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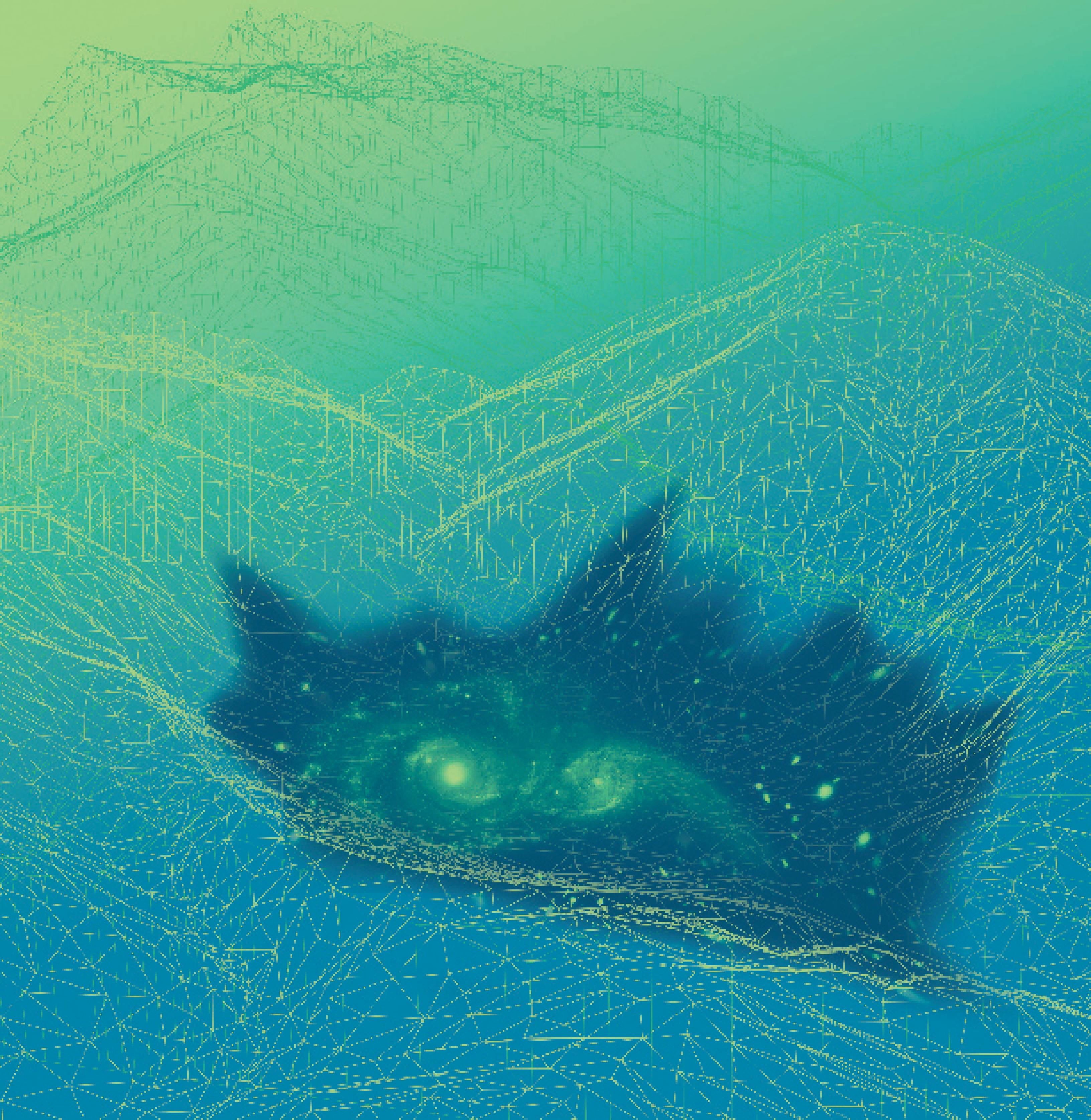
Genius I.Q. Not Required



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(m)agazine started as a project for Visualizing Physics, a required course in Minneapolis College of Art and Design's Bachelor of Science in Visualization program. It quickly grew into a collaboration between a dedicated team of Visualization students and Dr. Mikhail Shifman of the William I. Fine Theoretical Physics Institute at the University of Minnesota. We are very pleased with the final product. We hope you are too.

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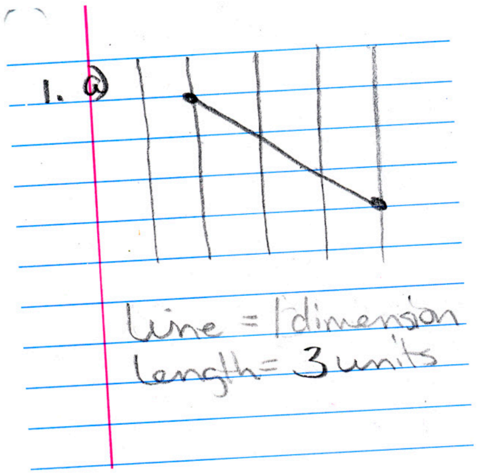
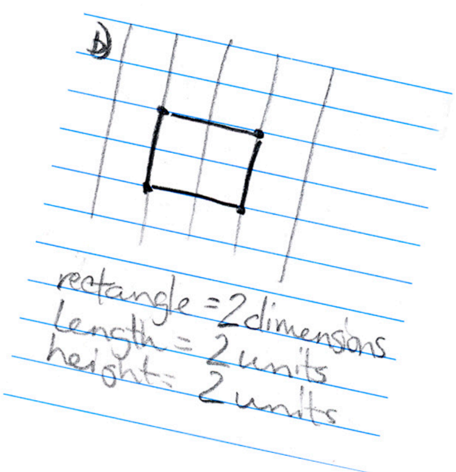
Genius I.Q. Not Required

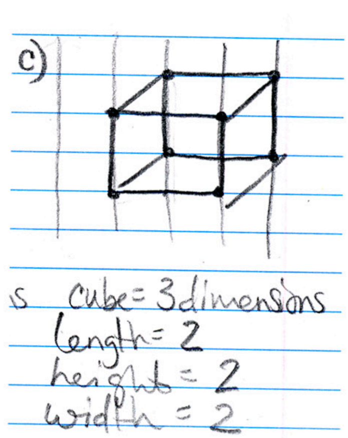
Dealing with

Dimensions

by Courtney Davis







Let's begin with what we know. As many of us remember from fourth grade geometry class, a square has a length and a width. These are two dimensions; therefore, a square is two-dimensional. By at least the sixth grade, we all became familiar with the third dimension, height, and could then draw a cube. So, we can be certain that length, width, and height make up the three spatial dimensions. If time is a fourth dimension, where do these crazy string theorists find six more dimensions?

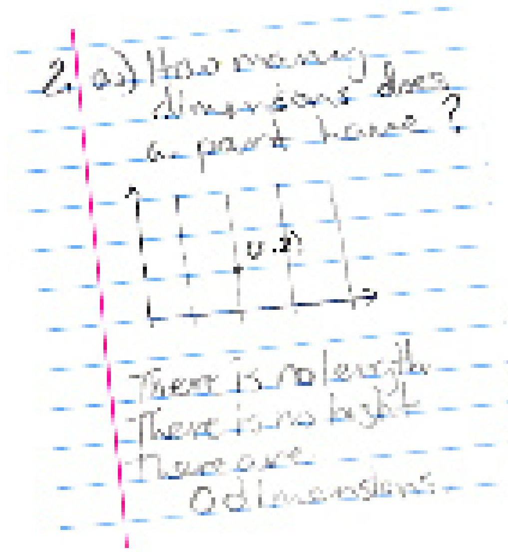
The truth is, it is difficult for most of us -- including many string theorists -- to imagine a world made up of extra spatial dimensions, but the idea of string theory is impossible without them. The mathematics behind the theories depends on at least 10 dimensions, 11 in the unifying "M-theory". If this is even possible, what could these extra dimensions possibly be or mean, and where are they? Is this a concept so abstract that humankind is simply unable understand? And, just how outrageous is the idea of extra dimensions?

For some, the idea of extra dimensions is not so absurd. In fact, mathematicians use extra dimensions all the time to solve complex equations, which may have no solution otherwise. When it is propose that these dimensions actually exist, however, the idea becomes absurd again. This is evident as early as the turn of the 20th century, when mathematician Theodor Kaluza, propose that there may be a fourth special dimension.

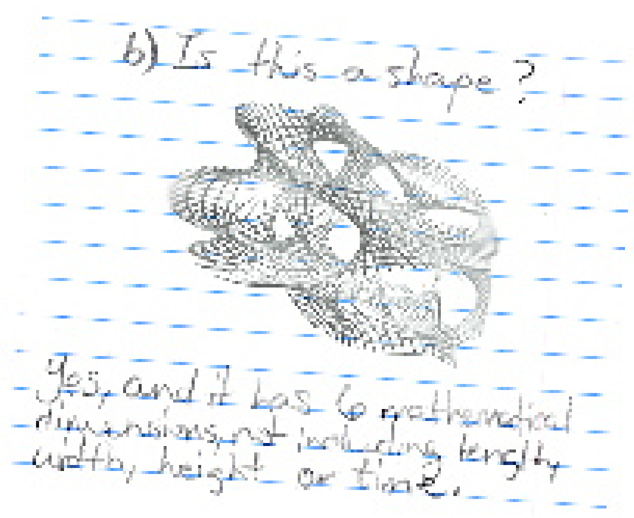
According to Kaluza in 1919, this fourth dimension might be the missing link between general relativity and electromagnetic theory. This idea proved to be radical for the time, yet only several years later, another mathematician named Oskar Klein, supported and elaborated on Kaluza's idea. Oskar stated that space was made of extended dimensions, which are those three special dimensions we are familiar with, as well as curled-up dimensions. In Klein's idea, these curled up dimensions can be thought of as a circle, nestled deep within the extended dimensions. The Kaluza-Klein theory of curled-up dimensions did not prove to unite the theory of general relativity and the electromagnetic theory, but the idea of extra dimensions left a huge door open for today's string theorists.

Accepting the Kaluza-Klein theory of a fourth spatial dimension (a fifth dimension when time is considered), means that at least five more dimensions are hidden somewhere according to string theorists. Consider now, that the fourth spatial dimension is a sphere instead of a circle. This adds three more dimensions, since we all agree that a sphere is three-dimensional. We are now up to six special dimensions. Is there a shape that has more than three dimensions? Conveniently for string theory, such six-dimensional geometrical shapes have been described. The mathematicians behind this finding are Eugenio Calabi of the University of Pennsylvania and Shing-Tung Yau of Harvard. When these six-dimensional Calabi-Yau shapes take the place of the spheres inside the curled-up space dimensions, ten dimensions become possible. However, this only brings us back to our first question,

How can we live in a world of extra dimensions that we cannot see or comprehend?



In fact, mathematicians use extra dimensions all the time to solve complex equations, which may have no solution otherwise.



In Search of
Supersymmetry

by Leigh Simmons

Yuri Golfand

Bruno Zumino

Julius Wess

Imagine a world that contains only two types of people – Green and Blue. Green people like to assemble into large crowds, sometimes standing on top of other Greens. They hate being alone. Blue people, on the other hand, prefer to keep a friendly distance from other Blues. These two types of people have nothing in common, it seems. Until one day, when scientists from both groups realize that some equations point to a bizarre and startling new idea: when a Blue person enters the world, there is also a hidden, massively heavy Green person, and vice versa.

The scientists call these unseen opposites "superpartners." The math looks great, but there's no experimental proof. The only way to get that proof is to take billions of Blue people, and slam them together at almost impossible speeds. These collisions break the Blue people into bits, and at a high enough energy, should briefly produce a Green superpartner, also known as an S-Green.

Perhaps this seems like a plot to another absurd sci-fi story or an incomprehensible animé film. However, enter the world of high-energy physics, and superpartners to fundamental particles – the bits that make up atoms – just might exist. The theory is called supersymmetry, or SUSY, and has engrossed physicists worldwide for more than thirty years. In fact, Ed Witten, a leading string theorist, calls the search for SUSY "one of the biggest adventures of all."

> "Supersymmetry, if it holds in nature, is part of the quantum structure of space and time."
>
> - Ed Witten

To understand supersymmetry, we must first understand what scientists call the Standard Model of particle physics. According to the Standard Model, there are two basic types of particles – fermions and bosons. Generally, fermions make up matter. Electrons are a good example. Because fermions have an internal spin of - 1/2, they obey the Pauli exclusion principle. In other words, like the green People, they cannot occupy the same space. Bosons, on the other hand, are generally the particles that distribute the forces. Think gravity or light. Because bosons spin differently than fermions (some of them do not spin at all), they are free to clump together just like the Blue people love to do. The laser operates on this principle by concentrating untold billions of photons, the carrier particle of the electromagnetic force, part of which is the light we see.

So what exactly is supersymmetry? In very simple terms, SUSY says that for every fermion, there is a massively heavy boson counterpart, or superpartner, and vice versa. Physicists discovered supersymmetry back in the 1970's while studying string theory equations and Poincaré algebra. In fact, even though SUSY exists independently of string theory, having real evidence of SUSY may indicate that experimental validation of superstring theories is possible. So far, scientists have not been able to observe SUSY in nature. The superpartners are too heavy and do not last long enough to measure. The only way to measure them is to actually create them. Unfortunately, the particle accelerators currently in existence don't have enough power to produce the heavy SUSY particles. That might change when the LHC, or Large Hadron Collider, at CERN in Switzerland goes online in 2007.

The implications are staggering if SUSY is found at CERN. Indeed, Ed Witten said it best::

"Supersymmetry, if it holds in nature, is part of the quantum structure of space and time. In everyday life, we measure space and time by numbers, "It is now three o'clock, the elevation is two hundred meters above sea level," and so on. Numbers are classical concepts, known to humans since long before Quantum Mechanics was developed in the early twentieth century. The discovery of Quantum Mechanics changed our understanding of almost everything in physics, but our basic way of thinking about space and time has not yet been affected.

Showing that nature is supersymmetric would change all that, by revealing a quantum dimension of space and time, not measurable by ordinary numbers. ... Discovery of supersymmetry would be one of the real milestones in physics."

Near Simultaneous Discovery:
Three teams of scientists discovered supersymmetry independently. Because of the isolation of the Soviets from the West, it was some time before the world was aware that Golfand and Likhtman were the first to glimpse the supersymmetrical world.

1971 - Yuri Golfand & Eugeny Likhtman
Moscow, USSR

1972 - Julius Wess & Bruno Zumino
CERN, Switzerland

1973 - Volkov & Akulov
Karkov, USSR

Short Fiction

Elementary Stuff, Really...

by Katy Smith

I've been a freelance Journalist working in New York City for about two years now. When most people think of any "freelance" occupations, the first words that come to mind are usually ones like "artsy," and "cutting-edge." After you've been at it for even a few months, you find that the more accurate terms sound more like "cold," and "starving." I was usually hired to write stories for independent magazines and small, underground newspapers in The Big Apple that often concerned reviews for new, bizarre forms of barely-listenable music that the group swears is the "hottest thing in Europe."

When the phone rang and echoed off the walls of my enormous drafty apartment, the first thing I thought was, "oh, Gods, here we go again... another pretentious Independent film or ear-bleeding album to sit through." I barely managed to crawl across the room from my mattress and pick up the phone. I held the earpiece a good six inches away from my head; my temples were pounding from a night on the town with the press team from my last assignment, and it showed in my voice.

" 'ello? Yuh, this's Jonathan... Scientist... mmhm. Lemme getta pen. Got it. No, no. Be quiet. Let me alone... I need sufficient sleep and a slew of painkillers before I tackle a story of this kind... yes, thank you, goodbye."

This was going to be a completely different assignment. On the opposite end of the line was editor from "Scientastic Monthly," a locally run pamphlet that was distributed in high schools. "Funducation," he called it. He explained that he wanted me to interview a New York professor named Leonard Susskind, who had recently come upon a scientific breakthrough. I blearily took down the information;

"PROF. LEONARD SUSSKIND, 6:30. PEARL OYSTER BAR, RUBBER BAND THEORY. $35"

A few hours of uncomfortable slumber later, and the notes hardly made sense to me at all. I wondered if the transaction had been some sort of audial hallucination, brought on by a combination of gin and a lack of sleep. This kind of thing had happened before, but with far more disastrous consequences than being stood up by imaginary men of science. I decided to chance the meeting with this Susskind character... if he did show, I'd have a cool thirty-five bucks burning yet another hole in my Levi's after the article was written.

"My hair was a mess; flattened on one side where I had slept on it, jutting out madly on the other. A half-Einstein."

I caught a glimpse of my reflection at the bar when it was too late in the game to do anything about it. My hair was a mess; flattened on one side where I had slept on it, jutting out madly on the other. A half-Einstein. I had slept in my clothes that I had worn the night -- no, two nights -- before, and my puffy, squinted eyes had dark circles hanging beneath them like great purple pendulums. I looked like a junkie; a madman. I pictured a clean-cut elderly gent with a neatly trimmed beard and pressed suit giving this approaching freak a hearty spray of mace. I sat at the bar ordered a Pabst from the tap, almost hoping that he wouldn't show.

6:45. I thought I was in the clear until I felt a tap on my shoulder that gave me such a start I nearly threw the bottom half of my beer all over the man who sat had next to me.

“Are you Jonathan? The journalist?” he asked me, gesturing toward the creased press badge on my jacket that was usually worn only to get the best seats at concerts and sporting events rather than proof that I was doing legit work. “Yeah, I am. Call me Johnny. You the scientist? Leonard Susskind?” I asked dubiously after checking my notebook again. He looked like he was only a few years older than me, and had the appearance that he’d been to Hell and back, forgotten his notes, and went back for a second trip. At the question, he scoffed.

“A scientist in name, yes, though recently I’ve been having doubts,” he sighed and ordered a scotch.

I realized that I had come completely unprepared. I had been so used to assignments where I could show up with merely a pencil and paper and wing it, but I had nothing to get this boulder rolling. I checked my information again, scouring for the topic. I scored the big one.

“Tell me about this theory,” I blurted. Susskind knew exactly what I was talking about; his eyes seemed to light up, but his face fell more deeply into a scowl.

“Yes. My theory that just got rejected from that pompous journal, the Physical Review Letters?” he asked bitterly. I felt a surprising amount of tension radiating from the man, and I hunched a bit behind my notebook, carefully writing the word “rejected” on the blank page.

Your guess is as good as mine,” I replied with a shrug. Leonard took a deep breath, his eyebrows furrowing. Before he could speak, I quickly cut in.
“Just give me the basics… I’m no grad student.”

“It started out simple,” he began, “a good friend of mine, Hector Rubenstein, gave me a mathematical formula.” Leonard snatched the pen from my hand, and scrawled an abstract series of numbers and symbols on the napkin that was set beneath his glass of scotch.

“See?” he continued, handing me back my pen, “a mathematical formula so simple, I thought to myself, ‘I can figure this out. I just need some time to dissect it; investigate it’.” I stared down at the napkin, feeling like the Greenwich Village Idiot. I nodded.

“Elementary stuff, really,” I said with playful sarcasm. Leonard seemed not to hear me.

“I spent three months sneaking in and out of my attic, spending as much time as I could trying to figure out what this mathematical puzzle meant; and I knew that it was going to be something very important,” he continued, his eyes becoming wild and excited. He answered my next question before it even formed in my throat.

“The formula basically is a description. It describes particles that are like elastic bands. Either circular or straight… and these ‘particles’ can move in innumerable different ways. Stretching, expanding, vibrating… countless different movements. Infinite!” he said, his voice rising.

As my hand scrambled across the notebook to keep up with Susskind, I began to feel the effects of the night before again. I jammed my hand into my pocket and choked down two aspirin with the suds that were left in the bottom of my glass.

“And what does this mean for science?” I asked, and then rephrased my question, “rather, what does this mean for a twenty-something journalist working for his next trip to McDonald’s?”

“And what does this mean for science?” I asked, and then rephrased my question, “rather, what does this mean for a twenty-something journalist working for his next trip to McDonald’s?” Leonard grinned.

“What it means for science is a bridge between General Relativity and Quantum Mechanics--”

“And for the journalist?”

"It means that these little loops and strings of oscillating energy is what you are made of. Hell, you, this bar top, your beer glass, even this damn sun giving us the torture of another New York summer," he exclaimed. I squinted my eyes, and everything began to fall into place. The pain in my skull seemed to vanish.

"So, what you're saying is that everything is made up of these... 'elastic bands'?" I asked. My first thought was that the city was getting to this man; that he was cracked. I kept a poker face as I continued taking my notes. Who knew what this man was capable of if he truly was the nut that I assumed him to be? Leonard raised his eyebrows at me, abruptly falling silent.

"Yes," he began evenly, projecting an image of complete levelheadedness to counter what he knew I was thinking.

"You see, Quantum Mechanics, in short, is a set of mathematical formulas that pin down the existence of microscopic things. Atoms, subatomic particles, quarks -- everything that matter is made of. Follow?" he asked. I straightened up on my stool and gave him complete, undivided attention. By Gods, I felt like I was back in high school Physics.

"Yes sir," I responded reflexively. Leonard nodded.

"And General Relativity is the mathematics that describe and explain enormous things; say the planets, galaxies... the whole encompassing universe, really," Leonard explained, taking a drink of his scotch that was no doubt watered down from the ice that had melted during his recitation. I took the chance to cut in.

"And you said that your theory makes a bridge between these two -- the microscopic and the massive?" I asked, starting to be reeled in by the concept that began to sound far more sane than I had thought just moments before.

"Up until now, Quantum Mechanics and General Relativity had worked incredibly well individually... but when you put them together, they clashed completely. Sparks flew; the mathematics collapsed and nothing agreed..."

"Like Mick Jagger and Keith Richard?" I quipped, citing music references to help me explain scientific theories. Leonard shrugged.

"Sure," he said, "or they were like puzzle pieces that wouldn't fit together. This 'Rubber Band Theory' acts like the fitting piece between the two. It basically implies that everything -- everything," he emphasized, staring me right in the eyes, "is made of these quivering bands. Each one of the infinite vibrations creates a new form of matter." My eyes widened, my pulse and brain racing each other toward the finish line that was this new, radical, magnificent breakthrough. It all began to come together; Rubber bands, The Rolling Stones, bad indie films, newspapers--

"All made of 'elastic' energy vibrations?" I thought aloud. Susskind chuckled and ordered me another Pabst.

"You've got it. The mathematics say it all; the theory fits perfectly." I was sure that my jaw had dropped to rest on the Formica counter top.

"Like Mick Jagger and Keith Richard?" I quipped, citing music references to help me explain scientific theories.

"The answer to the ultimate question of Life, The Universe, and Everything... the real-life 42," I mumbled, sipping the suds from the top of my beer. "Pure Douglas Adams. Hitchhiker's Guide," I muttered, my mind still reeling.

"Something like that, yes," Leonard said quietly. We sat in silence for a moment.

"Lenny!" I suddenly exclaimed, now feeling like the madman myself as I grasped him by the shoulders and gave him a bit of a shake, "you're a genius -- absolutely god damn brilliant! You need to get this thing out in the world -- this is huge!" I notice that I was attracting the attention of the other patrons. I lowered my voice. "I can't believe that journal rejected the idea."

"I can't, either," he said with a shrug, "after two months of writing the papers that I sent in, I thought that there were going to be headlines calling me the next Newton.” Instead of bitterness, this time his voice held undertones of disappointment. He paused in thought, and I looked downward to study my nearly illegible notes. Leonard stood up and left a five dollar bill on the counter.

“Thanks for hearing me out. Give me a call when the article is finished. I’d like to look it over,” he said, checking his watch. “I need to get home and change -- I have some kids to teach in an hour.”

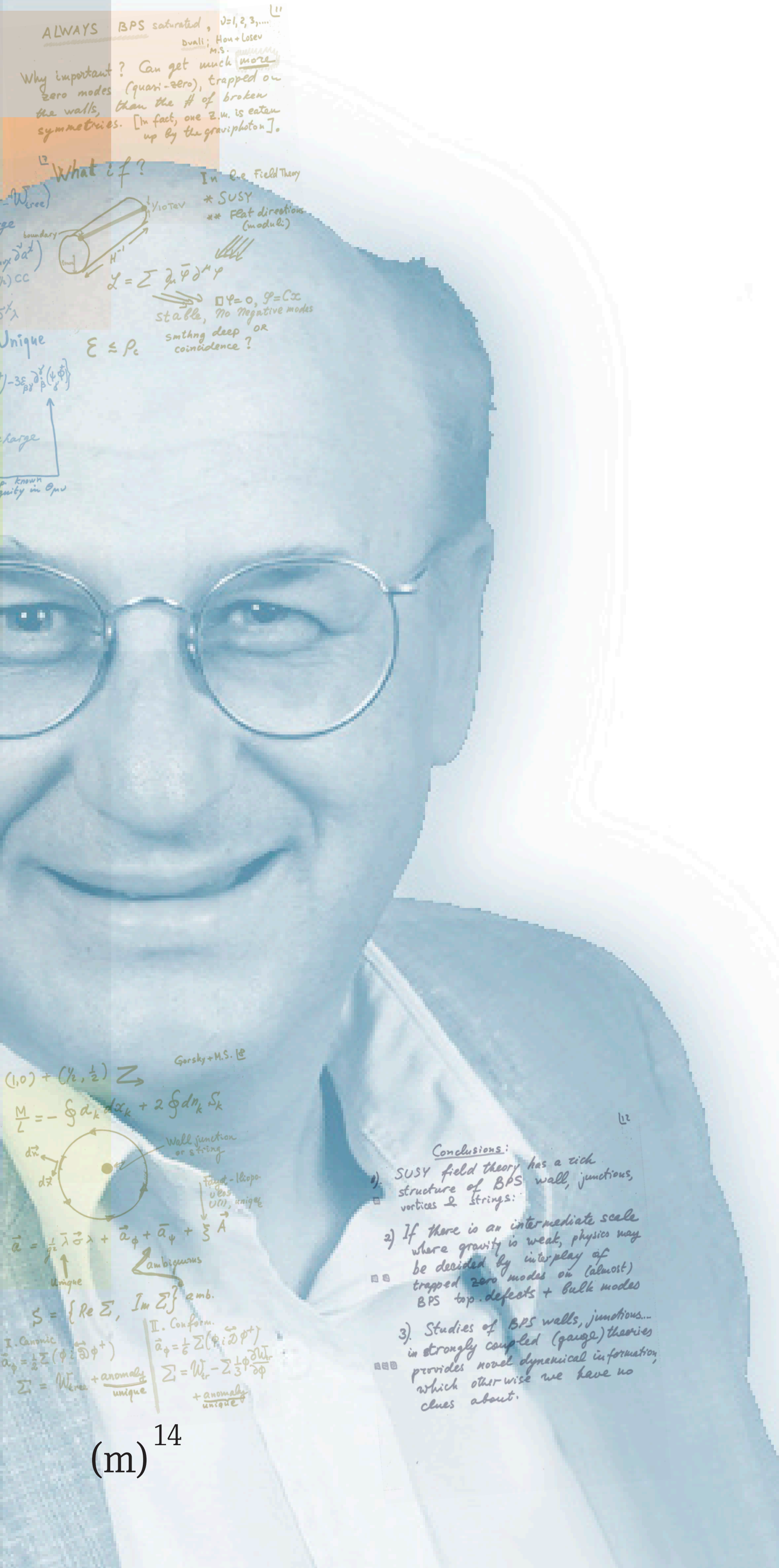
As he walked out the door of the bar, I picked up my notebook -- my mass of infinite vibrating energy strings that took on the shape of a notebook -- and started for the door.

“Me too,” I said to myself, paying the tender and leaving with a half-full glass of Pabst fizzing on the bar top.

A Conversation with

Dr. Mikhail Shifman

by Leigh Simmons



Sure, the directions seem easy. The map seems self-explanatory. But Ashley and I somehow manage to get lost between the Minneapolis College of Art and Design and the University of Minnesota. Not only are we lost, but we are completely out of our element. Our project requires us to venture from the world of artists and designers into the unfamiliar territory of particle physics and renowned physicists – two worlds that rarely collide.

After thirty minutes of circuitous driving, we finally make our way across the bridge to the East bank. Fortunately, once on campus, the Tate Physics Building is easy for us to locate. Stepping inside, we scurry past the students clumped together, heads bowed over heavy books. We pinpoint the elevator and then ascend to the fourth floor, the home of the William I. Fine Theoretical Physics Institute. Wait, no. We're in the Astronomy department. Five minutes, a stairwell, two corridors, and a different elevator later, and we find ourselves in the place we were supposed to be some forty minutes earlier – the office of Dr. Mikhail Shifman.

Never mind the movies, this is not the lair of a mad scientist bent on world destruction. Far from it.

The office is homey and situated conveniently close to the coffee machine. On the wall, among other things, is a certificate of U.S. citizenship signed by President Clinton. Dr. Shifman, a lively man with kind eyes and pleasant Russian accent, is dressed in a crisp yellow button-down shirt and khakis. Not surprisingly, like famed Russian writer Vladimir Nabokov, his command of English is far better than the majority of native speakers.

From the start, it's apparent that Dr. Shifman finds great joy in physics. He completely lacks the hunched, irritated look of someone who struggles in to work just for the paycheck. My teammate and I are greeted by a friendly smile, and a firm handshake. He offers us coffee and puts us at ease.

We start the session by looking over some illustrations of physics properties that Dr. Shifman has collected over the years. He takes time to explain to us why these are accurate visual explanations, not just pretty pictures. And he does it well. He radiates the easy air of someone who thrives on teaching others the subjects he's passionate about. "This is a visualization of a D-brane," he says, indicating what looked like the background of an early '90's rave flyer, a picture comprised of psychedelic striations on a black background. "You've heard of D-branes?" We nod in agreement, having spent weeks pouring over every book we had access to and every online article we could understand about string theory and its offshoots.

When I mention the supersymmetry article to be included in the magazine, Dr. Shifman responds excitedly. "This I can help you with," he says getting more animated. He steps to the bookshelf and extracts a paperback, *The Supersymmetric World: The Beginnings of the Theory* – a book he edited with Dr. Gordon Kane at the University of Michigan containing reminiscences and technical articles from the pioneers of supersymmetry.

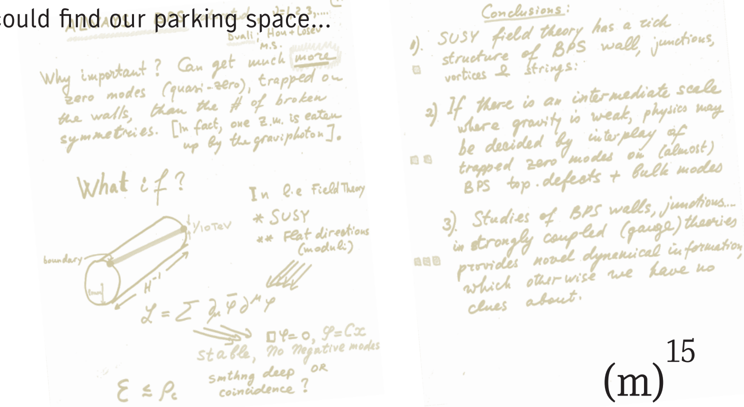
While Dr. Shifman is not a string theorist, his work deals with products of string theory, like the afore-mentioned D-branes – a kind of membrane structure – and supersymmetry. Beyond that, he earned his doctorate at the Institute of Theoretical and Experimental Physics in Moscow in 1976, was elected a Fellow in the American Physical Society in 1997, was named a joint-winner of the Sakurai Prize with Arkady Vainshtein and Valentine Zakharov in 1999, and was one of the most cited physicists during 1973-1988. Who better to answer the multitude of questions we have about this fascinating, but complex subject?

After a mind-expanding mini-lecture on supersymmetry, ask questions we did. Reminding myself that there is no such thing as a dumb question, I ask "Michio Kaku said in his book *Hyperspace* that our brains are incapable of perceiving extra dimensions. If

"This is a visualization of a D-brane," he says, indicating what looked like the background of an early '90s rave flyer...

that's true, then what's the point?" Dr. Shifman smiles, and says "We can see what we can experience. It's like if you are born blind, you develop some kind of a substitute through touch and hearing and so on. It's the same with extra dimensions. Nobody can claim they actually see them. When you're working and playing with extra dimensional expressions, you develop some kind of intuition which is a substitute for seeing."

We step out of Dr. Shifman's office, eyes open, feeling like we are finally on the right track to some understanding of Quantum Mechanics and String Theory, not to mention having a whole new appreciation of "the spirit of Physics". Now if only we could find our parking space...



The Worlds Next Door...

String Landscape

by Jesse Gadola

There are many unresolved mysteries within String Theory. These mysteries need to be explained if String Theory is indeed true, and not just a stretch of the imagination. One of String Theory's many mysteries is that it describes not just one universe, but a large number of universes.

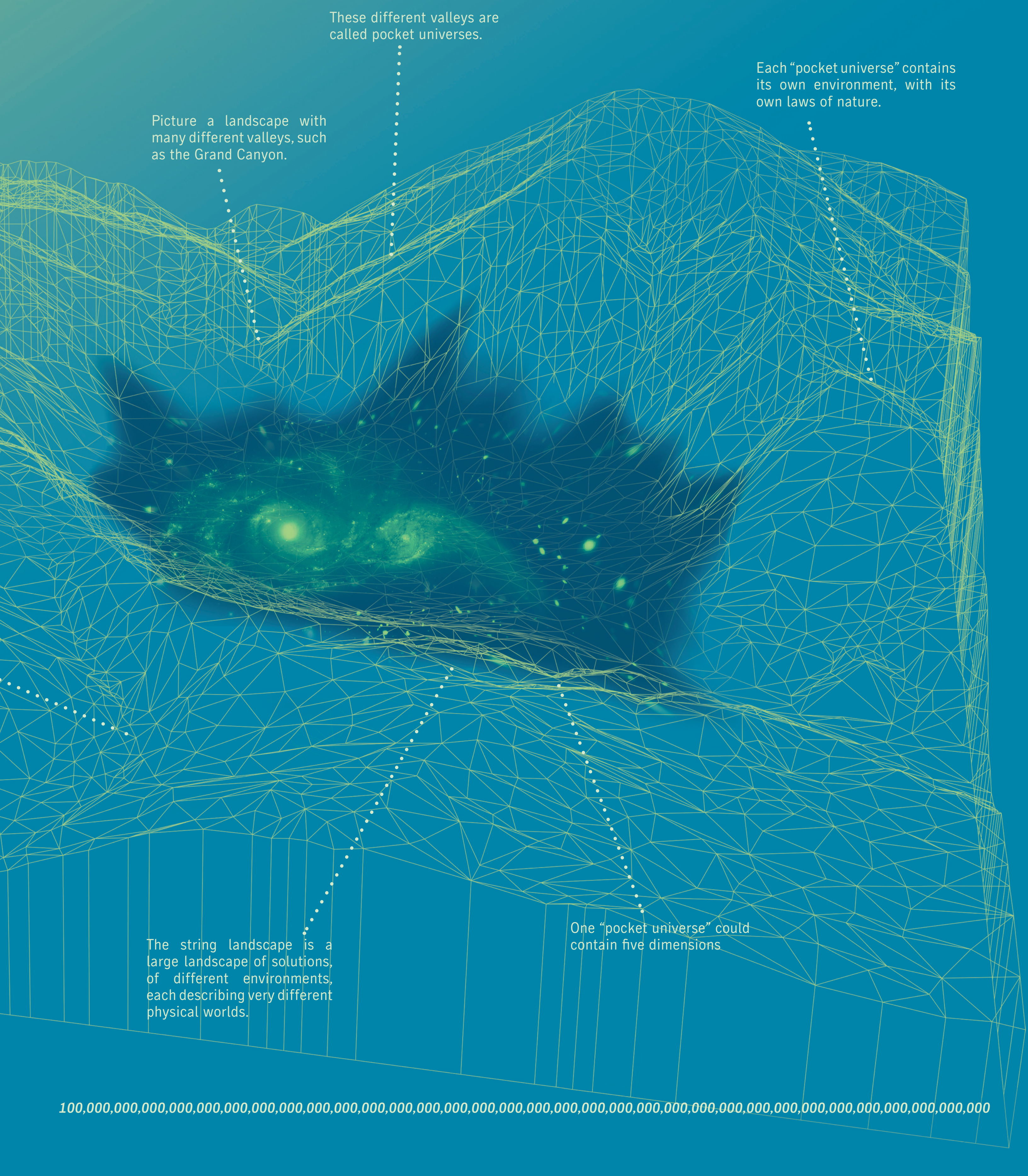
Theoretically, each of these universes has different constants of nature, and even different laws of physics. As a result, each universe contains a totally different environment from the next. The physical environment of one universe could be a lot like ours, while a parallel universe could contain no life at all. But if each of these universes are totally different from one another, how can they all coexist within one space?

The proposed solution is what physicist Leonard Susskind calls the string landscape. The string landscape is a huge space, which explains how billions of parallel universes could coexist in the same area of space. The string landscape is a large landscape of solutions, of different environments, each describing very different physical worlds. Picture a landscape with many different valleys, such as the Grand Canyon. Each of these valleys represents it's own pocket of space. These different valleys are called pocket universes.

Each "pocket universe" contains its own environment, with its own laws of nature. This means that our universe, which seems very big to us, would be constrained to only a small corner of this gigantic string landscape. Some pockets are small. Others are big like ours, but totally empty. One "pocket universe" could contain five dimensions, while another "pocket universe" may contain eleven dimensions. The string landscape allows for these billions of diverse universes to coexist in space, even though each may be totally different.

One "pocket universe" may contain eleven dimensions.

It is estimated that the number of different solutions within String Theory may even be more than 10 to the 100th power....



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One "pocket universe" could contain five dimensions
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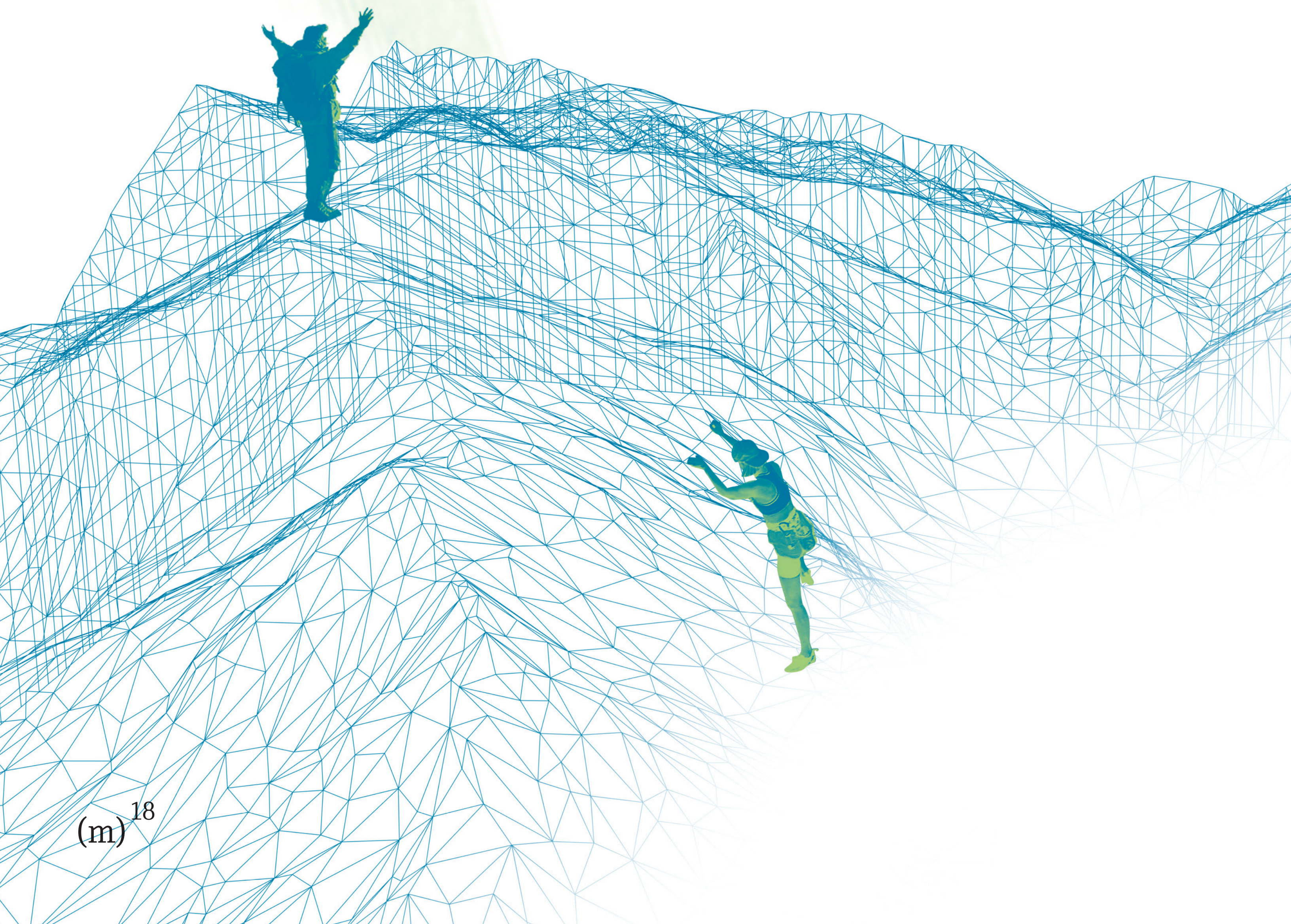
All Tied Up?

String Theory

by Courtney Davis and Jesse Gadola



Science has become such a part of our everyday lives that we don’t even see it as anything miraculous anymore. Think about it. You have a headache, you take an aspirin and the headache is gone. You forget to appreciate that it was science that made this possible. We, the general public, leave it for scientists to find the answers, even before there seems to be a problem. After all, what people thought was impossible years ago is now part of the fabric of our everyday existence, like cell phones and computers.

Most people don’t realize that you don’t need to be a scientist to understand what’s going on around you, and that there may be some things you just might want to know. For example, what if I told you that there was a possibility that we live in a world of eleven dimensions, instead of the four we are so familiar with? What endless possibilities could there be once we cross the dimension of time? Might this spark an interest in science?

The world we live in, or is it?

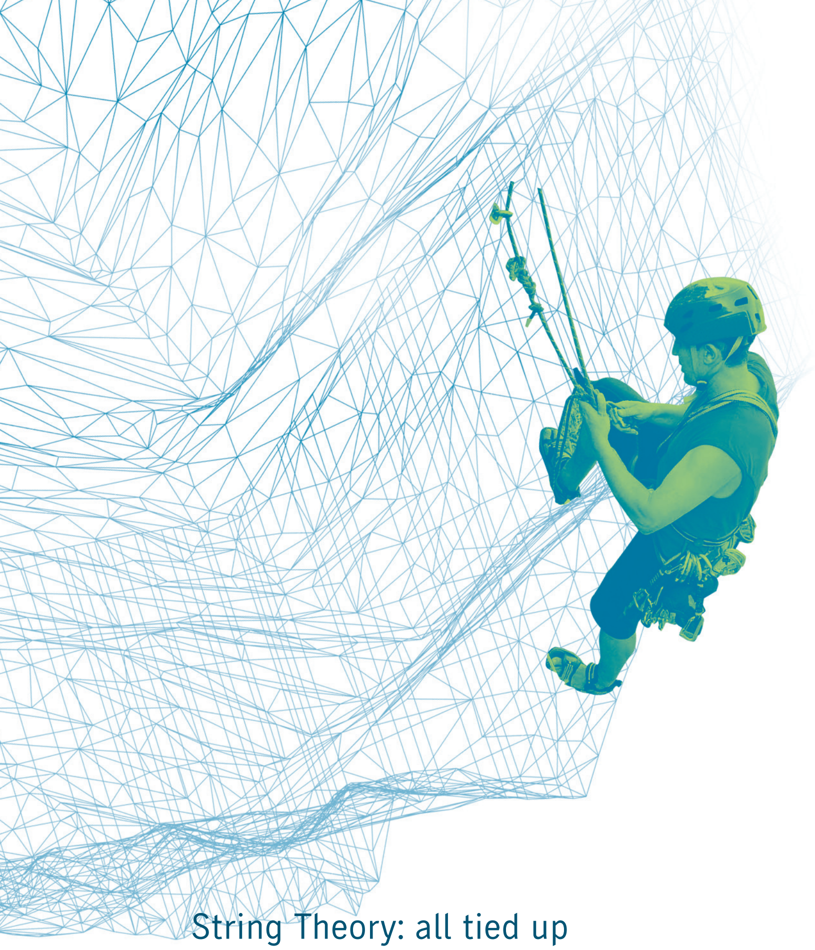
Eleven dimensions? Parallel universes? A world made up of little tiny strings? These strings are so small that if an atom were scaled up to the size of the solar system, a string would only amount to the size of a tree on earth. This idea, known as String Theory, can only be considered a theory in progress at this point. However, if String Theory proves to be true, one of science’s greatest conflicts could be resolved. String Theory is said to be the missing link that will connect the two fundamental pillars of Physics: General Relativity and Quantum Mechanics.

General Relativity: beyond our world.

General Relativity explains how things work on a large scale, such as, the gravitational attraction of planets, stars and galaxies. When Albert Einstein published the theory of General Relativity in 1915, he explained that gravity is a function of geometry. It is the result of curvatures in space-time. Space-time, as Einstein described, can be thought of as a trampoline with the weight of a massive object – such as the sun – creating an indentation in the surface of the trampoline. When this indentation from the sun creates a massive downhill curvature in the space-time fabric (trampoline), objects like Earth are inclined to stay within the sun’s gravitational influence. Thanks to Einstein’s theory of General Relativity, we have a greater understanding of gravity. By understanding how space and time warp, scientists discovered and were able to predict black holes.

Quantum Mechanics: beyond the atom.

Quantum Mechanics explains how things work on a subatomic level. If a person were to shrink down to this level -- smaller than an atom and even smaller than protons -- the fabric of space-time would appear unstable and chaotic. At this atomic or quantum level, the universe seems wild and frenetic, because it is ruled by chance. The best you can do is predict the chance or probability of one outcome or another. In the quantum world, nothing is defined as anything more than a probability. Because there is a probability for everything in the quantum world, it is possible for bizarre occurrences such as things jumping through walls. Physicists describe this action as tunneling. This very same tunneling occurs within computer chips.



String Theory: all tied up

It is clear that these two theories, General Relativity and Quantum Mechanics, describe very different worlds. Shouldn't they be facets of the same? Don't we live in just one world? Actually, scientists can calculate to great accuracy using both theories independently, and both are valid in describing the world in which we live. The problem arises when the two theories need to be used together. The laws of the quantum world are very different, and are in direct conflict with the laws describing the world we see (General Relativity). When General Relativity and Quantum Mechanics are needed to be used together in order to describe things like black holes and the big bang theory, the two theories break down. If there were a way to unify these two theories, such mysteries could be resolved. String Theory just may be the answer.

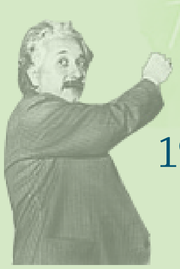
To understand strings as physicists describe them, picture a guitar string that has just been plucked. The way the guitar string vibrates when it is plucked is similar to the way a string moves. By varying the tension on different guitar strings, different musical notes are created. This is also an example of how strings differ from each other. Each string has its own vibration depending on the amount of tension impacted upon it. Some strings may vibrate faster than others, and some are different shapes and sizes. Now imagine that these strings are so incredibly small, that they fit within the quarks and electrons of an atom. The strings that have been described are open-looped strings. They are attached to membranes that make up all matter and all forces. Therefore, it is proposed that these many different strings are the building blocks of our entire universe.

Their theory suggests that there are a few, tiny, curled up dimensions at every small point in space-time and that the extra undefined dimensions exist all around us.

Before string theory: Kaluza & Klein.

In 1919, a physicist by the name of Theodore Kaluza suggested something mind-boggling. Before Kaluza, everyone knew of the four dimensions that can be distinguished by our senses: length, width, height and time. Mathematicians and scientists also knew that additional dimensions could be described using mathematical equations. What Kaluza suggested, was the idea of an actual, physical, fifth spacial dimension. He proposed that the universe has one more dimension that we cannot see.

So, if Kaluza was right, where is this hidden dimension? Another physicist, by the name of Oscar



1915 Albert Einstein published the theory of General Relativity, explaining that gravity is the result of curvatures in space-time.

1919 Theodore Kaluza suggested the idea of an actual, physical, fifth spacial dimension, proposing that the universe has one more dimension that we cannot see.

Oscar Klein explained that extra dimensions are hidden because they are tiny enough to coil together. Kaluza and Klein's ideas became collectively known as the Kaluza-Klein Theory.

Klein had an idea about how multiple dimensions could be possible. Klein suggested that extra dimensions are simply different than the four we are familiar with. These extra dimensions are so tiny, that they can fit together when they are coiled up. Kaluza and Klein's ideas became collectively known as the Kaluza-Klein Theory. Their theory suggests that there are a few, tiny, curled up dimensions at every small point in space-time and that the extra undefined dimensions exist all around us. The only difference between each dimension is their shape.

Before Strings

In the 1950's, new particles were being discovered using hadron colliders. Hadron colliders, also known as particle accelerators, are large machines that literally accelerate particles so fast that they collide with a massive amount of force. This allows scientists to see what particles are made of and how they react. A physicist by the name of Gabriele Veneziano was working on such research at CERN, when he developed a theory that would open the door for String Theory. Veneziano's amplitude governed the probability for different things to come out in different directions when two particles collide. It was a mathematical formula that was based solely on mathematical properties. In other words, it left scientists with no physical picture of what the equation was describing.

Picture this

In 1970, Yoichiro Nambu, Holger Nielsen and Leonard Susskind independently recognized that Veneziano's amplitude theory described an elastic string-like object that could wiggle. By this time, string theory, then known as the "theory of hadronic structure" or "bosonic string theory," gained popularity in the physics world as people started to develop a proper mathematical formula. Of the many scientists working on the theory, Pierre Raymond, working independently from André Neveu and John Schwartz, all found a problem with bosonic String Theory. If the theory was to describe nature, String Theory must incorporate fermions. The two scientist teams came up with two separate solutions that ultimately worked

Our universe could be stuck on one of these membranes, surrounded by other membranes all containing additional dimensions! In essence, our universe could coexist among multiple, parallel universes.

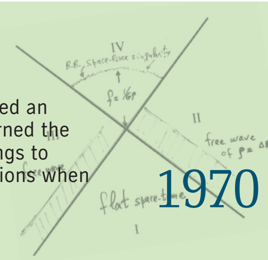
together to form one new theory. This new theory, called the RNS model (after the founders) required ten spatial dimensions.

The First Revolution in String Theory

In 1973, physicists John Schwartz and Joel Scherk kicked off the first revolution in String Theory. In a fateful paper entitled "String Theory for Non-Hadrons" they suggested applying string theory to our world at large rather than to a description of a limited area such as the interactions of hadrons. They found that String Theory predicted a massless particle, which they identified as the graviton of Einstein's theory. Theoretically, a graviton is a closed-looped string which transmits gravity at the quantum level. Closed-looped strings behave like open-looped strings in the way they wiggle. However, unlike open-looped strings, closed-looped strings are not attached to membranes, allowing them freedom to move in

1950's By the 1950's, new particles were being discovered using Hadron Colliders.

Gabriele Veneziano developed an amplitude theory that governed the probability for different things to come out in different directions when two particles collide.



1970 Yoichiro Nambu, Holger Nielsen and Leonard Susskind independently recognized that Veneziano's amplitude theory described an elastic string-like particle that could wiggle.

and out of other dimensions. This mobility dilutes the strength of gravity, making it seem weaker than the other forces in nature.

Scientists thought that if strings can describe gravity at the quantum level, it must be the key to unifying the four forces – gravity, the strong nuclear force, the weak nuclear force, and electromagnetism. However, by the mid to late seventies, the interest in string theory dwindled within the physics world.

Second Revolution in String Theory

Then in 1984, Schwartz, with his partner Michael Green, revived the field, creating a second revolution in String Theory. They worked out all of the inconsistencies within the theory, by reformulating the RNS model. This new description, known as superstring, concluded that strings could, in fact, describe all four forces.

Degrees of Freedom

String theorist, Ed Witten explained dimensions as "Degrees of Freedom," referring to the mobility of closed-loop strings. These extra dimensions allow strings to stretch into something like a membrane. A membrane can be imagined as a long, stretched-out piece of elastic. Membranes can run parallel to each other. With enough energy, strings could grow into an enormous membrane as large as a universe. This means that there could be another parallel universe right next to the one we are living on!

D-branes

Four years later, Joe Polchinski discovered that the mathematics of String Theory allowed, in addition to strings, higher dimensional things such as sheets or membranes. These membranes are called D-branes to distinguish them from other kinds of membranes. Polchinski's work explained how closed-looped strings could break open and attach to D-branes. By 1995, Joe Polchinski discovered that the mathematics does not just allow for these D-branes to exist, but requires them.

One interesting application of Polchinski's research is that some of these D-branes might be sitting in the extra dimensions proposed in the Kalutza-Klein theory. Our universe could be stuck on one of these membranes, surrounded by other membranes all containing additional dimensions! In essence, our universe could coexist among multiple, parallel universes. This idea might be tested in measurements of the gravitational force law, and with particle accelerators.

So many solutions

By this time, scientists had constructed five different versions of String Theory with varying dimensions. Each theory involved vibrating strings and multiple dimensions, but the mathematical details were different in every one. Then, at a conference in 1995, physicist Ed Witten proposed that the five theories were just five different ways of looking at one single theory. This new theory, requiring eleven dimensions, became known as "M" Theory. Ed Witten transformed the field into the mainstream of theoretical physics. Young scientists became enthusiastic about discovering the "theory of everything" (TOE) once again.

Finding Strings

Ed Witten proposed that the five theories were just five different ways of looking at one single theory. This new theory, requiring eleven dimensions, became known as "M" Theory.

Pierre Ramon and André Neveu & John Schwartz, came up with two separate solutions that ultimately formed one new theory, which incorporated fermions. This new theory, called the RNS model, required ten spacial dimensions.

1973

John Schwartz and Joel Scherk kicked off the first revolution in String Theory when they found that String Theory predicted a massless particle, later named the graviton.

1984

Schwartz and his partner Michael Green, worked out all of the inconsistencies within the theory by reformulating the RNS model. This new description is known as superstring.

If String Theory is able to unite quantum mechanics and general relativity, it could truly be called the “theory of everything.” Questions about the early universe and mysteries, such as black holes, would be revealed. The problem is, strings are much too small to see with modern technology. Currently, the theory can only be explored through complex mathematics.

Financing is also a problem. If it were possible to build a hadron collider powerful enough to observe strings, it would cost billions of billions of dollars. However, scientists agree that it is currently impossible. In response, physicists are in search of more effective methods to test the theory.

What if String Theory is true? What if everything -- you, the food you eat, this magazine-- are made up of strings? What if there are, at this moment, multiple dimensions with multiple universes existing all around you? What kind of scientific discovery could this lead to?

In today’s society, it is easy to take for granted what science has already given us. Investing an interest in the unknown can be a challenge for many people. However, the first step to conceptualizing a world that we understand and can utilize is to take an interest in such scientific issues as String Theory. What kind of doors will the development and discovery of String Theory open, as scientists push for answers? By being informed, active, and alert about the scientific issues around us, we will be able to value the world in which we live.

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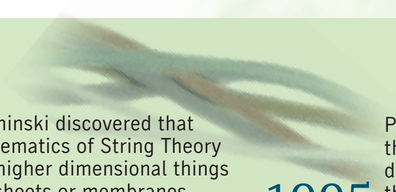

Joe Polchinski discovered that the mathematics of String Theory allowed higher dimensional things such as sheets or membranes, which he called D-branes.

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“M” Theory is now a field in the mainstream of theoretical physics, as young scientists enthusiasticly investigate the “theory of everything”(TOE).

Quiz

Test Your Knowledge

by Jesse Gadola

1) Why do we need String Theory?

a) To resolve the conflict between Quantum Mechanics and Special Relativity.
b) To find the Real Life “42”
c) Why not?
d) To resolve the conflict between general relativity and Quantum mechanics

2) String Theory is also known as the Theory of ____?

a) Creation
b) Parallel Dimensions
c) Everything
d) Underwater Basket Weaving

3) The smallest unit of all forces and matter are tiny ____?

a) Atoms
b) Strings
c) Protons
d) Spartikles

4) String Theory requires how many dimensions?

a) 10
b) 26
c) 11
d) All of the Above

5) What do these extra dimensions allow strings to do?

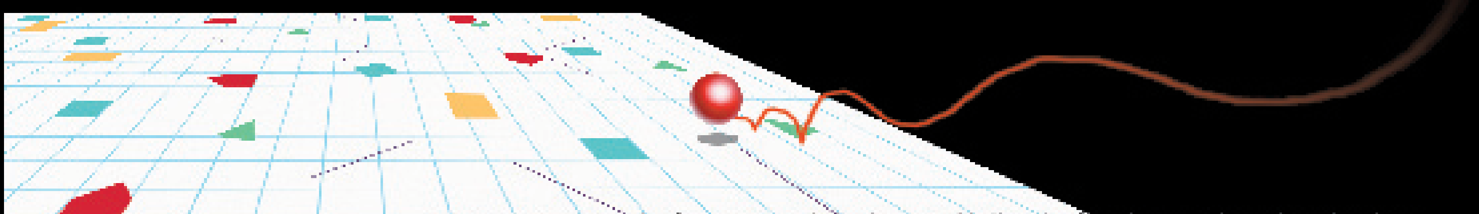
a) Travel between dimensions.
b) Stretch into membranes.
c) Grow as large as a universe.
d) All of the above.

Correct Answers: 1A, 2C, 3B, 4D, 5D, Open loop,
Closed Loop

Illustration inspired by

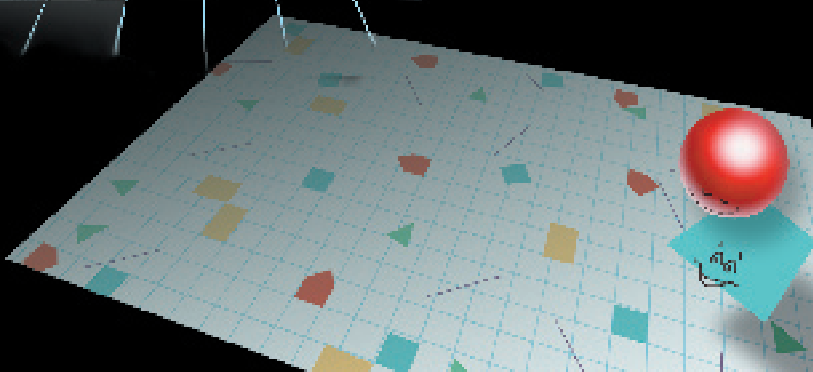
Flatland: a romance of many dimensions

Original text by Edwin A. Abbott 1884
Illustrations and text by Courtney Davis

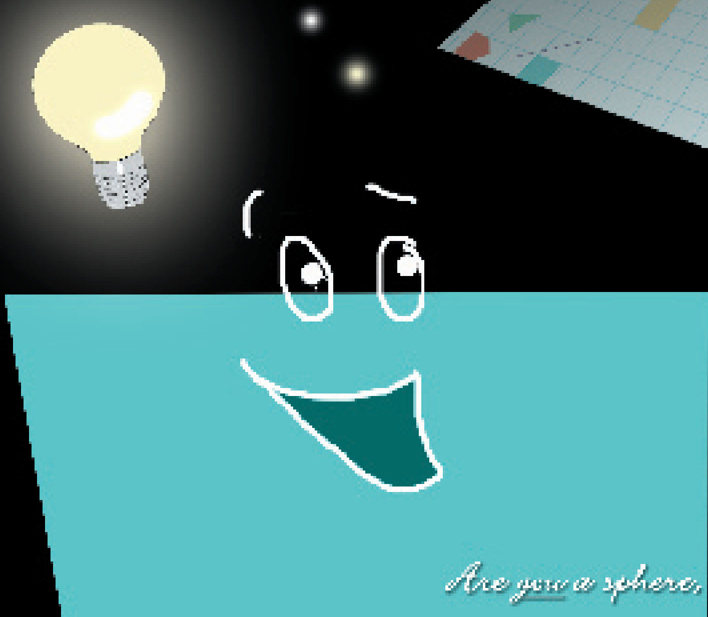


It was just an average day for Square in Flatland. He said hello to his friends as usual, watching their lines change length and brightness as they passed by. He was about to indulge in a mid-morning game of tic-tack-toe when a stranger came into town, and spoke directly to him. "Hello Square, my name is Sphere, and I'm from a land of three dimensions! I noticed that you don't move a whole lot. Would you like me to show you how to bounce up and down and move like me in three dimensions?" Square knew this tourist must be crazy. Three dimensions? That's simply bogus! However, Square was intrigued by his new friend.

Square wanted to show Sphere that he could bounce up and down too, but all he could do was slide back and forth.



So, to show quare a new view, Sphere took Square up above Flatland, where Square could see his friends the way Sphere could, as shapes! Finally, Square understood that he was 2-dimentional and Sphere was three-dimensional. So, Square turned to Sphere and said, "Let's find the land of four dimensions!" But, Sphere did not understand, for he could not imagine a world with more than three-dimensions.



Are you a sphere, or do you dare to think like a square...

Biographies

Faces of String Theory

by Courtney Davis

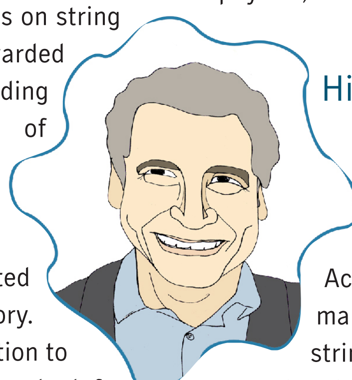
There are many men and women all around the world whose research focuses on or is related to elements of string theory. This is not a complete list by any means, but here are a few who have made huge contributions. Read about these amazing people to learn more about string theory's biggest fans.

Gabriele Veneziano

Gabriele Veneziano is an Italian theoretical physicist at CERN, where he has been researching since 1977.

His Claim to fame

It is said that Veneziano was the father of string theory in the late 1960's. Recently, Veneziano received the Heineman Prize of the American Physical Society and the Institute of Physics for his theories on string theory. In 1999, Veneziano was awarded the Pomeranchuk Prize for his outstanding contribution to the various areas of quantum field theory and theory of strings. In the 60's, string theory was deemed a failure, so, like other string theorists, Veneziano was not supported for his time spent on string theory. Veneziano eventually shifted his attention to quantum chromodynamics, a field where he left major contributions. When string theory became popular again in the 1980's, Veneziano was quick to apply the theory to black holes and the study of space and time.



Ed Witten

Ed Witten is currently a professor at the Institute for Advanced Study in Princeton, New Jersey. He has been working on string theory since the mid-eighties. Ed Witten's work focuses on high energy theoretical physics, mathematics, and string theory.

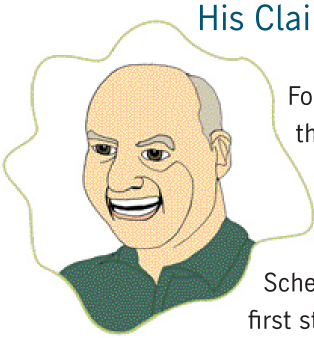
His Claim to Fame

Ed Witten is said to be the premier theoretical physicist of our time. Ed Witten is a member of the National Academy of Sciences and is known for his many contributions to particle physics and string theory. Among his many achievements, he's know for uniting the many versions of string theory to the one "M" Theory. Witten's outstanding achievements have earned him the Fields Medal, mathematics' highest prize, as well as the Dirac Medal and the MacArthur Prize.

John Schwartz

John Schwartz, another string theorist is currently a physics professor at California Institute of Technology, commonly known as Caltech. Caltech is a leading research university and has a strong emphasis on the natural sciences and engineering

His Claim to fame

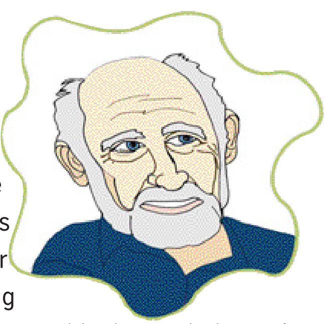


For Schwartz, it all started back in the sad days of drafts and send offs to Vietnam. At that time, string theory was beginning as a field in physics. With Joel Scherk, John Schwartz started the first string revolution. Then later, with Michael Green, he ignited the second string revolution. His current research interests include Elementary Particle Theory, Supersymmetry and Superstring theory. Schwartz is continually researching and publishing his findings.

Leonard Susskind

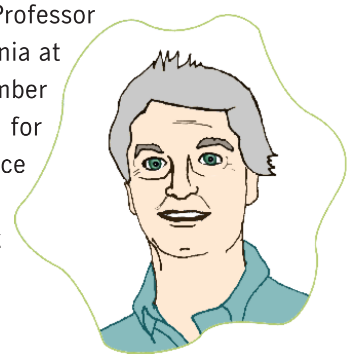
Leonard Susskind has been a professor of Physics at Stanford University since 1978. He is also a member of the National Academy of Science and the American Academy of Arts and Sciences. His current research includes ideas on Theoretical Particle Physics and Theoretical Gravitational Physics.

His Claim to Fame



Leonard Susskind was one of the founding fathers of the string landscape paradigm. Susskind has written many articles for the general public, including an award winning article on black holes in the Scientific American, the "Anthropic Landscape of String theory" in the New Scientist & an article on the status of String theory in Physics World. Susskind has received many prizes, including the science of writing price of the American Institute of Physics for his Scientific American article on black holes.

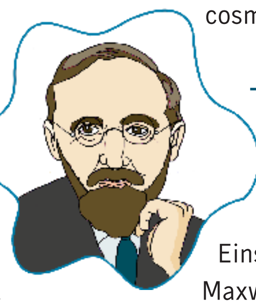
Joe Polchinski



Joe Polchinski has been a Professor at the University of California at Santa Barbara, and a member of the Kavli Institute for Theoretical Physics, since 1992. He is known among string theorists for his work on D-branes.

His Claim to Fame

Joe Polchinski wrote a two-volume textbook on String Theory, which is a standard reference alongside the two-volume text by Green, Schwartz, and Witten. In 2000, with Raphael Bousso, Polchinski explained the dark energy problem using the landscape of String Theory. Currently, he is working on using string theory mathematics to working on using string theory mathematics to solve the strong nuclear force, and on the idea that there might actually be some strings of cosmic size in the universe today.



Theodor Kaluza

Theodor Kaluza was a German scientist who worked to unify Einstein's theory of gravity and Maxwell's theory of light in 1919. Kaluza's work lead him to believe there may actually be more spacial dimensions than we know of. Oscar Klein (not shown) was an assistant professor at the University of Michigan. In 1926, he worked on the idea that extra dimensions may be physically possible. Both Theodor Kaluza and Oscar Klein's independent ideas became commonly known as the Kaluza-Klein theory.

Kaluza-Klein Claim to Fame

The Kaluza-Klein theory was considered ridiculous and strange at the time. It wasn't until several years later that Einstein considered the theory seriously. Today, string theorists find the Kaluza-Klein idea remarkable.

Words to Know:

Glossary

Atom:
Fundamental building block of matter. Atoms consist of nucleus (which consists of protons and neutrons) with orbiting electrons.

Big Bang (the big bang theory):
Theory that the universe was created around 15 billion years ago, from a state of extreme energy, density and compression.

Black Holes:
An object, within space, which has an extreme force, which traps everything when within close proximity.

Bosonic String Theory:
First known string theory, which contains vibrational patterns, which are all bosons.

CERN:
The European Organization for Nuclear Research, the world's largest particle physics center. CERN is a laboratory where scientists study the building blocks of matter and the forces that hold them together. CERN offers the most current technology for observing subatomic particles, accelerators. Accelerators accelerate particles to almost the speed of light and detectors to make the particles visible.

Closed-loop Strings:
Are responsible for all forces. Closed-loop strings are not attached to a membrane, and are free to roam between parallel universes. Theoretically, a graviton is a closed-looped string, which transmits gravity at the quantum level. Closed-looped strings behave like open-looped strings in the way they wiggle. However, unlike open-looped strings, closed-looped strings are not attached to membranes, allowing them freedom to move in and out of other dimensions. This mobility dilutes the strength of gravity, making it seem weaker than the other forces in nature.

D-branes:
A specific type of membrane that is classified by it's dimension. Theoretically, our universe could be stuck on one of these membranes, surrounded by other membranes all containing additional dimensions.

Electromagnetism:
James Clark Maxwell found there was a curious relationship between electricity and magnetism. This relationship can also be found when electrically charged particles flow, such as when lightning strikes. When lightning strikes, it creates a magnetic field. Evidence of this is shown on a compass. Maxwell devised a set of four mathematical equations which unified electricity and magnetism, into electromagnetism.

Electrons:
A negatively charged particle, which orbits the nucleus of an atom.

Fermions:
A particle with half a whole odd number of spin.

General Relativity:
Explains how things work on a large scale, such as, the gravitational attraction of planets, stars and galaxies. Includes Einstein's theory, which explains how space and time can communicate the gravitational force through their curvature.

Hadron Colliders:
Also known as particle accelerators, are large machines that literally accelerate particles so fast that they collide with a massive amount of force. This allows scientists to see what particles are made of and how they react.

Membranes:
A membrane can be imagined as a long, stretched-out piece of elastic. Universes exist on membranes Membranes can run parallel to each other. With enough energy, strings could grow into an enormous membrane as large as a universe.

Open-looped Strings:
Open-looped strings have two free ends which are attached to our universal membrane. Open-looped strings make up all matter.

Particle Accelerators:
Also known as hadron colliders, are large machines that literally accelerate particles so fast that they collide with a massive amount of force. This allows scientists to see what particles are made of and how they react.

Protons:
Positively charged particle, which consists of quarks. Protons are found in the nucleus of an atom.

Quantum Mechanics:
Explains how things work on a subatomic level, such as forces and particles.

Quarks:
The building blocks of hadrons and baryons, such as protons and neutrons. Also, a particle that is acted upon by a strong force.

Space-time:
Einstein's idea of space-time is that the three dimensions of space and the single dimension of time, which make up our universe, are bound together in a single fabric of space-time. Space-time is thought to be four-dimensional. Like a surface of a trampoline, space-time becomes warped and stretched by the weight of the planets.

Strings:
Used to describe the tiny particles which make-up everything in our universe, such as all forces and all matter. To understand strings as physicists describe them, picture a guitar string that has just been plucked. By varying the tension on different guitar strings, different musical notes are created. This is also an example of how strings differ from each other. Each string has its own vibration depending on the amount of tension impacted upon it. Some strings may vibrate faster than others, resulting in many different shapes and sizes.

Strong Nuclear Force:
The strongest of the four fundamental forces, and is responsible for keeping quarks inside of protons, and protons and neutrons inside of an atom.

Tunneling:
In the Quantum world, it is the bizarre possibility of things being able to jump through walls. Tunneling also occurs in computer chips.

Weak Nuclear Force:
One of the four fundamental forces, associated with mediating radioactive decay.

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Quiz

What Kind of String Are You?

by Jesse Gadola

1) If your friend started to talk to you about 11 dimensions and parallel universes, you would:

a) Immediately take them to the nearest psych ward.
b) Begin to argue with them, until you are satisfied.
c) Be a little weirded out, but willing to listen to their thoughts.
d) Agree with them, and join in on the conversation.

2) What would you wear to a string theory convention:

a) Formal wear; fancy dress or tux.
b) A casual, but clean, pair of jeans and shirt.
c) The cleanest clothes you could find on the floor.
d) Your custom-made string theory costume.

3) If you were offered a chance to live in another parallel universe tomorrow, what would you say:

a) "Hell no. God Bless the U.S.A."
b) "I would have to have more time to think about it."
c) "Maybe in my next lifetime."
d) "Hell yeah! What do you want me to bring you for a souvenir?"

4) If you were asked to present your newly developed theory at the next string theory convention, how would you present it?

a) With a straightforward PowerPoint presentation, lecture and Q & A.
b) With numerous scientific models and white board drawings.
c) Just you and a microphone, a one-man show.
d) With song and dance, like a musical.

Scoring:
A = 1 point **B = 2 points** **C = 3 points** **D = 4 points**

IF YOU SCORED:
4 – 8 points: You are an Open-looped string. The ends of these strings are tied down to our 3D membrane. Matter and light are made out of open-ended strings.

You require security, and don't like things to be spontaneous. You have a preferred routine and dislike change. You are also very intellectual. When making decisions, you are very analytical. You are a left-brained person. Your friends feel you are a very reliable, responsible, and trustworthy person. You are the one they come to for advice, because they trust your opinion.

9 - 16 points: You are a Closed looped string. One kind of closed looped string is responsible for gravity, a graviton. With closed loops, gravitons are free to roam in other dimensions, diluting the strength of gravity and making it seem weaker than the other forces in nature.

You are a very outgoing and spontaneous person. You love to stand out in a crowd, and are up for almost anything. You enjoy change, and love to try new things. When making decisions, you rely on your emotions, and are very creative. You are a right-brained person. You are free spirited and live by the moment.