions form the E_8 lattice. It's actually the arithmetic of these integral octonions that fascinates me, more than the sphere packing business.

But as you can see from the graph, there's a really interesting mountain peak called the 'Leech lattice'. This gives the densest known way to pack spheres in 24 dimensions. Nobody has proved it's the best — but Cohn and Kumar proved that no other packing in this dimension can beat its density by more than a factor of

1.0000000000000000000000000000165

It's a lot harder to describe the Leech lattice than the others I mentioned so far. Each sphere touches 196,560 others... and the pattern is rather tricky.

But 24 is 3 times 8, so you might hope to build the Leech lattice from 3 copies of the E_8 lattice... and you can! But you need a fairly clever trick. Various people have described this trick in different ways, but I like Greg Egan's the best. I explain this here: this series:

- John Baez, Integral octonions (part 9), The *n*-Category Café.

It relies on a great feature of the E_8 lattice. You can rotate it in a way that turns every point by the same specific angle, and expand it by factor of $\sqrt{2}$, and this transformation maps the E_8 lattice into itself. Any way of doing this gives a way to build the Leech lattice.

The graph of densities here is taken from Conway and Sloane's book *Sphere Packings, Lattices and Groups*. They take spheres of radius 1, work out the density of sphere centers, take its logarithm in base 2... and then add $n(24 - n)/96$. This is a parabola peaked at 12. I find this last touch a bit distracting.

Here's the paper I mentioned:

- Henry Cohn and Abhinav Kumar, Optimality and uniqueness of the Leech lattice among lattices.

For more, see the comments on my G+ thread.

November 7, 2014

> Man was winged hopefully. He had in him to go further than this short flight, now ending. He proposed even that he should become the Flower of All Things, and that he should learn to be the All-Knowing, the All-Admiring. Instead, he is to be destroyed. He is only a fledgling caught in a bush-fire. He is very small, very simple, very little capable of insight. His knowledge of the great orb of things is but a fledgling's knowledge. His admiration is a nestling's admiration for the things kindly to his own small nature. He

delights only in food and the food-announcing call. The music of the spheres passes over him, through him, and is not heard.

Yet it has used him. And now it uses his destruction. Great, and terrible, and very beautiful is the Whole; and for man the best is that the Whole should use him.

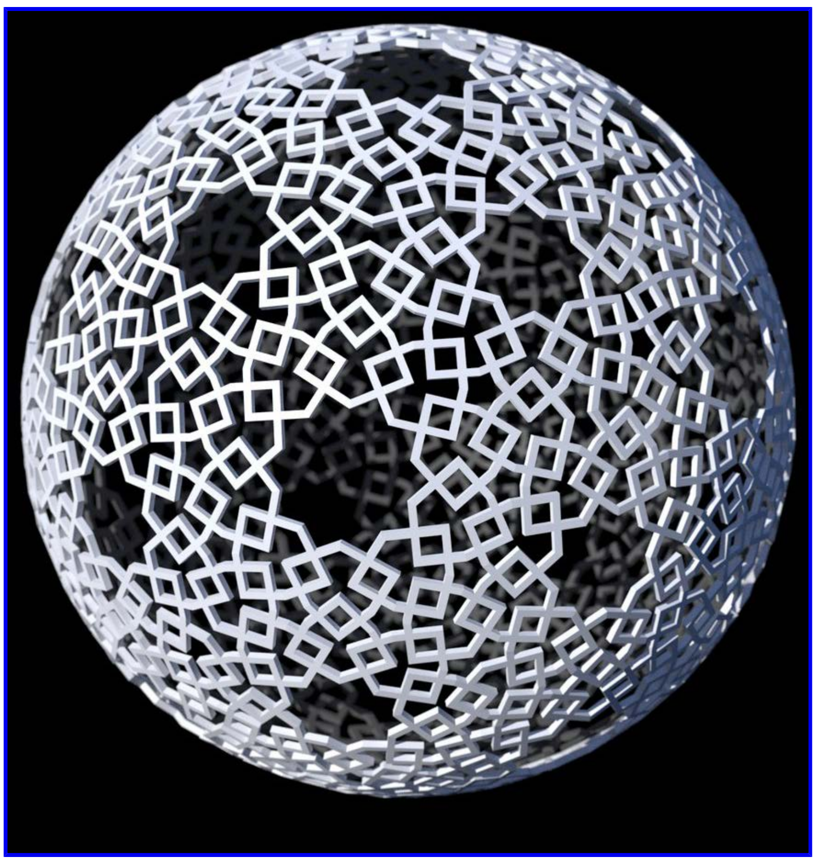
But does it really use him? Is the beauty of the Whole really enhanced by our agony? And is the Whole really beautiful? And what is beauty? Throughout all his existence man has been striving to hear the music of the spheres, and has seemed to himself once and again to catch some phrase of it, or even a hint of the whole form of it. Yet he can never be sure that he has truly heard it, nor even that there is any such perfect music at all to be heard. Inevitably so, for if it exists, it is not for him in his littleness.

But one thing is certain. Man himself, at the very least, is music, a brave theme that makes music also of its vast accompaniment, its matrix of storms and stars. Man himself in his degree is eternally a beauty in the eternal form of things. It is very good to have been man. And so we may go forward together with laughter in our hearts, and peace, thankful for the past, and for our own courage. For we shall make after all a fair conclusion to this brief music that is man.

This is the end of Olaf Stapledon's *Last and First Men*. An early SF classic, it describes the history of humanity for the next two billion years, embodied 18 different species and living on several planets. It was written in 1930, so try to forgive the sexist language and various kinds of naivete. You can read the whole book here:

- Olaf Stapledon, *Last and First Men*, Gutenberg Project.

November 11, 2014



Craig Kaplan has been taking ideas from Islamic wall tilings and adapting them to spheres. It's a great way to bring new life to an glorious old tradition.

See that star with 10 points and 5 nearest neighbors? That's 5-fold symmetry. You can't get perfect 5-fold symmetry in a tiling of the plane. The best you can do is fake it in various ways — and by 1200 AD the great tile masters of Afghanistan, Iran, Morocco and Turkey had figured out most of these ways.

Patterns with decagons and pentagons that fool the eye into thinking there's 5-fold symmetry! Quasiperiodic tilings — later rediscovered by Penrose — that never quite repeat but have 5-fold symmetry on average. Their discoveries were remarkable.

But when you tile a sphere, the dodecahedron comes to your aid: it has 5-fold symmetry, and things the old tile experts did with hexagons, you can now do with pentagons! It's like a whole new world.

And the world expands even more when you use the hyperbolic plane: then you can get 7-fold symmetry, 8-fold symmetry and so on. Kaplan has also studied that.

If you look carefully at this pattern, you'll see every star with 10 points is surrounded by 5 stars with 9 points... and every star with 9 points is surrounded by 6 stars, which alternate between having 9 and 10 points. The stars with 10 points are the centers of the faces of a dodecahedron, so there are 12 of them. The stars with 9 points are at the vertices of this dodecahedron, so there are 20 of them.

The whole pattern is made of little things that look almost like triangles, but have bent edges.

Puzzle: how many of these little things are there?

I thank Layra Idarani for making me pay attention to these details.

This image was created by TaffGoch based on a design by Craig Kaplan. For more beautiful stuff, check out this page:

- Craig S. Kaplan, Computer graphics and geometric ornamental design.

TaffGoch has a lot of great stuff on DeviantArt.

November 16, 2014

Europeans have trouble understanding the USA's love affair with guns. I have trouble too. But here is one of our folk heroes: Annie Oakley.

Born in 1860 in a log cabin in Ohio, at the age of 10 she was 'bound out' to a nearby family to help care for son, on the false promise of fifty cents a week and an education. Being 'bound out' was pretty common for poor children: at best it was like becoming an apprentice, at worst it was pretty much like slavery. Annie always called this family "the wolves" — and at the age of 12 she ran away back to her mother. She'd started hunting at the age of 8 to help support her brothers and sisters, and she got good at shooting. Really good.

A travelling show called Baughman & Butler came to town. Butler was a marksman. He placed a $100 bet that he could beat any local shooter. The last thing he expected was a five-foot-tall, 15-year old challenger named Annie! They took turns. After missing on his 25th shot, Butler lost the match.

A year later, he married Annie.

In 1885, they joined Buffalo Bill Cody's travelling circus. Buffalo Bill is another one of America's famous shooters. He began his career by exterminating buffaloes and Indians. But by this time, he was running a show called 'Buffalo Bill's Wild West'. It featured notables such as Wild Bill Hickock and Sitting Bull — a chief of the Lakota tribe who had helped defeat Custer in a famous battle.

By this point, Annie Oakley had become almost superhuman. Her most famous trick was to split a playing card, edge-on, and put several more holes in it before it could touch the ground — all using a rifle at 90 feet.

According to the *Encyclopedia Brittanica*:

> Oakley never failed to delight her audiences, and her feats of marksmanship were truly incredible. At 30 paces she could split a playing card held edge-on, she hit dimes tossed into the air, she shot cigarettes from her husband's lips, and, a playing card being thrown into the air, she riddled it before it touched the ground.

One day Chief Sitting Bull was watching when

> Oakley playfully skipped on stage, lifted her rifle, and aimed the barrel at a burning candle. In one shot, she snuffed out the flame with a whizzing bullet.

Later the show went to Europe. At his request, she used a bullet to knock the ashes off a cigarette held by Kaiser Wilhelm II. Later some people later said that if Annie had shot the Kaiser, she could have prevented World War I.

In fact, after the war started, Oakley sent a letter to the Kaiser requesting a second shot. The Kaiser did not reply.

And so on. Teddy Roosevelt turned down her request to lead a company of woman sharpshooters in the Spanish-American war. She won 54 of 55 libel suits against various newspapers when the publisher Randolph Hearst spread a false story that she'd been arrested for stealing to support a cocaine habit. At the age of 62, she won a contest by hitting 100 clay targets in a row from a distance of 16 yards.

At the age of 66, she died of pernicious anemia. Her husband Butler was so grieved he stopped eating and died a couple of weeks later.

Apart from Hearst, Annie Oakland and her husband are the only Americans named in this story who never killed anyone with a gun. Chief Sitting Bull was later shot and killed by the police.

I got interested in Annie Oakley last night while watching an episode of TV's best-kept secret, *The Murdoch Mysteries*. You can see it on Netflix. In this episode, Buffalo Bill's travelling show comes to Toronto, someone gets shot... and Annie Oakley is one of the suspects. I was wondering how accurate it all was. It seems pretty realistic, though I don't know if Buffalo Bill's Wild West ever went to Toronto.

I got my information here:

- Annie Oakley, Wikipedia.

November 18, 2014

In Alabama, 1/3 of black men cannot vote.

Why not? Because if you go to prison in that state, you may never be allowed to vote after that. Since black men are imprisoned at an extremely high rate, many can't vote.

There are 11 states in the US with laws like this. Others deny the vote for shorter periods of time — for example, while you're in prison or are on parole. Here are some of the consequences:

- 31% of black men in Florida can't vote.
- 31% of black men in Alabama can't vote.
- 29% of black men in Mississippi can't vote.
- 28% of black men in Wyoming can't vote.
- 26% of black men in Iowa can't vote.
- 25% of black men in Virginia can't vote.
- 24% of black men in New Mexico can't vote.
- 24% of black men in Washington can't vote.
- 21% of black men in Texas can't vote.
- 20% of black men in Delaware can't vote.
- 14% of black men in Tennessee can't vote.
- 12% of black men in Arizona can't vote.
- 10% of black men in Nevada can't vote.

These statistics are old, so they will have changed. But I don't think they've gotten better — except that in the last 20 years, three states stopped doing this.

An estimated 5.3 million Americans are denied the right to vote based on their felony convictions, 4 million of whom are out of prison. About a third of them are black, including 13% of all African-American men.

For up-to-date information, go to the Sentencing Project website:

- The Sentencing Project, Felony disenfranchisement and the 2014 midterm elections, October 2, 2014.

They list percentages of African American citizens who are denied the right to vote, not African American men, so the figures look slightly less shocking. More details are in this report:

- Christopher Uggen, Sarah Shannon and Jeff Manza, *State-Level Estimates of Felon Disenfranchisement in the United States, 2010*, July 2012.

but for African American men the most up-to-date comprehensive statistics I've found are from 1996, so that's what I used in my list.

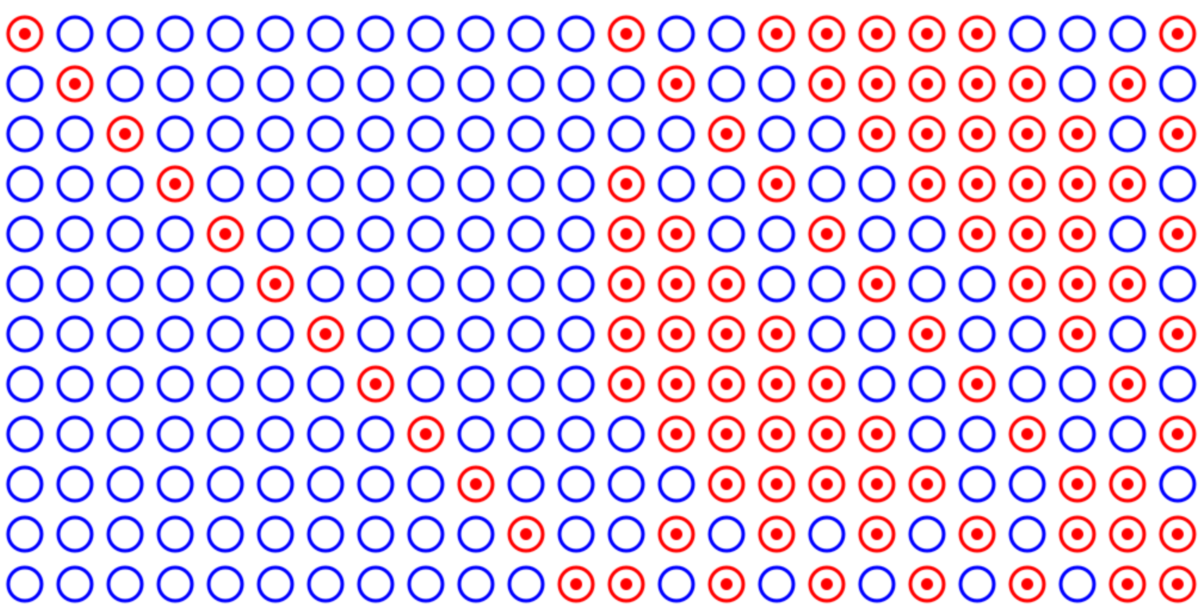
November 19, 2014

In 2005, white US households were about 10 times more wealthy than black ones, as measured by median net worth. By 2011, they were 14 times as wealthy!

From 2005 to 2011, the Great Recession knocked American white households' median net worth down by 21%. But for blacks, it dropped by 42%.

The numbers are from the US Census.

November 20, 2014



This is the 'Golay code'. Each row in this picture shows a string of 24 bits. There are 12 rows. If you look at any two rows, you'll see they differ in at least 8 places.

Here's how to get the Golay code. Take a 12 × 12 square of bits with all 0's except for 1's down the diagonal — you can see that at left here. Take another 12 × 12 square of bits that tells you when two faces of a dodecahedron share an edge: 0 if they do, 1 if they don't. Stick these squares together and you get the Golay code!

Some guys around here keep asking if the math I talk about is good for anything. In this case it is!

The Voyager 1 and 2 spacecraft needed to transmit hundreds of color pictures of Jupiter and Saturn in their 1979, 1980, and 1981 fly-bys. They had very little bandwidth, so they needed a good error-correcting code. They used the Golay code!

The point is that we can use the rows of this picture as code words. If we take some rows and add them — adding each entry separately, mod 2 — we get more code words. We get a total of $2^{12} = 4096$ code words. Strictly speaking, its this set of code words that is the **Golay code**.

These code words have a cool property: it takes at least 8 errors to turn any code word into any other. So, we say the **Hamming distance** between any two code words is at least 8. In fact, the Golay code is the only code with 24-bit code words where the Hamming distance between any two is at least 8.

There's a whole theory of codes like this, and this is an especially good one. You can transmit 12 bits of data with 24 bits... but since the Hamming distance between code words is big, someone can understand what you meant even if there are lots of errors! So, the Golay code is useful for transmitting data in a noisy environment.

But the reason I like the Golay code is that it has a big and important symmetry group. Its symmetry group is called M_{24} - one of the amazing things called **Mathieu groups**. It has

$$24 \times 23 \times 22 \times 21 \times 20 \times 48 = 244{,}823{,}040$$

elements. It's connected to many other symmetrical things in math: for example, it acts as symmetries of the Leech lattice, the densest way to pack balls in 24 dimensions.

To be more precise, this code here is called the **extended binary Golay code**. You can learn more about it here:

- Binary Golay code, Wikipedia.
- Mathieu group, Wikipedia.

Puzzle: I said the symmetry group of this code is M_{24}. But what do I mean, exactly, by a 'symmetry' of this code?

The extended binary Golay code is not only good for outer space. In 1993, the US government issued standards for high frequency radio systems. They require using this code for "forwards error correction" in "automatic link establishment"! See page 51 here:

- National Communication System Office of Technology and Standards, *Telecommunications: HF Radio Automatic Link Establishment*, Federal Standard 1045A, October 18, 1993.

November 22, 2014

The virus has landed!

This is a virus called a T4 bacteriophage. It has landed on a bacterium. Now it's getting ready to lower its tail, puncture the bacterium's cell wall, and inject its DNA.

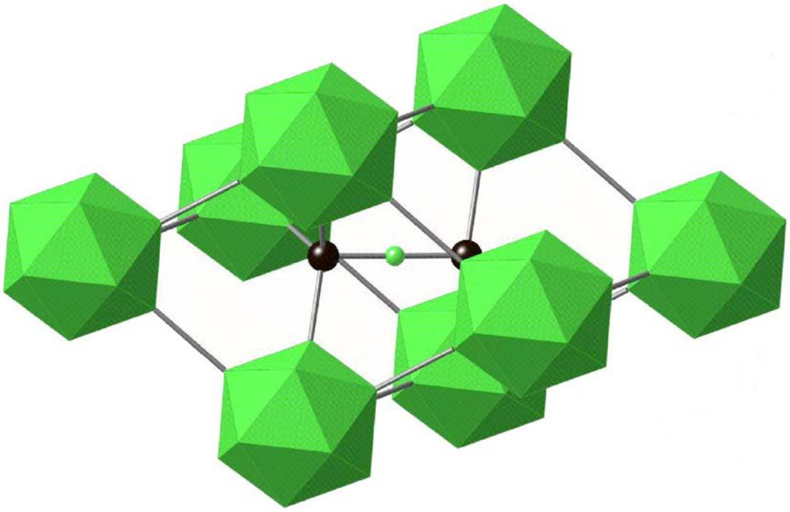
When this happens:

- It immediately stops the bacterium's own genes from being expressed.
- In 5 minutes, its DNA starts synthesizing enzymes needed to make new copies of the virus.
- In 10 minutes, its DNA starts replicating.
- In 12 minutes, new copies of the virus start being formed.
- In 30 minutes, the bacterium bursts, releasing 100 to 150 new copies of the virus!

This deadly machine is only 0.2 micrometers tall. Its DNA — the instruction book that makes everything work — is contained in the head, which is shaped like an icosahedron. The DNA is 169,000 base pairs long, and it codes for 289 proteins. Biologists understand it quite well now.

This picture is not a photograph; it was made by Mike Smith for a company called Xvivo Scientific Animation.

November 28, 2014



This is boron carbide, an extremely hard ceramic material used in macho gear like tank armor, bulletproof vests, and engine sabotage powder.

(*Engine sabotage powder?* Yes, you can pour this into the oil supply, and it will make a car engine grind itself to death.)

If diamond has a hardness of 10, this comes in at 9.497. But its crystal structure is even cooler than diamond!

A group of 12 boron atoms likes to form an icosahedron. You can see 8 of these icosahedra here — the green things. These form the corners of a rhombohedron — a kind of squashed cube. These repeat over and over, forming a rhombohedral lattice.

But that's not all! The icosahedra are connected by struts! These struts have carbon atoms at their ends and a boron in the middle. Only one strut is shown in detail here. The carbon atoms are the black balls and the boron is the little green ball.

Overall there are 4 boron atoms per carbon atom, so people call boron carbide B_4C.

Puzzle 1: Why are there 4 borons per carbon? I haven't done the counting, so I don't understand this.

Puzzle 2: What's the difference between a rhombus and a parallelogram?

Puzzle 3: What's the difference between a rhombohedron and a paralleliped?

Puzzle 4: What's the difference between a rhombohedral crystal and an 'orthorhombic' crystal?

Another macho application of boron carbide is to shielding and control rods for nuclear reactors! The reason is that boron can absorb neutrons without forming long-lived radioactive isotopes.

The structure of boron carbide has even more subtle features, which I don't understand. Maybe I'm not looking at the pictures carefully enough!

Puzzle 5: Where are the octahedra made of boron atoms? For clues, read this:

- Boron carbide, Wikipedia.

The picture here was made by 'Materialscientist' and placed on Wikicommons.

For answers to some of the puzzles, see the comments to my G+ post. For another marvelous boron molecule, check out my July 21st diary entry on borospherene.

For my December 2014 diary, go here.

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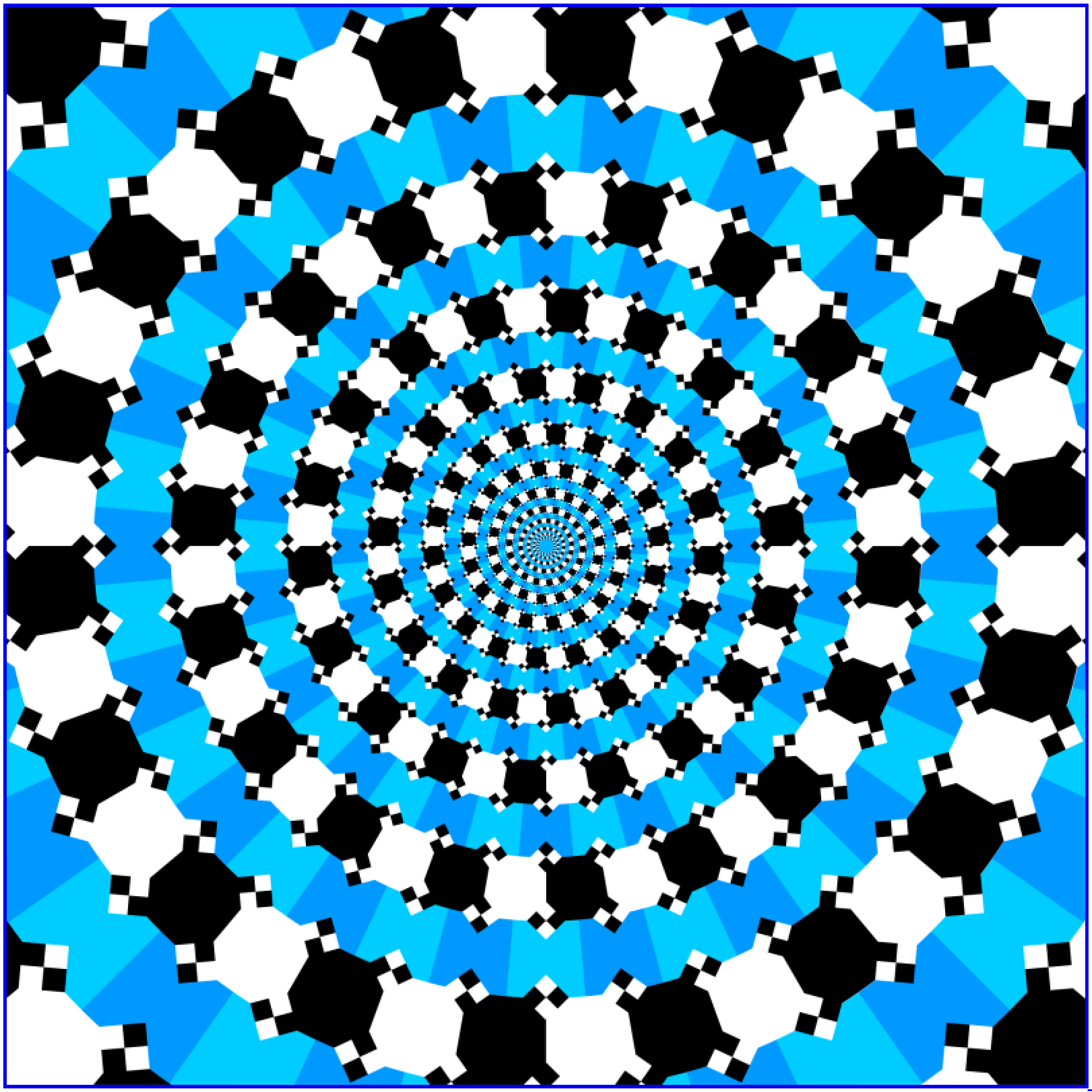
[For my November 2014 diary, go here.](#)

Diary — December 2014

John Baez

December 1, 2014



© Copyright Akiyoshi Kitayoka 2009 March 3

This is not a spiral! See

- Akiyoshi Kitaoka, Akiyoshi's illusions pages.

December 7, 2014

Loading [MathJax]/jax/output/HTML-CSS/jax.js

This is the ceiling of the tomb of the famous Persian poet Hafez, who was born in the city of Shiraz in 1315, and died there in 1390. The current version of the tomb dates back only to 1935 and was designed by the French architect and archaeologist André Godard. But the design is beautiful!

There's a lot of fun stuff to see if you zoom in, but let's think about the stars.

Puzzle 1: How many points do the stars here have?

Puzzle 2: How many different kinds of stars are there with this many points?

For example, there's just one kind of 5-pointed star, but two kinds of 7-pointed star. There's a 7-pointed star with blunt points where you draw a line from each dot to the dot 2 after it, and one with sharp points where you draw a line from each dot to the dot 3 after it.

Puzzle 3: How many different kinds of n-pointed stars are there?

Puzzle 4: How many of these are connected?

For example, there is no connected 6-pointed star. If you take a regular hexagon and draw a line from each dot to the dot 2 after it, you get the traditional Star of David, which consists of two separate triangles. If you draw a line from each dot to the dot 1 after it, you get the hexagon... you can decide if that counts as a star. If you draw a line from each dot to the dot 3 after it, you get three straight lines meeting at the center... you can decide if that counts as a star. And that's all you can get, if you're following the rules I have in mind!

You can learn more here:

- Tomb of Hafez, Wikipedia.

The photo above was put on Wikicommons by 'Pentocelo', and you can get a higher-quality version here.

Hafez was a Sufi, and his poems show that:

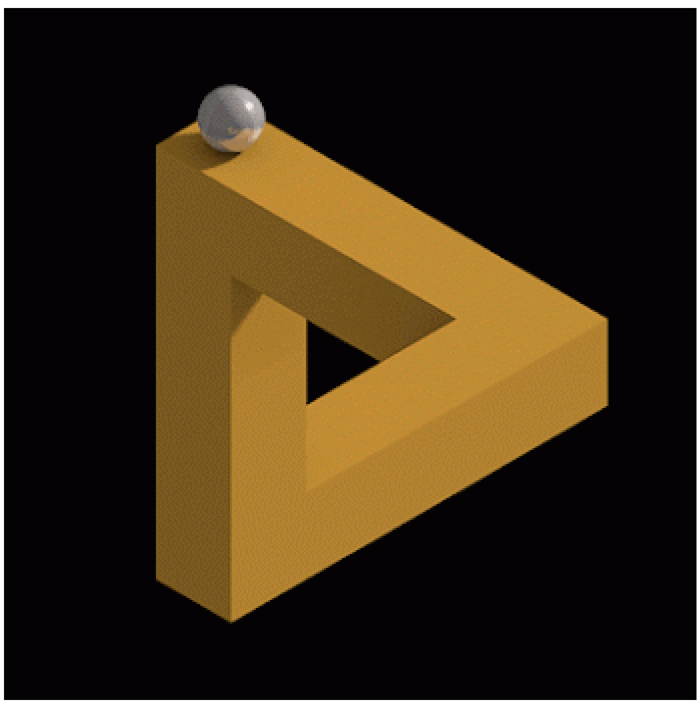
Change rooms in your mind for a day.
All the hemispheres in existence
Lie beside an equator
In your heart.

This is from The Subject Tonight is Love, translated by Daniel Ladinsky. For more in translation, try:

- The poetry of Hafiz.

December 10, 2014

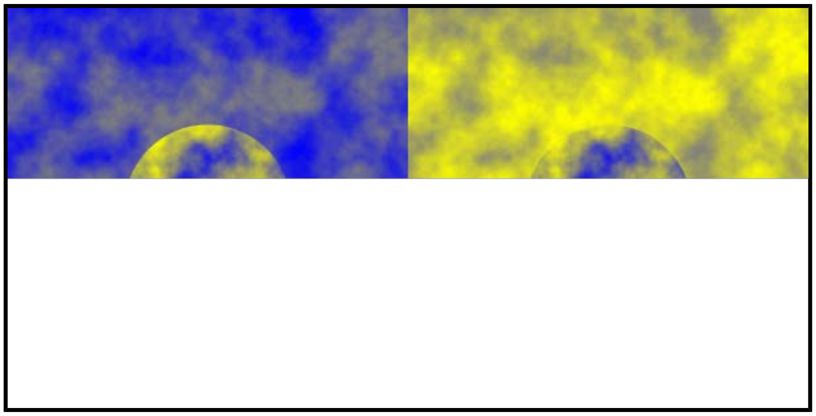
If a ball can roll on it, it must be real.



(But if only a *picture* of a ball can roll on it...)

This image is from 'Worldsday' at deviantart.

December 13, 2014



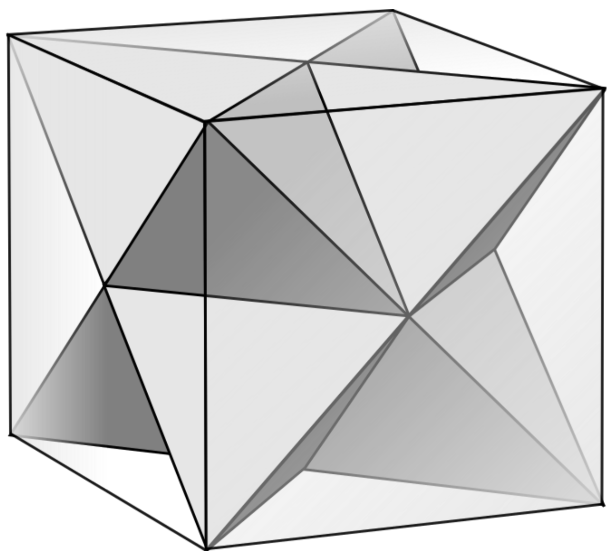
Context matters! The two disks are *exactly the same in every way*. Only their surroundings differ.

This is a metaphor for many things in life. What's the best example where the context of an event changed your perception of it?

For more great visual effects by the psychologist Akiyoshi Kitaoka, go here:

- Akiyoshi Kitaoka, [Akiyoshi's illusions pages](#).

December 15, 2014



If you take every other corner of a cube, you get the corners of a demicube.

In 3 dimensions a demicube is just a regular tetrahedron! So you get two tetrahedra in a cube, as shown here. Together they form a stellated octahedron. In other words, you can also get this shape by taking a regular octahedron and sticking a tetrahedron on each of its faces — getting a kind of 3-dimensional star! It makes a great Christmas tree ornament.

What's a demicube in 4 dimensions? A 4-dimensional cube has $2^4 = 16$ corners, so the demicube has 8. The cool part, special to 4 dimensions, is that all these corners point at right angles to each other, as viewed from the center of the cube!

If the corners of the 4-dimensional cube are

$$(\pm 1, \quad \pm 1, \quad \pm 1, \quad \pm 1)$$

then we can get a demicube by taking those with an even number of minus signs. That gives these four:

$$
\begin{array}{llll}
(1, & 1, & 1, & 1) \\
(1, & 1, & -1, & -1) \\
(1, & -1, & 1, & -1) \\
(-1, & 1, & 1, & -1)
\end{array}
$$

and their negatives. And if you know your math, you can check that the dot product of any two of the vectors I listed is zero! That means they all point at right angles to each other.

In fact, it means that the demicube in 4 dimensions is just the 4-orthoplex: the 4d analogue of an octahedron! We usually make a 4-orthoplex by taking these four vectors:

$$
\begin{array}{llll}
(1, & 0, & 0, & 0) \\
(0, & 1, & 0, & 0) \\
(0, & 0, & 1, & 0) \\
(0, & 0, & 0, & 1)
\end{array}
$$

and their negatives, and using those as corners. Each pair of the vectors listed is at right angles to each other. But the corners of a demicube work just as well, giving a 4-orthoplex that's twice as big in every direction, and rotated.

I don't know anything exciting to say about demicubes in 5 or 6 dimensions. But in 7 dimensions something very nice happens! A 7-cube has 2^7 = 128 corners, so a 7-demicube has 64. The 7-dimensional analogue of a tetrahedron, called a 7-simplex, has 8 corners. Notice: 64 is 8 times 8.

Can we take a 7-demicube and partition its corners into 8 sets of 8, each set being the corners of a 7-simplex?

Yes we can! Greg Egan figured out how.

The trick involves the Fano plane. This is a little gadget with 7 points and 7 lines, where any two points lie on a single line and any two lines intersect in a single point. If you haven't ever seen the Fano plane, what I just said is enough to draw it, so that might be fun to try... but beware: some of the lines will need to look curved if you draw it on an ordinary sheet of paper!

So, in 7 dimensions there's a picture like the one here, but with 16 different simplexes stuck inside a cube, instead of just two. That would be fun to see!

The next opportunity to partition the corners of a cube into simplices occurs in 15 dimensions.

Puzzle 1: can you take the set of 15-bit strings and find 16 of them, each pair of which agrees in exactly 7 places?

If you succeed, you'll have a 15-simplex inside the 15-cube, since you've taken the corners of a 15-cube:

$$(\pm 1, \pm 1, \pm 1, \pm 1, \pm 1, \pm 1, \pm 1, \pm 1, \pm 1, \pm 1, \pm 1, \pm 1, \pm 1, \pm 1, \pm 1)$$

and found 16 of them, any pair of which has a dot product of -1. This is exactly what you need for the corners of a 15-simplex!

Moreover, since any pair of your bit strings disagrees in an even number of places (namely 8), your simplex will actually lie in a demicube.

If this puzzle was too easy, move on to:

Puzzle 2: can you take the set of 15-bit strings and partition it into sets of 16, such that any two strings in a given subset agree in exactly 7 places?

If so, you'll have found a way to partition the vertices of a 15-dimensional demicube into 15-dimensional simplices! 2048 of them, in fact.

After first raising these puzzles, I figured out how to solve them. It turns out that we can partition the corners of an n-dimensional cube into sets, each being the corners of a regular n-simplex, if and only if n is one less than a power of 2. And when $n = 2^k - 1$ for $k \geq 2$, each of these n-simplices lies in an n-dimensional demicube, so we can partition the vertices of the demicube into simplices.

December 17, 2014

Down here in Southern California, we've had three good rains since the summer. Up north, they've gotten even more! In the first storm, ending December 3rd, San Francisco got more rain than they did all last year! They got 9.4 centimeters of rain in four days, compared to just 8.6 in 2013.

But we'd need a lot more rain to break the drought. It will take about 11 trillion gallons of water — 42 cubic kilometers — to fully recover from the drought. That's what researchers at NASA say, based on satellite data including measurements of the Earth's gravitational field, which depends on how much groundwater there is.

They say that since 2011, the Sacramento and San Joaquin river basins have decreased in volume by 4 trillion gallons of water each year: that is, 15 cubic kilometers. About two-thirds of the loss is due to depletion of groundwater beneath California's Central Valley:

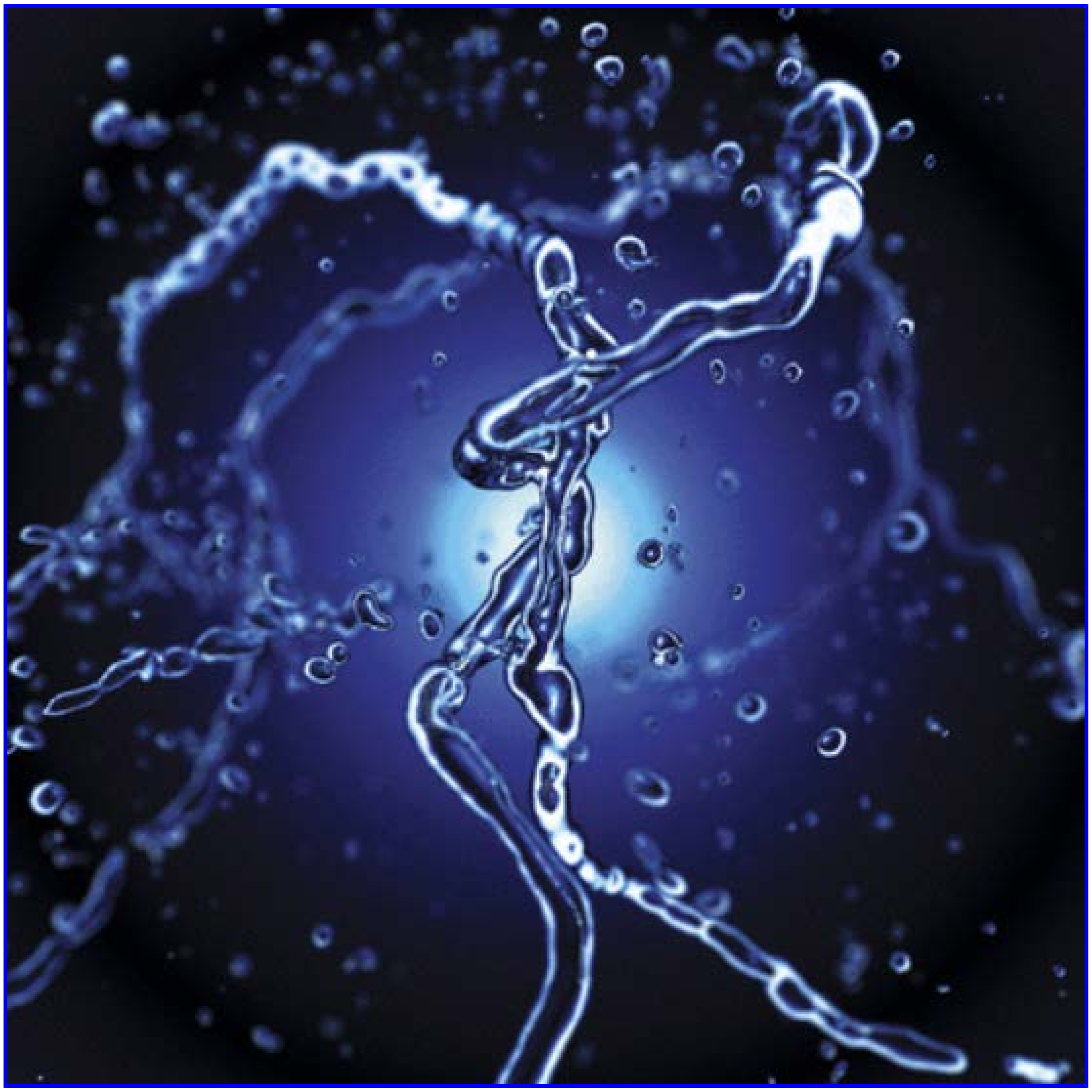
- NASA Jet Propulsion Laboratory, NASA Data underscores severity of California drought.

Some scientists studying tree rings have claimed that as measured by the Palmer Drought Severity Index — a measure of precipitation and evaporation — this is the worst drought California has seen in 1200 years:

- Daniel Griffin and Kevin J. Anchukaitis, How unusual is the 2012-2014 California drought?, *Geophysical Research Letters*, December 2014.
- Study: California's drought worst in 1,200 years, *ReportingClimateScience.com*, 5 December 2014.

I would like to see the evidence, and the definitions involved — but I haven't seen them yet.

December 19, 2014



Dolphins blow rings of bubbles and play with them. Like smoke rings, these are examples of vortex tubes. You can also make vortex tubes that are knotted!

Long ago, the physicist Kelvin conjectured that for any kind of knot, you can create a vortex tube shaped like that knot. He even guessed that atoms were 'knotted vortex tubes in the aether'. That wasn't true, but his conjecture is still interesting - at least if we state it a bit more precisely.

Say you had a incompressible fluid with no viscosity. Then its velocity vector field would obey the Euler equations. The Euler equations have lots of steady solutions where the velocity of the fluid doesn't change with time. The fluid is still moving, but the same way all the time.

In these steady solutions, the fluid flows along curves. These curves can be very complicated!

Kelvin conjectured that for any knot, there's a stationary solution of the Euler equations where the fluid flows along a curve shaped like that knot.

This was recently proved to be true!

- Alberto Enciso, Daniel Peralta-Salas, Existence of knotted vortex tubes in steady Euler flows.

This paper will appear in the prestigious math journal *Acta Mathematica*. The paper is deep: in addition to a lot of work on topology and differential equations, it even uses some number theory! To get 'invariant tori' — that is, surfaces of vortex tubes — they use the Kolmogorov-Arnold-Moser theorem. This requires checking that some flow lines spiral around a torus with a slope that's an irrational number that's hard to approximate by rational numbers! This condition makes the torus robust against small perturbations.

Here's the abstract:

> We prove the existence of knotted and linked thin vortex tubes for steady solutions to the incompressible Euler equation in R^3. More precisely, given a finite collection of (possibly linked and knotted) disjoint thin tubes in R^3, we show that they can be transformed with a C^m-small diffeomorphism into a set of vortex tubes of a Beltrami field that tends to zero at infinity. The structure of the vortex lines in the tubes is extremely rich, presenting a positive-measure set of invariant tori and infinitely many periodic vortex lines. The problem of the existence of steady knotted vortex tubes can be traced back to Lord Kelvin.

A **Beltrami field** is a vector field with no divergence:

$$v = 0$$

whose curl is proportional to itself:

$$\times v = cv$$

Any Beltami field gives a steady solution of Euler's equation!

William Irvine at the University of Chicago makes knotted vortex tubes in his lab, and this picture is from there.

Real-world fluids have viscosity, and then things get even more complicated and interesting. Vortex tubes can crash into each other and 'reconnect', as shown here!

December 20, 2014

Alien structure on Mars

Astronomers recently photographed this hole on Mars! There's no way to explain it by natural processes, and it's very regular in shape, so they believe it was produced by intelligent life. Since there's no life on Mars now, it must have been made by visitors from some other planet!

This hole is 1.6 centimeters across and 6.6 centimeters deep. It's in a rock in Gale Crater. It was drilled by the NASA rover Curiosity on May 19, 2013.

The rock, which NASA dubbed 'Cumberland', is interesting because it's made of ancient mud. NASA found that the ratio of deuterium to ordinary hydrogen in this rock is half the ratio seen in the water vapor in the Martian atmosphere. This suggests that Mars has lost a lot of water since the formation of Cumberland, probably about 3.6 billion years ago during the Hesperian Period — the period when Mars dried out and its atmosphere thinned to its current density.

Puzzle: Why would water on Mars have more deuterium now?

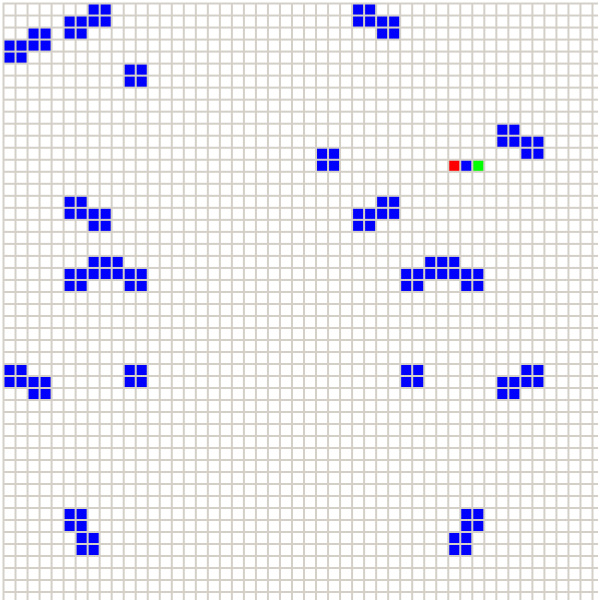
A bunch of the clay in Cumberland is 'smectite'. I had to look that up. Clay turns out to be quite interesting — like most other things, if you dig deep enough. Clay minerals are made of tetrahedral sheets of silica and octahedral sheets of hydroxide. There are two kinds: 1:1 clays and 2:1 clays. A 1:1 clay consists of alternating layers with one tetrahedral sheet followed by one octahedral sheet: examples are kaolinite and serpentine. A 2:1 clay consists of an octahedral sheet sandwiched between two tetrahedral sheets, and examples are talc, vermiculite and those in the smectite groups. I should include some pictures of these clay structures... maybe another day. For more on what they discovered by drilling this hole, read:

- P. R. Mahaffy et al., The imprint of atmospheric evolution in the D/H or Hesperian clay minerals on Mars, *Science*, 16 December 2014.

The photo is from this NASA webpage:

- Jet Propulsion Laboratory, PIA16936: 'Cumberland' target drilled by Curiosity.

December 21, 2014



They're not really quantum, and they're not really ants — but they're cute, and Alexander Vlasov calls them qu-ants. Here's his explanation:

> There are four states: 0 (empty, white), 1 (red), 2 (green), 3 (blue). A step may be divided into two stages:
>
> First stage. Mark all cells satisfying two conditions:
>
> 1) the total number of red and blue cells in four closest positions is one or two
>
> 2) the cells in the four diagonal positions are either white (empty) or green.
>
> Second stage. Change unmarked red cells to green, unmarked green cells to red, marked empty cells to red, marked red cells to blue, marked green cells to empty, and marked blue cells to green.

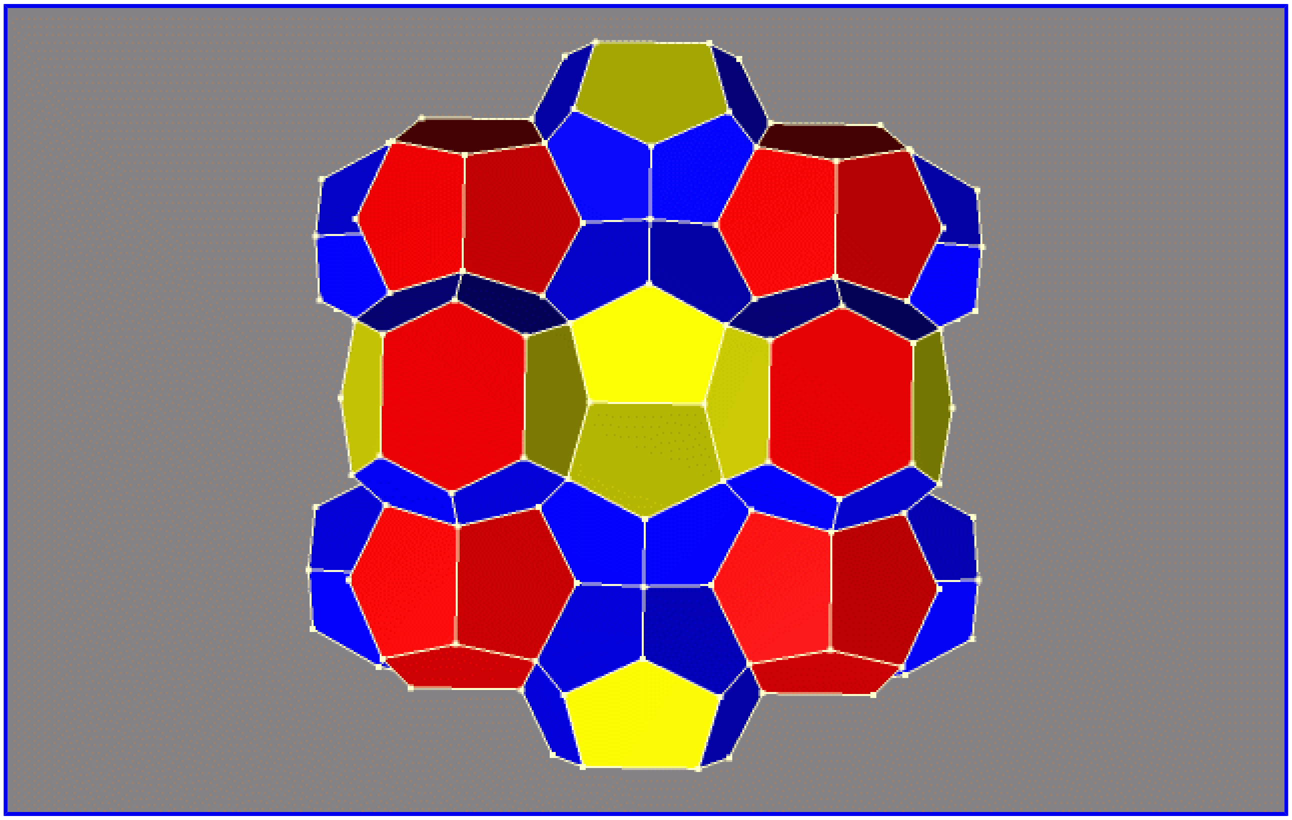
This is a cellular automaton. In other words, we've got a regular grid of cells, each colored from some finite set of colors, with a rule for updating all cells simultaneously based on the colors of their neighbors. But it's also reversible: the previous color of any cell before an update can be determined uniquely from the updated colors of all the cells. If you've got a reversible cellular automaton, you can run it backwards in time using another cellular automaton rule.

Vlasov actually constructed his qu-ants as a 'second-order cellular automaton'. This is a different kind of thing, where the color of each square depends on what's going on in its neighborhood in the previous two time steps. It's easy to make reversible second-order cellular automata... just like how Newton's laws of physics are reversible and given by second-order differential equations. But the description above conceals this fact, and describes the qu-ants as an ordinary cellular automaton.

For more information and more examples, see:

- Alexander Vlasov, Qu-ants.
- B. Schumacher and R. F. Werner, Reversible quantum cellular automata.
- Reversible cellular automaton, Wikipedia.

December 23, 2014



Water can freeze to form 'cages' that trap other molecules. They're called clathrate hydrates. There are several kinds, all beautiful. Nature is a great geometer!

This image, animated by Isaac Calder, shows a type I clathrate. The oxygen atoms in the water are at the corners of 12-sided and 14-sided shapes.

The 12-sided shapes have pentagons as sides, but they are *not* regular dodecahedra — if you look carefully, you'll see the pentagons are a bit off. The 14-sided shapes also have two hexagonal sides!

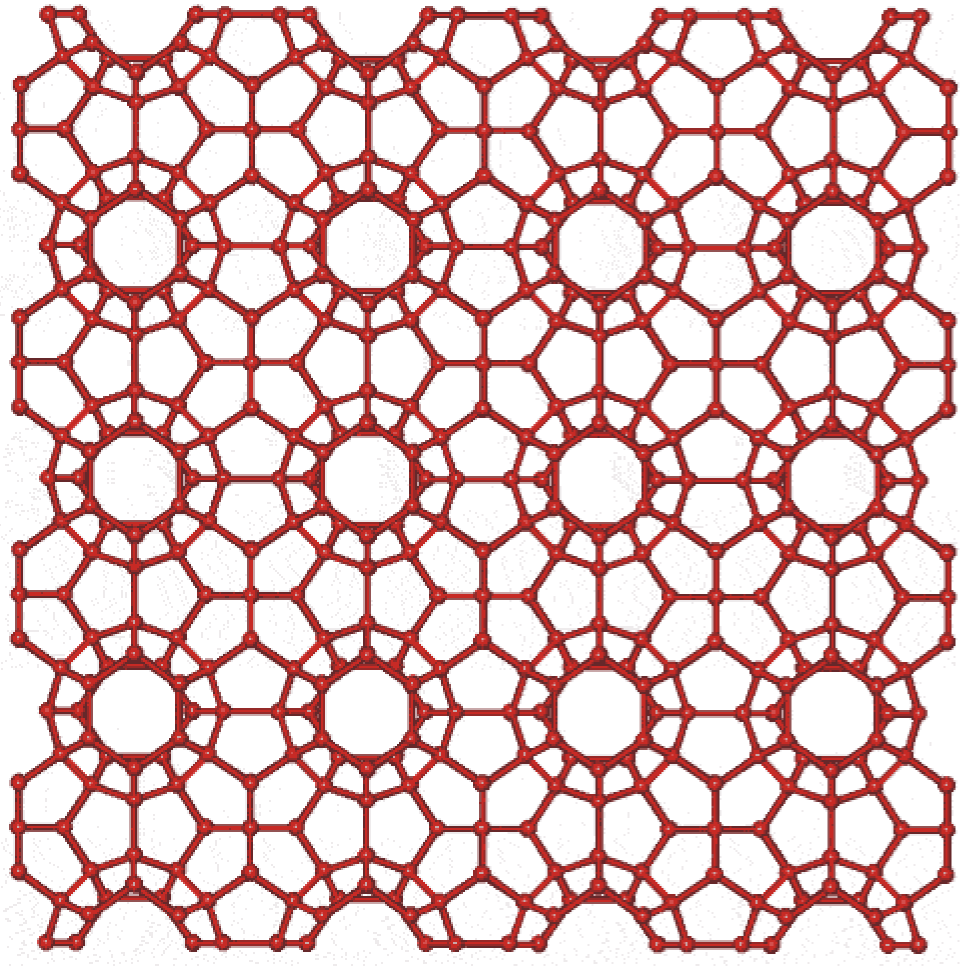
All this is very similar to the Weaire-Phelan structure, the best known solution to an old puzzle raised by Kelvin. He asked how space could be partitioned into cells of equal volume with the least area of surface between them. He proposed a solution, and for a long time people thought it was the best possible, but in 1993 Weaire and Phelan found one where the area is 0.3% less. It looks a lot like this, but the surfaces are *curved*.

For a great explanation of different clathrate structures, go here:

- Martin Chaplin, Clathrate hydrates, *Water Structure and Science*.

It's worth learning how to enable Java applets just to see these clathrates in motion! Nowadays Windows makes it really hard to use Java applets that aren't registered in a certain way. But you can still do it.

Here's another view of a type I clathrate:



December 26, 2014

This photo is almost unbearably cute!

It was taken by Barry Bland at TIGERS — The Institute for Greatly Endangered and Rare Species, in Myrtle Beach, Florida.

It's interesting to think about why this photo is so cute.

First of all, obviously, the young wolf and tiger seem like pals, walking in step — and the wolf is even smiling! But more deeply, I think we like the idea that animals of different species, even fierce ones, could be friends. The lamb may not lie down with the lion, but at least the tiger can play with the wolf! It gives us hope.

Finally, these are young animals, and thus more friendly, playful and inquisitive than their adult versions... and more cute. We seem to be innately fond of baby animals, perhaps thanks to our instinct to care for human babies.

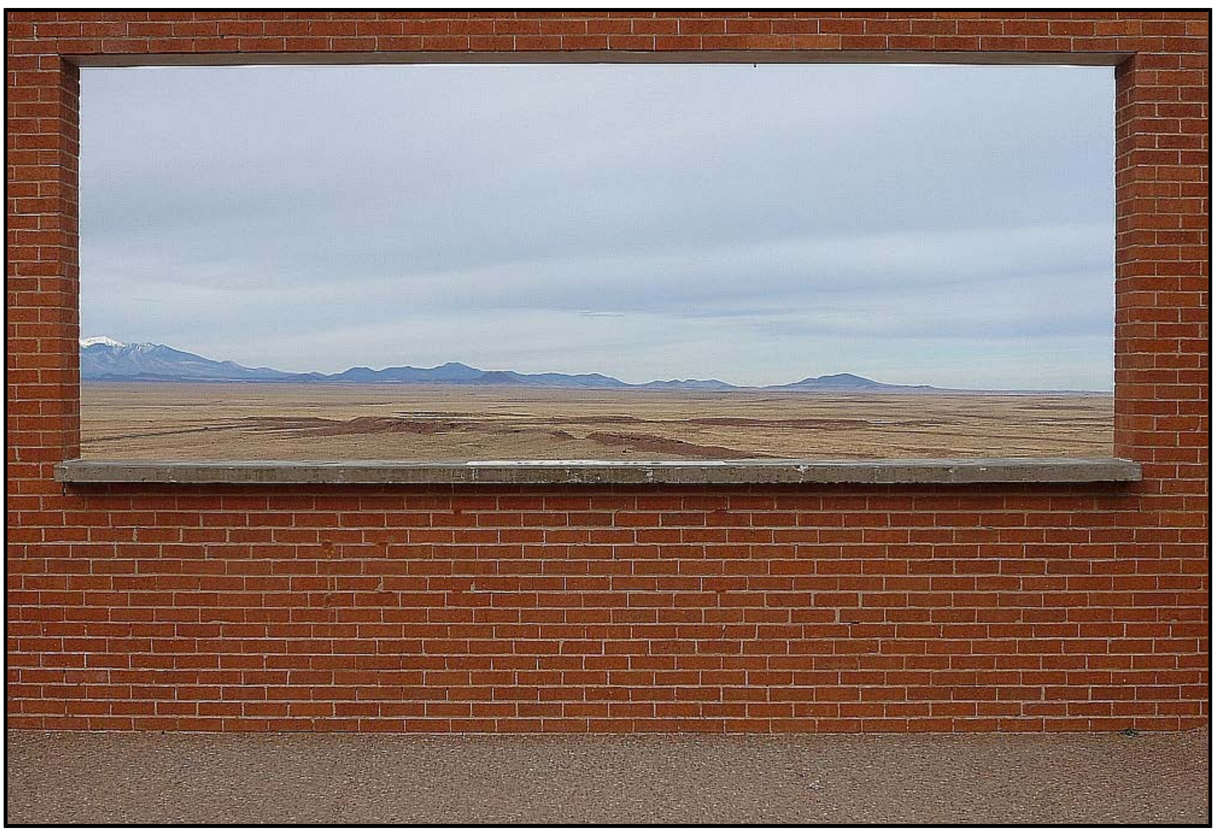
Dogs are neotenized wolves — adult dogs, especially of certain breeds, resemble young wolves, not only in looks (a more round head, etcetera) but in behavior. Dogs are now considered to be the same species as wolves, just a different subspecies. We clearly got along best with wolf puppies that stayed friendly and submissive.

We may ourselves be neotenized apes. It could be that intelligence, playfulness and curiosity are traits of youth that proved, in certain social contexts, to be adaptive even for adults. If so, there could be something profound about 'cuteness'. Perhaps our attraction to youthful, friendly, playful things helped spawn art, music, science, more merciful codes of morality, and more.

For more, see:

- Neoteny, Wikipedia.

December 29, 2014



Is this a clever painting on the wall of a building? No, it's a view from the parking lot at Meteor Crater, in Arizona. Looking to the northwest, you see a number of distant mountains.

For my January 2015 diary, go here.

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