Absolute Relativity

in the

Warped Æther

by

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Chapter 1

Lasagna

The cranky old guy stepped into his office and unpacked the lasagna from his backpack. The lasagna was still steaming hot in the steel container. Cranky's sweet wife had just pulled it out of the antique oven in their 100 year old bungalow in the suburban southwest of San Francisco. She had packed it in an insulated jar and sent it off with her husband to his hangout in the trendy, hipster, formerly industrial, southeast part of the city.

This office was a nice quick downhill bicycle ride from home, and Cranky was (unusually for a bicyclist) polite to the other traffic. He even stopped at red lights and waited his turn at stop signs. However, when he saw a chicken and a rooster scurrying across the road on the way to their secret lair in the scrapyard, Cranky just breezed by on his ridiculous tiny-wheeled oval sprocket bicycle. He even rode through a puddle and inadvertently splashed mud on the colorful birds.

Cranky's office was really more a *work space* with desks and a few couches. Besides Cranky, who just wanted to get out of the house, there were computer geeks scheming about the next big disruption of the internet. There were also hipsters making art to sell to wealthier but less talented other hipsters so they would have something to bring to the next Maker Faire or Burning Man Festival.

The lasagna was cooling on Cranky's desk and it was absolutely delicious. The smell wafted over to the scrapyard. The rooster and the chicken loved lasagna even more than beetles and worms and garbage. They gladly accepted the invitation of the open office window and swooped in.

As Cranky stepped out of the bathroom and saw that rude rooster and that cheeky chicken standing in his lasagna dish, flinging bits of cheese and pasta and tomato all over his laptop computer and his electric violin, little did he realize that these magnificent birds would soon become good friends and fresh inspiration for his shriveled imagination. He did however, resign himself to having lost his lasagna. He sat down on the couch and morosely watched the chicken and the rooster eat their fill. The food might as well go to the birds instead of being wasted.

Eventually the rude rooster and cheeky chicken fluttered back out the window. Cranky picked up some paper towels and wiped up the messy claw prints, composted the remains of the poor lasagna and generally cleaned up just enough to stay out of trouble with his hipster officemates. He opened up his laptop computer to put in some hours of consulting for one of the evil giant tech companies. But instead of trying to get his computer code to work, he browsed the internet, reading a bit about manual espresso machines and quarks and two-stroke diesel engines and combat robots. He got bored and looked out the window.

Outside was the abandoned harbor, the mouth of Islais Creek. There was a depot and workshop for the streetcars of the San Francisco Municipal Railway. There were scrapyards. There were seagulls and ravens, and apparently chickens and roosters. The creek used to be called "Shit Creek". It flowed down from Mt. Davidson, the highest of San Francisco's hills, through Glen Canyon, past slaughterhouses and tanneries into San Francisco Bay. These days most of the creek was underground. It no longer smelled as bad. It was one of the least foggy areas of San Francisco. In fact it was warm and sunny, a really nice day, and Cranky decided to go outside for a walk. He took along his violin so he wouldn't annoy his officemates by practicing in the office. That was, assuming these officemates actually made it into the office that day.

Chapter 2

Space

Cranky wandered over to the edge of the bay and looked over towards Oakland. He turned and there they were again, the cheeky chicken and the rude rooster.

The rooster cleared his throat, let out a loud "hieeheeriheee" and then said "hi". Cranky was totally not expecting to hear "hi" but responded "hi!". On a whim, he added "nevermore" in his best gravelly raven imitation.

"Listen asshole, don't mess with me or I'll show you *nevermore*."

"Oh my god! You really can talk! Sorry! I had no idea, wow, I've got so much to ask you." responded Cranky.

"Slow down, guy, I'm not your god, just trying to be friendly for a change."

The chicken just stood there silently. It was hard to tell if she was surprised that the rooster was striking up a conversation. It was hard to tell even if she was paying any attention or just staring into space. But it turns out the chicken was quite observant.

The conversation went on.

"How did you learn to talk? Are there other talking roosters?"

"Well how did YOU learn to talk? Listen guy, I don't usually go around being chatty, especially not to other roosters. YOU can try to get them to talk."

"Sorry, right now I just want to talk to you. There is so much I could learn from you, I never heard of a bird as articulate as you. Talking to you is amazing. I have so many questions."

"Calm down, you've got questions, I've got answers. Just don't waste my time asking what worms taste like or what it feels like to have feathers."

Cranky paused. He was actually planning to ask about feathers and worms. In a slight panic he strained to find a question less trivial and more worthy of this particular bird. Perhaps he was going too far in the other direction when he paraphrased Dr. Faust.

"What I really want to know is what makes the world tick, what fundamentally holds it together?" He continued, "What is space made of? How is matter attached to space? Why is there so much nonsense in physics?"

This question did seem to please the rooster. He hopped closer.

"OK, what exactly is that physics nonsense you want to know about?"

Cranky was not a physicist. Not even an amateur physicist. Many years ago, before becoming a cranky old guy, he had been a mathematician, a logician. Later he became a *software engineer*, which actually means *someone with enough common sense to figure out how to look up on the internet how to fix a computer program.* Now the world's most intelligent bird was putting him on the spot with physics questions. When Cranky was a child, his family had a talking mynah bird named Poincaré. But Poincaré had been easy to talk to, he only yelled "mama" and barked like a dog and meowed and did not expect an answer. Oh well, just press on fearlessly.

"One hundred years ago the great physicists discussed some paradoxes. An astronaut goes on a long fast space voyage and comes back younger than his twin brother. A cat in a box has no idea if it's dead or alive because nobody can see inside the box. The students of these physicists just said 'oh great ones, you are so wise' and mistook questions for answers. So now if you want to learn physics, they teach you about younger twins and semi-dead cats. It's as if in calculus class they were to teach you that calculus is really deep and mysterious, as shown by the fact that Achilles is a super fast runner but can never catch a tortoise."

"OK" said the rooster, "You say you understand math. You're asking about the world. The word *world* has so many meanings, but you seem to want to know about physical space. You can't really talk about space while ignoring time, so I'll tell you about time *and* space. You have 3 dimensions of space and orthogonal to that is the time dimension, so 4 dimensional spacetime. You can imagine points in spacetime, you can assign numerical coordinates, you can imagine lines, curves, planes, directions, all the stuff you learn about in math class. It would all be really boring except that spacetime is *warped.* That's easy to say but perhaps not easy to truly understand."

"That's what Einstein said. Spacetime is 4D and it's curved and that explains gravity. I can sort of visualize that by thinking about 2D curved surfaces like the coin funnel at the museum or the surface of a sphere like the Earth or the surface of donut. My dad is an expert on curved 3D manifolds and has a bunch of models made of cardboard and rope to try to visualize curved 3D shapes."

⊙̃< "So that's a start, but you have to realize that the surface of the Earth is very different from a sphere. Sure, if you ignore all the details, the Earth is a sphere, but the details are the most important thing. The hills, the valleys, the footprints, the trees, the walls, the doorways. You don't actually understand the shape of the Earth if you ignore the details."

⊙̃< "The next thing is that spacetime is actually warped, not curved."

⊡ "Warped, curved, bent, what's the difference? Don't they all mean the same thing?"

⊙̃< "The surface of a sphere is curved. Any two straight lines eventually cross. If you draw a triangle and carefully measure the angles, they add up to more than 180°. Look at the steel roof on that shack. That's warped and not curved. You can draw parallel lines in any direction on the surface of the corrugated roof. The triangle printed on the steel has angles that add up to exactly 180°. In 2 dimensions, there are not many ways a flat surface can be warped. It can be bent in only one direction. If you try to bend it in a second direction, the surface would need to be stretched or squished and develop curvature. It turns out that spacetime is not curved, just warped. Because it's 4 dimensional it can have a complicated warped shape that still obeys all the rules of Euclidean geometry."

⊙̃< "What you really want to know are the details of warped spacetime, the waves and the curls that run all over and all through it. Einstein showed how 3 dimensional curved space, taken together with 1 dimensional straight time gives a shape that explains gravity. You can also explain gravity using 4 dimensional *flat* spacetime that nevertheless is warped. But the warp of gravity and the fact that time is just one of 4 directions in the æther is only a tiny part of the story. The devil is in the details. Yes, I can talk and talk, but you'll understand better after I show you a few things."

Chapter 3

The Trolley

õ< "Come on, I'll take you for a ride," said the rooster. "Follow me."

They walked over to the MUNI (Municipal Railway) garage, slipped through a hole in the fence and went around the building. There was an old LRV or trolley or streetcar or whatever you want to call it parked there. It was perhaps 50 years old. Too modern to be included in the F line fleet of classic streetcars that go up and down Market Street but too old for service in the tunnel under Market Street. This one was a bit odd. Instead of an electric pantograph it had a smokestack sticking out of the roof. Inside was a huge boiler and piles of coal and water tanks and levers and valves and knobs and dials. Underneath were two cylinders and double acting pistons attached to cranks on the wheels.

It was a crazy combination of old and older discredited technology, but it could follow the tracks even where there were no overhead wires.

Immediately the chicken and rooster got busy lighting some rags in the fireplace and kicking in lumps of coal. It was truly amazing to see the strength and cleverness of these birds. Since the rooster had already been talking about spacetime, Cranky was perhaps less astounded than he should have been. Cranky did love steam engines and wished he could ask all about this one, but wisely decided to just let the rooster do what he was going to do and not add to his list of questions. He just watched the rooster and chicken run around oiling joints in the mechanism, opening and closing valves, pumping bellows for a blower to get the fire going.

The rooster asked Cranky to play something on that violin. It was actually an electric violin, but Cranky had left the amplifier and speaker at home and was just planning to practice without making much sound. Even so, the vibrating strings made enough sound for the three of them to hear the playing. Cranky was in a mood to play a few bars of *Casey Jones.*

□ “Are these sound waves some of the details of warped space that you’ll show me?” asked Cranky.

⊙̃< “No, these waves are pressure waves in the air, the air is a bunch of molecules bouncing around, and each molecule is a bundle of timespace warp curls. The frequency of your sound wave is perhaps 440hz and the frequency of the waves I want to show you is more like the frequency of light, a million million (10^{12}) times as high.”

⊙̃< “Still, it’s amazing what you can get out of a bundle of waves. All your music, all my talking is just waves in the air. It’s the same gas pressure that pushes the pistons under the trolley. You just wiggle the pressure the right way and you get music. Still we’re going to get a million million times as detailed.”

It only took an hour or so and the trolley seemed to be steamed up ready to move. The chicken hopped onto the dashboard to look out the windshield and the rooster opened the throttle. Off they went. The sign on the trolley said *Training Coach* and it was painted a different color from the more modern streetcars, so the passengers waiting at the stations and the oncoming trolley drivers seemed to just ignore it, even with black smoke shooting out of the chimney. After a while the trolley went underground and eventually its operators pulled into a side tunnel and parked.

⊙̃< “There’s something I want to show you above us,” said the rooster.

They got out and followed a dark stairway up to the surface. They were in Glen Canyon Park. The famous Islais Creek was also above ground here and was flowing through a bushy muddy creek bed. The canyon looked more like a valley, but one side was very jagged and rocky and steep.

⊙̃< “This is where the first dynamite factory in the US was, 150 years ago. Dynamite had just been patented by Alfred Nobel and it was useful for mining and firefighting and whatnot in California. A year after it opened, the factory was destroyed in a big explosion and the workers were killed.”

□ “Wow, but what does that show me about the details of warped spacetime?”

⊙̃< “All it means is that if you know how something works, that does not mean you can completely control it. A million years ago you guys figured out fire and by now you’ve burned down most of the world’s forests and caused the extinction of over half of all species of life on earth. Even now, the San Francisco Department of Parks and Recreation is waging a war against trees just ahead of us on Mt. Davidson. I just wanted you to know the risks before I show you too much about how the world works.”

Despite the rooster’s accusation about fire, he seemed to be a big fan of fire, not just to power his trolley but also for cooking. In fact, he smelled some more cooking in the air and went uphill to investigate.

They walked up the canyon towards the smell. It seemed to be coming from a huge building at the head of the canyon. From a distance it looked like a resort hotel but as they approached, they could see that the windows were replaced by steel panels or painted over. What had once been a superb example of brutalist architecture now looked more like a prison than the actual youth prison across the street. This building housed the San Francisco School of the Arts, with another school, the Academy of something other than Arts, occupying the basement. As the path looped around the side of the school, all they saw of the school was forest and an abandoned concrete tower with a stairway. It looked like a remnant from some jungle war half a century ago. Eventually they came into the courtyard with a huge metal canopy, looking like the world's second biggest truck refueling station.

It was getting later in the day and the high school students had gone home to do their homework. Many of their teachers felt that when it comes to homework, more is always better. The students would be more tired and defeated and not ask silly questions in class. Still, the students at this school were the lucky ones. The school board's mission was to destroy art, but so far, this school was spared. For now, these students were taught a variety of arts and were practicing their art all afternoon. Besides that, not all the teachers were sadistic about homework. Some were even trying to make class inspiring and uplifting. Today the Italian teacher had the students cook Italian food and that is what the rooster was smelling.

The rooster and the chicken and Cranky got into the school's cafeteria. The rooster seemed to have a special talent for unlocking doors. The former cafeteria kitchen was now the Italian classroom and there stood a huge bowl of spaghetti.

õ< "This is a model of the universe!" Before Cranky could ask how a bowl of spaghetti was a model of the universe, both the chicken and rooster were standing in the bowl, slurping spaghetti and flinging it around. The only thing Cranky could think of was to write *grazie* on the blackboard and add a stick figure drawing of a chicken.

õ< "Now we'd better get going, I want to show you the sunset over the Pacific Ocean."

They made their way back to the trolley. The trolley came out of the west portal of the tunnel and continued past rows and rows of houses, past the zoo and to the beach.

Chapter 4

Waves

The rooster and Cranky watched the waves coming in from the Pacific Ocean at dusk. The swells moved in from the horizon and got taller and finally curled over and broke as they hit the beach. The chicken was just hanging back and observing.

õ< "Here you see in 2 dimensions and extra large, some of what spacetime has in 4 dimensions. Waves and curls on a bent surface. The surface is bent toward the horizon. On top of the big bend there are patterns of smaller bends. In some places the surface curls around entirely."

õ< "Forget that these particular waves are in a 3D ocean. The surface is 2D and when you measure distance, you measure along the surface, not through the water. The higher waves bend the surface more and consume more distance than the lower waves. Note also that the surface of the ocean is curved along with the surface of the Earth. It's a warped 2 dimensional surface."

□: "OK so there are waves in spacetime, but also particles, right? I'm made of particles. I like particles. What do particles look like in 2 dimensions?"

õ< "What actually is a particle? It's something small in the 3 space dimensions and long in the time dimension. It's small, but it lasts through time. On the other hand, a wave is part of a pattern. It's hard to distinguish one wave from the next. There are more waves just like it next to, earlier and later than that particular wave. The wave repeats through time and repeats through space. It's a pattern that's spread out in time and in space and it varies over time and space."

õ< "Here you have just 2 dimensions. Basically we see waves and not what would count as a particle. Let's say the time dimension is north-south along the shoreline and space is east-west towards Hawaii. The waves are coming in at an angle. If you had more dimensions, the waves would not just go up and down, but also in circles. The pattern goes up and down as you look east-west and it goes up and down as you look north-south. The waving happens in space and it happens in time. On the other hand, a particle has to be something that is a small single thing in the east-west direction and extends a long way north-south. The feature here that is like a particle is the last wave by the shore that is curling over. There is usually one curling wave in approximately the same spot. It's perhaps a meter high and a meter wide but a kilometer long."

"Fine, when I was younger I learned that particles sometimes behave like waves. But just saying a particle is a really long wave that curls over itself is missing the main point. You have a wavy probability of finding the particle in one place or another and interference patterns in these waves. Your long curl doesn't do anything like that even though you say it's a wave."

"Aha, the particles you're talking about are electrons and photons and such. What I'm talking about are protons and neutrons and such. The electrons are waves that just enjoy hanging around near *real* particles. As long as they stick close to a particle, they also end up thin in 3 space dimensions and long in the time dimension. They become like particles by hanging around other particles. But they're not locked in to particlehood."

"The real story is that the æther of spacetime is a flexible static blob that has lots of warped bends in it. The particles are curled over bends that are locked in and can't unwind themselves. The waves are more fluid, fanning out from these locked particles.

"What the heck is a *locked in* wave?"

"We need to get back. Chickens and roosters aren't nocturnal. The coyotes are coming out."

Chapter 5

Energy

The trolley headed back from the beach and Cranky was full of questions.

□ "OK, so spacetime is this 4 dimensional elastic warped blob. Why does it stay bent the way it is? Why doesn't it just go *sproing* and flatten itself out?"

The trolley stopped. Some plumbing company had parked their van so close to the tracks that the trolley couldn't get by. Cranky just kept asking questions.

□ "Why didn't it go *sproing* a long time ago?"

õ< "Time? I told you, time is just a direction inside the blob of æther. Each piece of matter curled up in the blob points in some direction and that direction is the time axis relative to that particular bit of matter. The æther blob is not unrolled and flattened out because it has these curls of matter locking it into its warped shape."

The trolley rolled forward against the parked van that was blocking the tracks. Crash! The van got pushed just clear, but now it had a huge dent.

õ< "Uh-oh! Serves them right, but now the plumbing company is going to file a police report and they'll dig out security camera footage. Too may questions will be asked, even more questions than you keep asking. Better fix this."

The rooster showed Cranky a bicycle pump with a huge rubber plate on the base. Like everything else in the trolley, it was somewhat modified. Instead of generating pressure by pushing the handle, pulling the handle generates a vacuum. Cranky got the message and pressed the rubber plate against the dent, pulled on the handle and popped the dent out. Luckily, the popping sound was not so loud that it attracted attention.

õ< "There's your example. The matter in the æther of spacetime is like a dent. It won't just pop out by itself, but someone who puts in enough energy could pull it out. It would be a humungous pop as the energy got released, but it would also take a pretty strong tug to budge it."

"The key word here is *energy*. There is energy trapped in the æther by the curled up matter. As much as possible, all the energy is spread out and the æther is as relaxed and unenergetic and unwarped as it could get, but if the curls could all be popped, all the energy would be released."

"So, there is this locked up energy. It's spread out as far as can be to minimize the total energy, but still, the æther is stuck in its tangled shape."

"Hmmm, bending or warping the æther takes energy, unbending releases energy, a tighter bend holds more energy than a longer, more gradual bend. That all sort of makes sense but seems awfully vague. I used to be a mathematician, tell me a formula!"

"All right, at each point P the æther has a warp $w(P)$. The warp energy $\mathcal{WE}$ is w^2 and $\int \mathcal{WE}$ is the total energy of the æther. This total energy is minimized with respect to local changes in w. The æther is relaxed."

"Uh, OK, I don't get it. On second thought, using formulas is just for engineers. Mathematicians need to understand and prove formulas. Can you help me understand?"

"So, I can't prove it but I can show you an example that will make you wish the formula to be true. You won't have the logical certainty of a proof but you'll get the hope of having a plausible theory."

"Take out your spare E string from your violin case. It's 1 dimensional but it's elastic. It bends and twists but it stretches hardly at all. When you stretch it on your violin it holds energy. The energy is proportional to the square of the force you use to stretch it. But we're just going to bend it, not put it on the violin. As soon as you take it out of the packet, it unwinds and straightens. It likes to be straight. It stores less energy when it's straight. Now tape the ends together (certainly duct tape was on hand in the trolley). The string can no longer be straight, but it relaxes into the biggest, smoothest circle it can. That's the minimum energy shape it can have while the ends are connected. Then w, the warp is constant along the string. The more the string is bent, the more energy it holds. The $\int$ just means add up all the energy of the entire string."

"But why w^2? When I bend it more, there's more energy. If I loop it around twice, I get a circle half as big, the string makes 2 full turns, it's twice as bent. The formula says it should have 4 times the energy. Why not twice the energy, or 3 times or π times?"

Snip! The rooster cut the string in half. Luckily it was a *Goldbrokat* string. Quite cheap while also being among the very best.

"Put the half string into a loop. How much energy does that take compared to putting the whole string into a loop? Why is it not the same? Why does the formula say it takes twice the energy to make a loop of the half string? (So that if you do it to both half strings you get 4 times the energy of doing it to the whole string.) Pretend you could make the half string bigger by just expanding it. You get a string that's as long as the original string but twice as thick. Try bending that and it takes more energy."

⊡ "Uh, it would be twice as thick, so it would have 4 times the cross section so wouldn't it be 4 times as hard to bend?"

$\tilde{\odot}$< "Crap!" The rooster picked up a sheet of paper and started bending that.

$\tilde{\odot}$< "If the paper is expanded to twice its size it would be like bending 2 sheets of paper at the same time so it would use twice the energy."

⊡ "All right, but since when is it ok to expand a violin string or a piece of paper and assume it takes the same amount of energy to bend it."

The rooster was getting annoyed.

$\tilde{\odot}$< "*Since when*? I keep telling you time is relative to a particular piece of matter. We're talking about timeless warped æther here. Since always. Since never. Since the north pole."

Cranky decided to drop that line of questioning. They had made it into the tunnel and were cruising along under Market Street. Eventually they surfaced at the Embarcadero. The moon was full and reflecting off the bay. Everybody calmed down.

⊡ "OK, I accept the w^2. The bigger the loop, the less bent, the less energy. This is supposed to be about the shape of the universe. Why isn't everything just the biggest possible circle or even flat?"

$\tilde{\odot}$< "Yep!" The rooster took the looped violin string and bent it into a figure 8 and put it onto the bench. Actually it did not look quite like an 8, more like ∞. Instead of two circles next to each other, it was sort of teardrop shapes with an $\times$ where the wires crossed.

$\tilde{\odot}$< "What prevents the loops from ballooning out into a circular shape more like the 8 and less like the ∞? It's the fact that the total energy is at a minimum. The 8 is 2 full turns while the ∞ is just a $\frac{3}{4}$ turn on each side. Even though the bends are tighter, there is less bentness and the total energy is less. The 8 has an abrupt change in curvature at the middle while the ∞ has the energy distributed evenly. Even a change in curvature contributes to the energy. The wire is straight in some parts because that gives the lowest total energy. There you have it. Minimum energy is what gives that shape to the ∞."

The string was sitting on the table and as soon as the rooster let go it jumped up and flipped itself into a circular shape.

⊙̃< “Ha! There was enough energy in there to make the string jump. If we had a way to keep the string in 2 dimensions it would be trapped storing that energy with no way to release it.”

⊡ “So the string is actually free to bend in 3 dimensions.”

Cranky picked up the string and removed the tape. The string sort of straightened out but not entirely. It ended up as a section of spiral ᘓᘓᘓᘓ shape instead of totally straight.

⊙̃< “So it’s not mathematically perfect, but it’s showing you something very important. The 1 dimensional string can be twisted and bent in 2 different dimensions simultaneously. When describing how much it’s bent, you can’t get by with just a number, it’s bent in multiple directions, you need multiple numbers, you need a vector.”

Cranky had learned about vectors in high school. Instead of a course about trigonometry he had a course all about vectors. Maybe that would come in handy when trying to understand the rooster but at the moment his head hurt trying to remember what he had learned when he was 15 so he decided to change the subject.

⊡ “OK, so what about a formula that everyone has heard of, $E = MC^2$?”

⊙̃< “Oh, that’s a version of the same formula. C is *the distance of time*, simply the conversion between units measuring time and units measuring space. Calling it *the speed of light* is not particularly accurate. M is mass, or simply the bending energy trapped in a set of locked warp curls in the æther.”

⊙̃< “The fact that C is *constant* is important though, it says that the æther does not stretch or compress. It bends and warps, but the distance along the surface does not change. There is no curvature in spacetime, just warpage. If you had space stretching somewhere, the ratio C would change at that place.”

⊡ “So if I want to imagine the energy in a 2 dimensional warped surface, I make a grid out of violin strings, like chicken wire?”

The rooster did not appreciate the reference to chicken wire and turned away from the conversation.

Chapter 6

The Tablecloth

Cranky and the rooster and the chicken got back to the scrapyard and parked the trolley. They had to put out the fire in the trolley and dump the ashes and blow out the sludge from the boiler. Eventually it was time to go.

$\tilde{\odot}$< “Come back tomorrow with more lasagna and I’ll tell you more about energy!”

The rooster was, unfortunately, somewhat of a messy eater. The next day Cranky not only brought more lasagna, he brought along a plastic camping tablecloth. By the time the chicken and the rooster appeared at the window, there was a tablecloth on the desk and a big tray of lasagna.

The rooster was delighted by the lasagna, of course, but also by the tablecloth.

$\tilde{\odot}$< “Pick up a handful of the tablecloth, right out of the center!” Cranky pinched a bit of the cloth and grabbed a section in his hand. The plastic bunched up and made waves radiating away in all directions from the clump in Cranky’s hand. Some of the waves ended at the end of the cloth and some flattened out and ended at the lasagna dish where it held down the tablecloth.

$\tilde{\odot}$< “Now grab some tablecloth in each hand.” Cranky obliged and now there was a wave of tablecloth stretching between the two clumps in his hands and a more waves radiating away from the clumps.

$\tilde{\odot}$< “This tablecloth is flexible and bendy but it doesn’t stretch or compress. It’s a lot like the æther, but the tablecloth is 2D and the æther is 4D. Now imagine the tablecloth could pass through itself.”

Cranky had learned about mathematical topology so what the rooster said actually seemed to make some sense. Maybe you can bend something and not have it collide with itself, just pass right through.

⊙̃< "You can bend and roll the tablecloth and tighter bends store more energy. The shape of one part of the cloth can go all the way through a different part of the cloth. With the violin string you could loop it around and then loop it around once more like this: . If you let that string relax, the steel wire would just expand the loops to get them as big and low energy as possible. If you tape together the ends of the string you would just end up with it looped around and around on top of itself."

⊙̃< "Now suppose you could do something like that with the tablecloth, in 2 dimensions instead of 1. Spin the shape around horizontally and you get a curled ring with the tablecloth looping up and around and through itself in a ring shaped loop. Basically you get the shape of the surface of a donut. The rest of the elastic tablecloth would round out the loop to have bends that are as loose as possible but it would not straighten entirely. If the loop gets too big around, the ring has to get bigger and ends up storing more energy than a smaller ring. The tablecloth ends up stuck, locked in a shape that it can't straighten out. Besides being stuck with that donut shape, the fact that it does not stretch or compress means it also is scrunched and wavy radiating out from the ring. The material is bunched up in the middle so the tablecloth doesn't lie flat any more."

⊙̃< "If you had more of these loop-ring-curls, waves that radiate out from the curls would actually be connecting them."

Cranky picked up a mouse pad from one of the desks and started bending it. The mouse pad happened to have a pattern of circles printed on it.

⊡ "I think you're cheating with that tablecloth. You are stretching it a bit to get it into a ring shape. All I can do to this mouse pad is roll it into a cylinder or a cone or a wave shape that is straight in one direction."

⊙̃< "Yes, you caught me exaggerating. The mouse pad and the æther are what mathematicians call *flat*, even if sane people would call them *curved*. I'm just going to say *warped* instead of *curved*. If the tablecloth were totally non-stretch, the waves radiating out would not be able to smoothly transition into the donut shape. On an infinite non-stretch tablecloth, the waves would have to be parallel like the waves in the corrugated steel roof. The slight stretchiness of the tablecloth lets it have more variety of shapes, just as the extra dimensions of the æther let it warp into more complicated shapes than just parallel waves."

⊙̃< "On the surface of a sphere, when you draw a circle with radius r, the circumference ends up shorter than $2\pi r$. The bigger the circle, the more you notice that the circumference and the radius are being funny. The surface of a sphere is called *intrinsically curved*. On the mouse pad the circles can't bulge out. As long as the mouse pad is only bent in one direction, the circles don't have to bulge out. It's the same story as the angles of a triangle summing up to 180°. The mouse pad and the æther are *intrinsically flat*. In the 4D æther, instead of measuring a circle, you check a 4D sphere, and that sphere has the diameter and volume and surface area you expect, no funny business."

Cranky had forgotten the formula for the surface area or surface volume or whatever you call it of a 4D sphere, so he was not going to argue, but it all still seemed pretty fishy.

□ "So if the tablecloth were 4D you would not be cheating?"

õ< "Yes, even though the 4D æther is *intrinsically flat* in the sense that volumes don't stretch or bulge, it can warp into all sorts of shapes. At any point, it can bend in all directions. You can add up the energy from all the bending at that point. The total energy of all the points of the æther is at a minimum, but the warped bends are *locked in* because it would take additional energy to untangle the æther and make it unwarped and truly flat."

Cranky pondered for a while. He could sort of imagine this warped loop in the æther. The springiness of space would prevent the loop from trying to get bigger and bigger or smaller and smaller. The energy of the curves would balance out. But how big would this loop be?

□ "If you keep the shape of this warped tablecloth loop and make it twice as big or half as big, it would still be balanced. It would still trap the same amount of energy. In the æther, why aren't things random sizes?"

õ< "When you have more than one loop in the æther the lowest total energy is when the loops are the same size. There is nothing absolute to measure the size against, but relative to each other they are all the same."

Finally the rooster's talkativeness gave way to his hunger. He and the chicken pounced on the lasagna and ate an amazing amount. And yes, quite a bit of lasagna ended up on that tablecloth.

Chapter 7

4D

Eventually the rooster was done eating.

□ "So how does the real 4 dimensional world work? You're telling me it's also curled up in ring shapes?"

The rooster explained:

⊙̃< "You and I are part of the 4 dimensional spacetime æther. Our existence is literally wrapped up in the æther. As we sit or move and age, we each are a bundle of warped æther curls."

⊙̃< "3000 years ago everyone thought that the earth was flat, that *up* was the same direction for everyone. Even now most people believe that *time* is the same direction for everyone. They think of spacetime as 3 dimensions of space with an added dimension for time. They talk about the age of the universe as if there were one timeline for everything. They assume it makes sense for something to happen simultaneously throughout space."

⊙̃< "If you ignore the details of the shapes, you and I are just thin parallel strands of spaghetti in the æther. We're parallel because we stay close to each other. These strands are not the 0-width infinitely long lines from math class. The lines are only as long as our existence, perhaps your line is 90 light years long if you exist for 90 years. That's around 8.5×10^{17} meters. Your line has 3 dimensions of width, something like 1.75 meters by 0.5 meters by 0.6 meters. In any case, this spaghetti strand is pretty long, and very thin compared to its length and it is not exactly straight, but pretty close."

⊙̃< "When you go home and I stay here, your strand bends a little compared to mine and the lines are a bit farther apart, perhaps 5000 meters instead of 2 meters, but hardly noticeable compared to the lengths of the strands. As the earth rotates and orbits, both strands curve slightly, this way and that and spiral around each other."

"Time, for each of us, is the direction of the strand. But, as Einstein already convinced you, spacetime itself is bent due to gravity. That's true even though spacetime is mathematically *intrinsically flat*. It's not just that my line and your line are a bit squiggly as we move right, left, up down or forward and back. The æther that these lines are attached to is warped."

"When it's not curved or warped, you can understand one dimensional space, two dimensions, three and four dimensions, and so on. You assign X, Y, Z and perhaps T coordinates. If everything is straight, adding another dimension is just adding another coordinate. That gets a lot more interesting when it's warped. Your coordinates and measurements end up the same as in flat Euclidean space but nevertheless, the space has a funny shape if you think of it in 5 dimensions."

Cranky could remember being 4 years old and his parents trying to explain topology by telling him that a teacup was the same as a donut and something about pulling a string through the opening. It did not make a whole lot of sense back then or even now, but was somehow mysterious and important. By now, curved 2 dimensional surfaces no longer seemed all that difficult. The sphere, the Möbius strip, the lasagna covered tablecloth or the surface of that teacup from his childhood memory. Still, the distinction between curved and warped was a bit strange.

"OK, so I'm a long thin line somehow attached to the æther and the æther is warped. How am I attached? Why doesn't my curl just go straight when the æther bends? Why am I not just floating freely in space and time?"

"You're made out of curves in the æther. It's all just one huge 4 dimensional surface and you are a sliver of that. Instead of floating in the æther, you are part of it. Your existence is just a cluster of curls in the æther. Every molecule in your body, every proton and electron is nothing more than warped æther. The most basic piece of that puzzle is a long skinny curl that is locked in by its own shape and stores a bunch of energy. It's what you call a quark. A long rolled up warp that can't unwind itself."

"So it's supposed to be something *like* the dent in the plumbing van or the ring shaped loop in the tablecloth, but what shape is it really?"

"Just as with the 2D tablecloth or mouse pad, you can imagine curling 4D space around an imaginary line. Since the æther is springy and a lot of energy is stored in the curl, it would just unwind itself, the curl growing wider and wider as it expands. But if the line you're curling around is not a straight line and if the line is bent the right way, it would take extra energy to start the unwinding, so the æther is locked around that bent line. It's similar to the tablecloth's shape getting locked in the ring curl around an imaginary circle, but instead around a spiral line."

"4D space can get locked up around an imaginary helix. It's a helix like the spring in your ballpoint pen, but longer and thinner. The helix is a 3D spiral shape and the long dimension is time. That leaves 2 dimensions of the helix embedded in the 3 space dimensions of the æther. If you could look at it, you would see a point spinning around in a circle as time advances. That imaginary helix has the elastic æther wrapped and locked around it."

⊙̃< "The helix curl causes quite a distortion in the æther and holds a lot of energy. You get 3 helix curls sticking together to smooth things out and reduce the energy. Each helix curl represents a point spinning in a circle. A helix spinning around the X-axis will be attracted to another one spinning around the Y-axis and a third one spinning around the Z-axis. The helix curls can spin clockwise or counterclockwise and the æther can be wrapped around one way or the opposite way. One way is matter, the other way is antimatter."

⊡ "So where do these helixes come from? What are they made of? Are they flexible like the æther?"

⊙̃< "The helixes are imaginary. The æther curls around a helix shape, but there's no actual helix there. The helix curls clump together, the clumps attract and repel each other, form atoms and molecules, those stick together to form roosters and cranky old men."

⊡ "I guess the matter strands stick together because the quark curls bend the æther so much that there is less energy if they stick close. The twisting and turning just goes out from there to trap waves called electrons and give you chemical bonds and so on. How does gravity fit into all of that?"

⊙̃< "The æther can wrap around the helix in one direction or the opposite. One way is matter, the other way is antimatter. Matter causes a slight upward warp between masses in the æther and antimatter causes a slight downward warp in the æther. That makes the long gradual bends in the æther that Einstein discovered to be gravity. In the end, the tiny warped curls of matter lead to huge slow warps in the æther as a whole."

There was sunshine streaming through the open window and Cranky was reminded of his next question.

⊡ "What about light? How does that shine through the universe?"

The rooster was anxious to go out and enjoy the sunshine.

⊙̃< "Come back tomorrow with more lasagna and I'll tell you about light."

Chapter 8

Light

Another day, another portion of lasagna. Cranky wasn't being quite honest with his wife about where all this lasagna was going, but she obliged by preparing another large dish of lasagna and filling up an insulated container for Cranky to take along. The camping tablecloth was disposable and was disposed. Cranky still needed something to control the mess of a chicken and a rooster standing in a dish of lasagna and flinging food all over the place. He had a burlap bag that used to hold green coffee beans. The opening of the bag had a drawstring. He packed that bag to use as a tablecloth and headed to the "office" on his bike.

When he got there, he found the rooster and chicken already waiting for him. The chicken was standing by his computer and the rooster was standing where he knew the dish of lasagna would be set. The rooster seemed excited by the burlap bag that Cranky pulled out and spread on the table. He pulled on the drawstring, shutting and compressing the open end a bit.

⊙̃< "See how there are wrinkly waves in the bag caused by the string closing off one end? You certainly have an educational collection of tablecloths!"

Cranky saw the waves, but mostly he wanted to hear about light.

⊡ "You said that C, the *speed of light* is just the distance of time, the conversion factor between the way I measure distance and the way I measure time. But what I can't understand is why, if it's not just by definition, does light move at that speed. I suppose light is all those scrunched waves stretching between the curls in the æther, something like the waves you just showed me in the bag. But what does it mean for light to *move* and why does it always move at that same speed?"

⊙̃< "You're right that light is just waves in the æther. That's why they used to call it the *luminiferous æther*. It carries the light.

“Just think of drawing a graph in 2 dimensions, with time measured vertically in seconds, and distance measured horizontally in light-seconds. The source of the light is the vertical line at the left edge of the graph. That’s a particle, it lasts a long time but takes up little space. The destination of the light is another particle, the vertical line at the right edge of the graph. If you think of light traveling at speed C, it means the light starts at the lower left corner and follows the diagonal to the upper right corner. Every second it moves the distance of one light-second. But actually the light spreads out in the middle. It leaves the lower left corner at a 45° angle and arrives at the upper right corner at a 45° angle, but the light waves spread out in the middle of the path. In the æther, particles are thin strands but light is not a particle and it’s not a thin strand. It’s not locked into a tight curl and it spreads out in all directions from the sender. The receiver collects the light at a small point.”

“So light ends up following the diagonal but why? Why not some other angle?”

“The source of every *ray* of light is a strand of matter and the destination of every ray of light is another strand of matter. Light just flows out equally in all directions, but then some of it actually gets collected at some destination. Both endpoints are quite similar, scrunching waves in the æther, like the drawstring on the bag. However, the difference is that if you follow the time line, the source is sending the waves and the destination point is collecting the waves.”

“You have light fanning out and getting collected, but why at 45°, why not straight across, following the shortest distance?”

“The burlap bag tablecloth can help explain. Suppose the source of the light is the left edge and the destination is the right edge. The light is actually wrinkled æther caused by source and destination curls of matter wrapping up part of the æther. Where can these light waves fit? Along the time axis, the æther is pulled tight and it can’t be stretched further, just as you can’t stretch the strands of burlap that run from the top of the bag to the bottom. The æther going directly from the source to the destination of the light is also as tight as it can go and can’t be stretched further, otherwise those two pieces of matter would pop further apart. That tight æther is just like the strands of burlap that go from the left to the right side of the bag. But diagonally, the bag does stretch. That’s the direction where the æther is loose enough to get wavy. The light waves just spread out and occupy the loosest sections of æther.”

Cranky tugged sideways on the bag, Cranky tugged vertically on the bag, Cranky tugged diagonally on the bag and sure enough, it stretched diagonally, but not in the directions of the burlap strands. The tension from Cranky’s tugging got distributed across a wide diagonal section of the bag. Perhaps the æther really was enough like burlap to make light go diagonally. It certainly gave a new meaning to *the fabric of space and time*, but Cranky was starting to get skeptical.

□ "So the light coming to us from the Sun is coming in at a 45° angle to our time axis. But since Saturn is moving relative to us, Saturn's time axis is a little bit tilted compared to our time axis and 45° from Saturn's axis is a slightly different angle. When there is light going from the Sun to Saturn, is it going at a different speed than light going from the Sun to the Earth?"

õ< "Yes, the speed of light is C relative to the matter that is receiving the light, but light going to someplace where we are not is not moving at speed C relative to us. We can't see or measure that light anyway because it's not going to us. There are tendrils of matter sending light to each other and they can't send light to us or we to them because the time axes are too far misaligned. Their time axis is skewed more than 45° from our time axis. It's dark matter as far as we're concerned, it's faster than light if you insist on talking about the speed of light."

The rooster always sounded so confident, but the abbreviation of confident is *con*. Was the rooster just messing with Cranky, checking how gullible he was?

Until that point, Cranky had not realized how outrageous the rooster's story was. The speed of light is supposed to be constant. He only then figured out that letting spacetime be 4 dimensional, with no special status for time over the other 3 dimensions, meant throwing out what he thought he knew about the speed of light.

□ "So if Saturn is moving towards us and we look at it through a telescope, is the speed of that light relative to Earth's time axis or Saturn's time axis? Is the light from Saturn coming in faster than sunlight?"

õ< "The fabric of spacetime near the Earth is aligned with the Earth's time axis and the fabric near Saturn is aligned with Saturn's time axis. So the light leaves Saturn at speed C relative to Saturn and arrives at Earth at speed C relative to Earth. Light going to Mars arrives at Mars at speed C relative to Mars."

□ "But that means the light has to be curving."

The rooster explained more:

õ< "Yep, light does not follow a narrow path and the path it follows is not entirely straight. Light gets stretched around curves when the æther is warped. Each quantum that's received has a direction pointing to where it came from. This is a 4D direction and the time component of the direction is always the same magnitude as the distance component. Because the time lines of the sender and receiver are not parallel and because the light is traveling over warped space, the direction at which the light was received does not quite match the direction at which it was sent."

"That's a lot of curved light. All the light coming from far away is coming from stars that are moving away from us really quickly due to the Big Bang."

The rooster actually laughed. It was something in between a crowing sound and a laugh.

"You still believe in the Big Bang and all of space compressed into a single point at the absolute beginning of all time? Today only, I can make you a special deal. You can buy that Bay Bridge out there, half price!

Remember, time is relative. It's just the direction of your strand of matter. The 3 dimensions of space are orthogonal to your time dimension. There is no universal time direction and no absolute beginning of everybody's time. The red shift of starlight is not due to the stars moving away quickly from some huge explosion, it's just because the stars are far away. The light waves get stretched by the warp of gravity the same way they get stretched by the curved path they follow due to Saturn's movement relative to the Earth's movement."

And with that the rooster jumped into the lasagna dish along with the chicken and they started feasting.

Chapter 9

Logic

After the chicken and rooster had eaten enough, it was time to clean up. The burlap bag was somewhat messy with tomato sauce so Cranky washed it out in the sink. To squeeze out the water, he twisted it into a long rope shape. As he kept twisting, the shape became like a corkscrew, a helix. Cranky released the pressure and folded up the bag into his backpack and continued with his questions.

□ “So you say the æther is this warped blob with strands of matter twisted up in it and wrinkles of light connecting the strands diagonally. How did it get there? Who put in the twists? Who made it?”

⊙̃< “It exists just because it CAN exist. As long as it’s a consistent mathematical object, there is nothing to stop it from existing. Think of the number 971. Does it exist? Of course! Who made it? Nobody in particular! Where is it? No place in particular! You could say the same about some number that is huge and mind bogglingly complicated, some number you could never accurately describe in this finite universe. There is nothing to stop it from existing. Mathematical shapes are the same way, *a sphere, parallel lines*, the idea is consistent so the shape exists. Nobody in particular put these shapes anywhere, and you could just as well have hugely complicated shapes in many dimensions.”

□ “But why is the æther the shape it is and not some other shape?”

⊙̃< “That’s like asking why a circle is not a square. It simply is not. However, when you have extra rules, such as saying all the angles have to be the same or all the side lengths are the same, or the curvature has to be the same everywhere, that does restrict what the shape can be. The æther is like that. It is intrinsically flat yet it is warped. It has energy in the bends but it is *locally relaxed*. If you were to change the shape of the æther somewhere, that would increase the overall bending energy. The fact that it is locally relaxed everywhere as well as intrinsically flat is hugely important. That’s why there are physical laws like conservation of energy or conservation of momentum or atomic bonds or light traveling in a straight line or cause and effect in your daily life. The universe is overwhelmingly complex, but because of a few basic rules about geometry and elasticity and energy, things make sense. Logic applies. You can figure out what's in one part of the æther by knowing what's nearby."

Cranky thought a bit about putting the rooster's stories to the test by simulating the æther in a computer program. Set up a mess of points with 4 coordinates for the position and 4 values of how bent the space is in every direction. Come up with a configuration that remains bent and does not unwind itself into a lower energy configuration. It would be like making a 4 dimensional sheet of elastic chicken wire and bending it into the 5th dimension. Unfortunately, using any old coordinate system, there can be a point where space is straight in all the coordinate directions but bent along the diagonals. Figuring out the bending axes is tricky. Perhaps one day he would give the program a try, but today he'd just keep asking questions as long as the rooster was willing to answer.

□ "Since the æther is continuous and relaxed, we can explain the present based on the past, we can explain the future, based on knowing enough about the present. But how can I explain that I'm talking to a rooster and he knows everything about how the universe works?"

Cranky ended up with deep regrets for having asked this particular question. He overcame his feelings of guilt by rationalizing that he could not have known the effect his question would have, but he sure wished he had never asked.

$\tilde{\odot}$< "I'm sorry, there is no way to explain that. You are right, I don't belong here and logically, I shouldn't be here. I need to get back to where I belong."

The rooster gave a long look to the chicken, and Cranky had no idea what it meant. The chicken looked back but did not seem to react. The rooster lay down and stopped moving. At first, Cranky was surprised, then worried, then panicked. He had once learned CPR but just applied to a human mannequin, not a bird, and did not know what to do. He also knew deep down that the rooster would not let Cranky interfere with his destiny. This rooster was dead.

After sobbing a while, Cranky pulled himself together and played *Amazing Grace* on his violin. He realized that he should put the violin away in the (now dry) burlap bag and put the rooster into the violin case. The chicken put what was left of the lasagna into the narrow part of the case. Cranky and the chicken went outside with the case and stopped to pick some wildflowers and add those to the contents of the rooster's coffin.

Cranky followed the chicken to the trolley in the MUNI yard. They both joined in starting a fire under the boiler. Once the coals were really going, Cranky carefully tossed the violin case into the firebox and waited for it to be consumed and turn to ashes.

He sat there for a long time contemplating what the rooster had shown him and told him as they let the fire burn itself out.

Chapter 10

Language

Cranky was trying to digest and make sense of his conversations with the rude rooster.

How come the rooster spoke English? Why did he not use fowl language? Presumably because Cranky would not have understood any of it. When he talked about logic and topology, perhaps the rooster should have spoken German. Cranky spoke German before he learned English. Cranky learned the logic of grammar long before he studied the logic of the foundations of mathematics. Maybe the rooster should have spoken in ancient Greek or in Hungarian or Chinese. Cranky wouldn't have understood, but perhaps he could have recorded the answers and run them through translation software.

Every language has its own words and structures that make it possible to express certain thoughts. Sometimes new words need to be invented or borrowed from a different language. It's hard to think about something without words, or perhaps symbols. Math is full of symbols. They allow mathematicians to communicate, to convince each other, to be precise. They also scare away anyone who isn't sure what the symbol means or can't relate the symbol to anything more familiar. After studying math long enough, Cranky knew and became familiar with a few symbols and eventually forgot again what the symbols meant. What stayed was the confidence that, given some patience, the symbols do eventually make sense, or at least there will be a convoluted story about why they're nonsense. The same goes for jargon, a little less scary than mathematical symbols. The jargon keeps away and turns off the outsiders while helping the insiders understand each other.

That does not mean that language should be or can be or needs to be precise. One of the most powerful bits of language that Cranky ever *read* was the Tao. Cranky did not actually read that. The only words he knows in Chinese are the word for *beer* and a very rude insult. But seeing a variety of translations of the Tao, each with a different interpretation, made the Chinese text more meaningful than if it had been in German or English. The meaning of the text is not precise, it's subject to interpretation and imagination. That makes it even more informative.

Language helps Cranky think and communicate, but people and especially animals can think and communicate without language. Visualizing shapes and motions can be worth thinking 1000 words. Listening to music can communicate more than 1000 words. The wakeup crowing of a rooster is worth a few hundred words. Sometimes language even gets in the way of the truth. People believe the words they hear or read more than they believe what they observe. Cranky had always been extremely skeptical, but now he found himself trusting the words of a rooster.

If the rooster had spoken German he might have used the words *Fläche* instead of *surface*, *Ebene* instead of *plane* and for *warped* he would have said *verdreht* (not to be confused with *gedreht* or *durchgedreht*).
Die Fläche jeder Ebene ist flach, doch verdreht.
In German the surface is obviously flat, being flat is part of its name, but it's also "turned" in some sense.

Cranky had never discussed language with the rooster. It was enough of a puzzle that this rooster, in contrast to every other rooster, spoke at all. All they ever talked about was physics and geometry and pasta.

Nobody would expect the rooster to paint a picture or do a dance or present an image other than his handsome colorful silhouette, or start making music other than his crowing, but what if he had decided to do some of those things besides just talking? Would Cranky even have understood any of it?

Now it was too late. The fire had died out and they left the trolley.

Cranky headed home on his bicycle and the chicken went her own way. It had been a rough day.

Chapter 11

The Record

Cranky thought about the æther of spacetime as the elastic, warped 4 dimensional blob crisscrossed with spaghetti strands of matter with fabric filaments of energy radiating out and stretched between the matter.

Somewhere as a part of all that, was he himself, his entire life, past and future, as was San Francisco, as was the Earth, the galaxy.

To visualize spacetime he would need 5 dimensions, the 4 dimensions of the æther plus another dimension to bend into. How to even begin to understand it?

He was sitting in his 100 year old house drinking espresso from his 60 year old Italian open boiler coffee press. This espresso machine was one of the most perfect pieces of engineering in all of spacetime, but best of all, Cranky felt he *understood* how it worked. He wished he understood how the rooster's world worked.

He decided to listen to music, run his old turntable through some various tube amplifiers through his studio loudspeakers. A collection of obsolete equipment from the last 40 years. The cranky old guy with his cranky old toys. He pulled out a record, Prokofiev violin concertos by Kyung Wha Chung, recorded 1977.

Here was a whole world of sound, some of the best music ever heard, fantastic compositions by a fantastic composer, played by a fantastic soloist with a fantastic orchestra and recorded by fantastic audio engineers. All of it on a round disc of plastic. Actually, the fact that the record is a disc is not what matters. What matters for the music are the grooves in the record, the waves in the 2 dimensional surface of the record. It doesn't matter what the record is made of or what's inside, just the shape of the surface. That surface contains close to an hour of music, rhythms, harmonies, feelings, inspirations, beauty, sorrow, happiness.

Contemplating the surface grooves of the record made the spaghetti curls of the æther more familiar, made it more plausible that such a mathematical structure could hold a human lifetime of experience, a universe.

Another thing about the record is that it does not have a time dimension. In the record, time goes around and around in a spiral and eventually continues on the other side of the record. On a monophonic record, space is perpendicular to time. As the waves in the groove go left and right the needle follows and vibrates, the vibrations get amplified and eventually the speaker cones vibrate and the air vibrates and Cranky's eardrum vibrates and something in his brain vibrates. This record was stereo, so by vibrating the needle along 2 diagonal axes, it could replay 2 dimensional sound.

The record just sits there until someone plays it on a turntable. The music is heard at the spot where the needle plays. There could be a second tonearm and a second listener at a different spot in the music. Someone could make a record that plays two entirely different pieces on the separate stereo channels.

In the æther of spacetime, instead of following record grooves, there are the strands of mass. Each quark is a long thin curl, a locked deformation in the shape of the 4 dimensional surface. The quarks stick together to form protons and neutrons. Those stick together to form atomic nuclei that trap electrons to form atoms. The atoms form compounds, the compounds form objects and gases and the objects might generate pressure waves in the gases playing music.

All these objects still form long thin strands in spacetime. One of these objects is the man we call Cranky. Somehow, there he was, playing the concerto on his record but also *playing* the strands of the object that is his body while experiencing his life.

It turns out that nearby, just outside the window, stood the cheeky chicken, experiencing her life, observing Cranky, listening to the music he played, perhaps even reading Cranky's thoughts.

Do the grooves in the record determine the shape of the record or does the shape of the record determine the shape of the grooves? Perhaps the latter.

However, the long strands of matter in spacetime are all wound up and tugging at the æther and causing spacetime to warp. That's gravity. The strands don't go straight, matter bounces around, but besides that they're going through warped spacetime, warped by all the other matter, even matter that otherwise wouldn't even be noticeable.

The surface of the vinyl record is not elastic the way spacetime is. A record of AC/DC won't just spring into the shape of a Brahms violin concerto because that configuration has less energy. But the æther is bent and curled and knotted by the spaghetti strands of mass and it all settled into the lowest energy shape. The music of the universe was not pressed in by a recording company. The shape is just the result of the æther trying to relax as much as it can. The energy gets distributed as evenly as possible. The bends straighten out as much as they can and that's the shape of the universe. The æther includes the past and future of all the strands of matter that can be played like some sort of recording.

So why was Cranky then and there, experiencing that particular groove in the æther? Why was this cosmic record playing forwards instead of backwards?

Eventually Cranky just fell asleep unable to answer any of his own questions and no longer able to ask the rooster.

Chapter 12

Time

Although Cranky didn't talk with the chicken the way he had talked with the rooster, he was happy to see her around at his office the next day. She seemed to be curious about what he was doing. What he did not realize, is that she was also curious about what he was thinking, and aware of what he was thinking. He of course was entirely unaware of what she was thinking. He gave her cheese and crackers from his lunch and she appreciated the friendly gesture as well as the nourishment. Cranky resolved to bring more lasagna the next day.

One thing Cranky was curious about was the trolley. He went out to visit it and the chicken followed along. But when they got to the MUNI yard, the trolley was gone. Perhaps it had been hauled away for scrap. Cranky had no idea but decided to at least ride one of the regular streetcars. They walked over to the T line and took a train towards downtown. A few people seemed to disapprove of his *companion animal* and eventually the driver made them get off. They got onto the next F train and nobody seemed concerned that a chicken was riding along.

At Powell St. they got off. Cranky had decided to ride the cable car. The electric trolleys were simply not exciting anymore after riding the steam powered one. There was a shop there that sold kitchen supplies and Cranky decided to buy a colander. He had realized that asking his wife to cook more and more lasagna every day would be problematic. The office workspace had a sink and a hotplate and a cooking pot and he would cook in the office.

There was a long line of tourists waiting to get onto a cable car and Cranky with the chicken joined the line. It was a rare clear day and the sun was beating down on Cranky's bald head, so he put on the colander as a hat. The chicken was tired of worrying about being stepped on so she jumped up and sat on top of the inverted colander. It was all just part of the show, part of the *San Francisco experience* for the tourists.

What Cranky was wondering about was the direction of time. Why does it go forward and not backward? Looking into the tangled spaghetti of the æther, how could you distinguish forward from backward time? One difference was the light rays. The incoming rays actually had less energy and lower frequency waves than the outgoing rays. That was the red shift. Also the outgoing light goes out in big quantities from a single source, basically a star, but is received in small quantities in lots of places such as the eyes of people standing on planets. The incoming light is not focused and concentrated the way the outgoing light is. Overall, as time advances, energy is getting spread around. Entropy is what gives a forward and backward direction to the time axis associated with each cluster of matter.

Besides entropy, time is also tied up with observations. Physicists were saying that nothing is real until it's observed. But you can only observe the past, not the future. Then you can record the observations, in your brain, on paper, even the sun aging your skin is a kind of observation of light that your skin is recording. The moon observes meteorites and records the memory as craters. The past is what's been observed and recorded or might have been recorded. The new and unknown future is where time goes.

Cranky wondered about the beginnings and ends of these timelines. As the line gets longer, the energy gets more and more dissipated until the timeline no longer has a clear forward or backward direction. Perhaps some force then acts on all that matter and compresses it and concentrates the energy, but that would amount to time running the other direction along that line. The beginning of the timeline would be a highly concentrated bundle of energy. Possibly some sort of little bang? The rooster had mocked the big bang, but perhaps the æther supports a whole bunch of little bangs? Maybe such spots of minimum entropy are the *ore* buried in the æther?

Eventually they got to the front of the line and the chicken jumped onto the roof of the cable car and Cranky got to hang off the side, standing on the running board. The underground cable pulled them up the hill and they got off at the cable car museum. Cranky was not just there to enjoy the ride, he also wanted to see how it all worked.

The big motors in the basement were very impressive. They used electricity generated at a dam in Yosemite Park to pull the cables for all the cable cars in San Francisco. The electricity had been transmitted across California in wires by electromagnetic waves. The turbines generating the electric power got their energy from gravity pulling water out of the Hetch Hetchy Reservoir. The lake was filled with water that had evaporated off the ocean due to sunlight. Energy was being dissipated in amazing ways.

So went their day, being tourists and spending the time thinking about time. By the end of the day Cranky had less energy than in the morning, but the chicken had more observations than she had that morning.

Cranky decided that observation was as important as logic in understanding the world. Imagination and skepticism and hubris were also important. He would think about imagination later.

Chapter 13

Consciousness

Cranky was lying in bed, thinking, or daydreaming, however you want to put it.

He wondered how he was *playing the record* of his life, his experiences, while his consciousness mysteriously followed some strands of spaghetti in the æther. It certainly did not seem like he was being pulled by a cable along some cape gauge tracks in the pavement or some groove in a vinyl record as he was going about living his life. It did not seem like his choices and decisions were already engraved in the æther before he got around to making these choices or decisions. On the other hand, suppose he went through life making choices in some entirely unpredictable perhaps random way, and that somehow got recorded. Would the replay of the experience feel any different from the original experience? Is there actually any freedom in randomness? Mostly freedom of decisions meant that Cranky acted based on his instincts, his experiences, his morality, with no interference, including no interference from some random process that would lead him to do one thing over another.

What was his morality even trying to accomplish? What was a *good* deed and how was it different from a *bad* deed? The deed might be selfish, but what's wrong with that? He needs to eat, he needs to stay away from harm and if nobody else is harmed, that seems totally good. That sort of selfishness is not even about morality, it's his instinct. Millions of years of evolution favored the choices and decisions that were good for *him* and weeded out the decisions that would be bad for his survival. If his instincts were leading him to destructive choices, he wouldn't be here. His ancestors would have ceased to exist long ago. But his morality is not just about him, it's about his family, his neighbors. Again, if morality is inherited or somehow passed from generation to generation, and this morality is destructive to his family or his society, he wouldn't even be here.

His being here also depends on the choices made by others. Not just other people, but even his own cells. If his immune cells chose self preservation over combating viruses, he wouldn't be here either. Bad for him, bad for his cells, bad for his family, bad for his genes. His decisions are not just good or bad relative to himself as the man Cranky, but relative to his genes, relative to his society, relative to humanity, relative to life on earth. He is not just an individual man, but a human, a life form, and his decisions might affect the survival of all these aspects of himself.

Do these other aspects of Cranky also have consciousness? He's pretty sure other people have consciousness, the chicken has consciousness, his pet bearded dragon has consciousness. Do plants have consciousness? Does a single cell have consciousness? Are there parts of his body that are individually conscious? Is there a collective consciousness of the people he's related to? Does humanity have a collective consciousness? Does life have a collective consciousness? What would an expanded consciousness even feel like? Perhaps some day he would find out.

In any case, the choices he made, his values, his concepts of good versus evil, were relative to himself. But that *himself* was not just a single man with a conscious brain, it was himself as part of humanity, himself as a carrier of certain genes, himself as a father, as an American, as a lifeform.

That led Cranky to consider religion. In particular, what was the rooster's religion? Given that he talked about spaghetti a lot, probably Pastafarianism. Perhaps he was an animist, perhaps he believed in animal spirits infusing the world around us and affecting the way things happen. That pretty much described the rude rooster himself, so how could he not believe in that? It did seem to be the case that what the rooster said about the world was compatible with quite a lot of varied religions. There certainly could be a creator who pays close attention to what we're doing and might help us out or get mad at us. Following the strands of existence backwards, there certainly seemed to be ancestor spirits subtly controlling us and our environment.

At that, Cranky's consciousness changed to sleep. If he dreamed, he was not aware of it and neither was the cheeky chicken who was sitting on the roof just above Cranky's bedroom.

Chapter 14

Infinity

How big is the universe, wondered Cranky? He was back in the office and cooking pasta for the chicken. Lasagna was too complex for a cranky old man, so he was cooking angel hair pasta. The chicken just sat quietly and patiently watching him.

There is a limit to how far light can travel before it gets bent so far that it's no longer light. When light gets bent by gravity, there is a horizon past which things are hidden. If gravity is stronger, this horizon is closer. If the gravity is strong enough, you get a black hole.

Suppose you are near the black hole at the middle of the Milky Way Galaxy. As you move farther away, the gravity of the stars orbiting around the black hole adds to the gravitational attraction you feel towards the black hole. When you get far enough away, that gravitational force is from the entire galaxy as well as the black hole. Anything trying to reach you from the center of the galaxy has to overcome all that gravity. That includes light from the center of the galaxy; the hole appears larger and more black.

In the opposite direction, the horizon of the farthest-away stars you can see is receding. More and more of the far away stars appear at the horizon. As you continue to go away from the center of the galaxy, perhaps away from our cluster of galaxies, what happens? Does the horizon just keep receding? Do you stare into some starless flat infinity? Do you get to the land of antimatter where everything is opposite and backwards? Do you somehow get back to where you were, approaching from the other side?

If you go back to approach the black hole, do you ever bump into the fearsome monster ball that you see in science fiction movies? Does the hole just keep receding as you wander into some sort of wormhole as described in other science fiction stories? Or does the hole just get smaller until it's no longer black, just a dip in the gravitational shape of the universe? Unfortunately, the rooster was no longer around to give an answer.

Cranky got back to wondering about the infinity of numbers, something he had pondered back when he was a mathematics student. Can you really say there have to be infinitely many numbers because you can always add 1? At some point the numbers are so big, you have no way to describe certain specific numbers or destinguish them from all other numbers. You can be very specific about certain huge numbers such as $2^{2^{100}}$ but you can only be vague about some of the numbers smaller than that. You could think you're counting forward and end up where you were before. What would the rooster say to that?

They shared the pasta and it was very nice, with pesto. The chicken was a much neater eater than the rooster, but it was just not the same, just not as much fun, with the rooster gone. After lunch, Cranky puttered around a bit on his computer. Then he left on his bike and the chicken went to her nest in the scrapyard.

That night the chicken was standing at Cranky's laptop computer after everything was quiet in the office. The computer had a few specks of pesto on it and some of the keys that never really worked very well had beak marks from being pecked too hard. There was a document open and it was complete except for the last chapter. Other than that, the computer was just the way Cranky had left it earlier that day.

Soon the manuscript would be finished for Cranky to find once he got back to his work. It was the chicken's goodbye present and record of their visit, to help Cranky understand and remember her and the rooster. It was the chicken's thanks for the pasta meals.

By the time Cranky sat back down at his computer, the chicken would be long gone, having flown out the window one last time, flying not to the scrapyard, but up toward the sky in long spiraling circles, higher and higher until she was no longer visible from the ground.

Cranky's Geometry Epilog

It has been a few years since the chicken and rooster disappeared. My ideas of physics will never be the same, but I wish they were less vague. What was the rooster really trying to tell me?

Most of what he said contradicts accepted *science*. Why should anyone believe anything the rooster said? The heretical assertions include:

• There is a *luminiferous æther* after all, in fact, it is *omniferous*. Light, matter, forces, energy are all *carried* by the æther.

• Time is just one of the 4 dimensions of spacetime and the local direction of time is relative to each strand of matter in the æther.

• The æther is 4-dimensional and elastic but also Euclidean and *intrinsically flat*. All matter, energy and forces are just *extrinsic* surface curvature of the æther.

• Light leaves and approaches the matter that sends and receives it at speed C relative to that matter. There is no absolute speed limit for light because there is no absolute direction of time. The constant C is just the conversion between units of distance and units of time.

* If point A is moving relative to point B, light emitted by A and received by B curves so that it leaves A at speed C relative to A and approaches B at speed C relative to B.

* Light going from point A to point B travels at speed C relative to A and B but relative to point D that speed might seem higher or lower than C.

* Light traveling through space is redshifted by the curvature of the gravity warp.

• Quantum effects are deterministic yet chaotic. There can't be a "*simultaneous* quantum collapse" because the direction of time within the æther is relative to each strand of matter so there is no absolute simultaneity.

These assertions are intertwined and should somehow fit into a geometric model that can be checked against physical observations.

As the chicken correctly observed, I've forgotten most of the math I ever knew. However, I know how to look up concepts on the internet and avoid panicking at the jumble of symbols that appear as soon as someone writes about *differential geometry* or *Riemann surfaces* or *general relativity.* Not panicking is fine, but better yet would be to actually understand what the heck the symbols are supposed to mean. What I can try to do is use the notation and the accumulated wisdom of mathematics to make the rooster's answers more specific and check that they fit together consistently. If the rooster is not contradicting himself, someone can then check if he's contradicting the observations of physical reality.

First of all, there is 4-dimensional Euclidean space. It's *intrinsically flat.* The extrinsic curvature can only be sensed or measured by sensing or measuring the energy or forces of this curvature. Since I myself am made of curvature energy, I interact with the extrinsic curvature, but geometrically there is nothing unusual to see *within* these four dimensions. There are parallel lines. The angles of a triangle always add up to 180°. To learn more, it's necessary to imagine stepping outside of the æther, to form some sort of geometric model that is bent into a 5th dimension. However, just a 5th dimension is not nearly enough. To explain the complexity of energy and mass in the æther we need to warp it into multiple additional dimensions. Consider a one-dimensional curve spiraling around in three dimensions. The geometric possibilities for such a curve are many more than for a curve restricted to stay within two dimensions.

Is the æther infinite in all directions? The rooster did not say. Mathematically it could be a huge cylinder. It could be cylindrical in all directions and every straight line eventually circles back on top of itself and has a finite length. Depending on the direction, the line would be shorter or longer, but always finite. "In which direction do you get the shortest line?" It's certainly far easier to assume space is infinite than to try to ponder questions like that. Occam's razor says the æther is infinite.

Is the curvature always finite or can there be a singularity in the æthereal warp? Again, the principle of mathematical simplicity makes me prefer a model without singularities.

To study the æther geometrically, it's standard to pick a coordinate system with axes in four directions, x, y, z, t. Every point in the æther has some coordinates (a, b, c, d). The goal is to come up with a mathematical or a computer model of some significant but not overwhelmingly complex part of the æther, perhaps a hydrogen atom.

The more we can translate the geometric constraints into mathematical formulas, the easier it is to create a model.

At each point the æther has some amount of curvature that the rooster insists on calling *warp*. The warp varies depending on the direction. The most familiar example is a 2-dimensional surface embedded in 3 dimensions. At each point in each direction, the conventional concept of curvature is just a number. When the surface is *intrinsically flat*, the curvature at every point has to be 0 in one *principal* direction and the maximum magnitude of curvature at the point occurs in the orthogonal direction. No stretching is allowed and that means no point is surrounded by a bowl or a saddle shape. That is Gauss' *Theorema Egregium.*

To visualize some of the possibilities, consider the 2-dimensional case of a corrugated roof lying flat in three dimensions. On this surface there are parallel lines of maximum curvature, coinciding with the peaks and valleys of the corrugation. The slope at those maximum or minimum elevation points is 0 and the slope is greatest in the slanted sections right between those lines. Someone could roll up the corrugated metal and the positive curvature in the low elevation valleys becomes just a bit greater than the magnitude of the negative curvature at the peaks. That additional curvature makes the whole sheet wrap around and around. If we put a coordinate system onto the corrugated sheet, lining up with the corrugations, the curvature in the x direction is not very different in the two cases, perhaps $\mathcal{K}_1(x,y) = \sin(x)$ vs. $\mathcal{K}_2(x,y) = \sin(x) + \epsilon$. Also note that the direction of the curvature (up vs. down) is different from the perspective of being embedded in the geometrically flat sheet of steel compared to observing the roll of steel we see in 3 dimensions. When the roll is viewed externally the "top" surface of the sheet might be pointing up, down, sideways, depending on which point is considered.

Those curvature functions arise as the derivatives of slope and elevation functions $\mathcal{S}_1(x,y) = -\cos(x)$ and $\mathcal{E}_1(x,y) = -\sin(x)$ for the unrolled version compared to $\mathcal{S}_2(x,y) = -\cos(x)+\epsilon x$ and $\mathcal{E}_2(x,y) = -\sin(x) + \frac{\epsilon}{2}x^2$ when rolled up. The elevation $\mathcal{E}_2$ in the rolled-up case gets really large when the x coordinate gets farther from the origin. The elevation and the slope do not correspond very well to the height or angle of the roll when looking at it within 3D space.

It is also instructive to check what a "straight" line on the corrugated sheet looks like in 3D. Assume someone drew a straight line on the sheet before it got bent into that corrugated wave pattern. The line runs diagonally to the corrugations. When we look at the corrugated sheet, laid flat except for the corrugations, from our 3D perspective the line waves up and down but it also waves side to side. The direction of the line at the peak of a corrugation does not quite point at the segment of the line at the next valley or the next peak. This line not only has curvature but also *torsion* in the 3D space. We might set coordinate axes aligned with that diagonal line and crossing in the valley of a corrugation. Then the vertical curvature along both axes is positive, but the axes also have torsion in two opposite directions. With diagonal coordinate axes on the surface, the warp is a combination of the vertical curvature and torsion. However, a line that is parallel to the corrugations has no torsion and remains straight when viewed in 3D. A line that is perpendicular to the corrugations curves up and down but also has no torsion in the 3D embedding.

Another interesting feature of an infinite and *intrinsically flat* 2D sheet is that any warp or bend at one point constrains what the warp can be at other points arbitrarily far away.

The rigidity of the space dictates the edge lengths and angle measurements not just of small triangles but also huge triangles. All the 0-curvature lines have to be parallel. If we can measure a nonzero warp at a single point, that measurement says something global about the shape of the 2D space. One way to try to model the action-at-a-distance effect of local curvature is to start at one point and *develop* the Euclidean metric along the surface, carrying along constraints as the shape expands outwards.

A way to help visualize a 2D flat sheet warped into *two* external dimensions is to consider a curve in three-space and think the time dimension as another space dimension. The curve could be something that looks 3-dimensional like a helix or a knot. The idea is that as time passes for the curve, the area that is swept out stays Euclidean with no stretching. One example is an analog to the corrugated sheet where the cross-sections are helices instead of sine waves.

It is hard to visualize more dimensions than a 2D sheet in 3 dimensions. One way to see further possibilities is to just consider a ribbon in 3-space. If the ribbon were extended to be wider, the model would encounter singularities in the curvature, but these singularities can be avoided if the embedding space has more than 3 dimensions.

Now let's try to be mathematically precise about the warp at a single point in the two-dimensional case.

According to linear algebra and differential geometry as presented in textbooks, at each point and in each direction there is some curvature κ which is a real number. At any particular point $P = (a, b)$ we can rotate and shift the coordinate system so that P is at $(0, 0)$ and each coordinate axis points in a direction of maximum or minimum curvature at P. Using those coordinates, the *principal curvatures* at P are κ_x, κ_y. When the plane is intrinsically flat, the product of the principal curvatures has to be 0 but it is interesting to show the equations without that assumption.

Suppose we have a vector $\vec{v}_\theta$ starting at P and rotated at angle θ from the positive x-axis toward the y-axis. The curvature along $\vec{v}_\theta$ is
$\kappa_\theta = \kappa_x \cos^2(\theta) + \kappa_y \sin^2(\theta)$

The vector also has *torsion* at P given by
$\tau_\theta = (\kappa_x - \kappa_y) \sin(\theta) \cos(\theta)$

Furthermore, the vector $\vec{v}_\phi$ perpendicular to $\vec{v}_\theta$ (where $\phi = \theta + \pi/2$) also has curvature and torsion
$\kappa_\phi = \kappa_x \cos^2(\phi) + \kappa_y \sin^2(\phi) = \kappa_x \sin^2(\theta) + \kappa_y \cos^2(\theta)$
$\tau_\phi = (\kappa_x - \kappa_y) \sin(\phi) \cos(\phi) = -\tau_\theta$

Note that $\tau_\theta \cdot \tau_\phi + \kappa_\theta \cdot \kappa_\phi = \kappa_x \cdot \kappa_y$ no matter what the angle θ is.

Now assume the case of a 2D sheet embedded in 3 dimensions with $\kappa_y = 0$. The curvature

κ is in a direction outside of the 2D sheet, call it d_1 and the torsion is a parameter ρ. If we graph the (torsion, curvature) points for all the values of θ on the $\rho \times d_1$ plane we get a nice circle with diameter κ_x passing through $(0,0)$, $(\frac{\kappa_x}{2}, \frac{\kappa_x}{2})$ and $(0, \kappa_x)$.

We can say the surface is flat if and only if for every two perpendicular lines, crossing at P, the dot product of the vectors $(\tau_\theta, \kappa_\theta)$ and (τ_ϕ, κ_ϕ) equals 0 in the $\rho \times d_1$ space. That avoids the need to mention the maximum and minimum curvatures.

Now what happens when our two-dimensional sheet is warped into two additional dimensions d_1 and d_2 instead of just one? At each point on the plane in each direction the curvature is now a 2-dimensional vector, a pair of numbers. The torsion also becomes 2-dimensional, so we get 4-dimensional warp vectors in $\rho_1 \times \rho_2 \times d_1 \times d_2$ with parameters $(\tau_1, \tau_2, \kappa_1, \kappa_2)$.

Consider some examples. First we can imagine the surface is "flat" when curved into dimension d_1 and also "flat" when curved into dimension d_2 and these curvatures are "stacked" and rotated by a quarter turn: At the origin of the coordinate system, in the direction of the x-axis we have curvature purely in the d_1 direction, $\kappa_x = (1, 0)$. In the y direction we have curvature purely in the d_2 direction, $\kappa_y = (0, 1)$. The combined torsion is greatest along the diagonal directions.

As another example we figure that "bowl curvature" in one external dimension can cancel out "saddle curvature" in another external dimension: Let the curvature in the d_1 direction be constantly 1 in all directions, forming a bowl shape in the d_1 direction. The d_1 curvature is not accompanied by torsion. Let the curvature in the d_2 direction form a saddle shape by being 1 in the direction of the x-axis and -1 in the direction of the y-axis. This d_2 saddle curvature is accompanied by torsion in the diagonal directions.

Those two examples are actually the same when we transform the external d_1, d_2 coordinates. Rotate the d_1, d_2 axes by $\frac{1}{8}$ turn and stretch by a factor of $\sqrt{2}$. The dot-product of the warp vectors associated with any two orthogonal directions in the plane gives 0.

In general the principal (maximum) directions of the two external curvatures need not be perpendicular. There will be some amount of torsion in all directions.

Moving on from 2-dimensional examples, what might the 4-dimensional warped æther look like? It's a 4-dimensional flat Euclidean space in dimensions x, y, z, t with warp into four external dimensions d_1, d_2, d_3, d_4. The choice to have 4 dimensions of curvature is so that there can be 4 mutually orthogonal warp vectors corresponding to each of the x, y, z, t directions at points in the æther. If we add more external dimensions, it is harder for the space to be locked in an energy minimum, as in the rooster's example of the violin string. It is stuck in the ∞ shape only as long as it can only curve in one dimension. So having more than 4 dimensions to curve into makes it less likely for the space to support *locked curls* and having fewer than 4 dimensions to curve into restricts the complexity of the shape.

Analogous to the 2-dimensional case, the local shape at each point is represented by considering 4 orthogonal directions with mutually orthogonal warps of various magnitudes. We can orient this coordinate system arbitrarily, but in general it is impossible to align it with *principal* directions in which the there is no torsion.

The *Theorema Egregium* carries over to higher dimensions as the **Orthogonal Warp Principle**. Given a point and a line through the point, the line has curvature and torsion at that point. The curvature and torsion are vectors and their sum is the *warp*. The principle states that in a Euclidean space, orthogonal lines through the point have warps that are also orthogonal. Although warp is more complicated than principal curvature, it has the advantage of being omnidirectional.

When we move in some principal curvature direction the path might twist a bit and the principal curvature takes a turn. The 2-dimensional example is a cone where as we follow the direction of maximum curvature we trace out a circular arc. For a given cone the radius of this arc is proportional to the cone's curvature radius along the arc. We'll use the term *curvature field lines* for these paths of principal curvature. At each point in the æther there are perhaps 4 curvature field lines intersecting at the point and these lines can be curved. If we allow more than 4 external dimensions we get more curvature field lines.

To understand shape of the æther, the paths of these curvature field lines are interesting. Each one is a curve that can be characterized just like any other curve embedded in 4 dimensions. This curve has curvature, torsion and further directional derivatives. As seen in the example of a cone, the field line curves when there is a change of warp in the space surrounding the field line. The mixed partial derivatives of the principal curvature determine the curvature of the field lines. Figuring out the constraints between all the various derivatives of the warp seems pretty hairy but undoubtedly there are some nice equations to be derived.

For the overall shape of the æther, what is also relevant is the *energy* of the warp. A line at a point has warp $\vec{\omega}$ and the energy of that warp is $\vec{\omega} \cdot \vec{\omega}$. To get the energy at a point in the æther, add the warp energy of 4 mutually orthogonal lines at that point. Fortunately, it does not matter which orthogonal frame is chosen. However, there will be certain orthogonal frames that minimize the torsion energy and maximize the curvature energy. Following the directions of maximizing curvature energy we can define *energy field lines*. These energy field lines have the nice property of being perpendicular to each other at each point.

The energy field lines curve within the æther based on the directional changes in the warp. Besides the energy from the magnitude of the warp, it seems that there is also energy associated with changes of the warp. With 4 dimensions we have 16 directional derivative vectors $\vec{\delta}$. It might make sense to sum up the 16 values of $\vec{\delta} \cdot \vec{\delta}$ to get a *warp-change energy* that is also minimized in the æther.

According to the rooster, the overall shape of the warped æther is determined by a combination of the constraints of intrinsic flatness and energy minimization. This energy is minimized so that any local deformation of the 4D space would increase the energy. The warp does not flatten out entirely because some *locked curl* shapes form a local energy minimum.

It is hard to visualize the shape of a warp of a 3D or 4D space but we can consider the warp of a 2D slice of the space. Even that is not easy to visualize since the slice is warped into several external dimensions, not just the single familiar third dimension. Besides up-and-down deformation we can have turning, analogous to a 1D curve embedded in 3 dimensions. The rigidity of the æther means that localized deformation into the external dimensions affects the shape of the æther far away. Alternately consider a straight line within the æther. Visualize its curvature and torsion in the 8 dimensions of the embedding space to get a sense of the hidden complexity of the flat Euclidean æther.

For the locked curl, the rooster suggested the helix shape and the chicken wrote about wringing a wet burlap bag into a twisted spiral that balances the twisting forces against pulling forces. Another geometric inspiration is a smoke ring; smoke swirling around a torus shape. The geometric challenge is to make a model of such a twisted-locked-curl-helix, then expand that model to include more helices. If the total energy goes up when the helices are put closer to each other, the model says they repel each other. If the energy goes up with the helices farther from each other the model says they attract. Since the warp of the helix will pinch and ruffle the surrounding space, the model will include corrugations (light) and large-scale bends (gravity) in the æther due to the wrapped helices deforming the space around them.

The rooster also said that 3 helices (quarks) stick together to minimize energy. What that looks like in a geometric cross section is 3 points (or perhaps 3 donuts) spinning around each other. In fact, when following the familiar geometry of 3 directions of space with the orthogonal time direction, the points are spinning around faster than the speed of light. The movement is not just fast, but with 3 points all attracting and orbiting each other, the movement is also chaotic. A mathematical model cannot precisely predict how this twisted strand interacts with all the other twisted strands without simulating all the details. Even when the world is deterministic there is no algorithmic shortcut to make it predictable.

So far that's all I know about the geometric model of spacetime.