Life As We Don't Know It
By
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Among those who practice science fiction professionally, there is an unspoken faith that our form of literature is the most expansive of all. This may seem like conceit considering the lowly respect in which the literati hold us, but I believe we have logic on our side, if not public opinion. Take the western genre as an example. Westerns, by convention, take place between the years 1800 and about 1910 and are confined to that land which is west of the Mississippi River and east of the Pacific Ocean. Their north-south boundaries are not so constrained that they can't stray beyond these borders – say as far south as Northern Mexico or north to the Yukon Territory of Canada. In the main, however, they usually occur on the Great Plains, in the Rocky Mountains, the gold fields of California, or the deserts of the Great Southwest. The canvas on which practitioners of western fiction practice is practically claustrophobic to a science fiction writer

Want another example? Take the World War II novel. That is even more constrained than the Western. Whether fought in the air, at sea, or on the ground, war novels are constrained to a time frame of only six years, barely two thousand days! Considering the number of them that have been published, the population of fictional soldiers rivals that of real soldiers.

Contemporary novels may be set anywhere on Earth, of course, but only in that extremely short period of time known as "now." Historical romances typically are confined to Europe, or the Far East, or sometimes South America, but almost never stray beyond one millennium into the past.

Each of these genres has its limitations of time and space that form the box in which the writer must work. Not so science fiction. A science fiction story can be set anywhere and anywhen. In fact, there is no other branch of literature where a word like "anywhen" would be necessary. Our heroes fight among dinosaurs that were 60 million years dead when our first ape ancestors were chased out of the trees and down onto the savanna. They march with the legions of Imperial Rome, and pilot the spaceships of the Third Interstellar War in the 30th century. A science fiction writer refuses to be pinned to one country, one era, or even one universe. Tired of this vast expanse of vacuum that we inhabit? No problem. Travel sideways in time to a parallel universe where anything can happen. Not happy with the local real estate? Then go out and find new worlds to conquer. There are certainly enough to go around. Want to change history such that Lincoln lived and the Confederacy won the civil war? Go right ahead, although you should be warned. One of my contemporaries, Harry Turtledove, seems to have cornered that particular market.

Since we don't allow ourselves to be pinned to any particular time or place, science fiction writers tend to take a more expansive view of life than most people do. While all around us are hyperventilating over whether we are ruining the planet with our industrial activities, we are asking, "What difference will it make in a thousand years?" While government can't seem to see past the next election, we are pondering the fate of the universe some 20 billion years hence.

And so it is that most science fiction writers can't help but be attracted to the stars when thinking up story plots. Possibly we are all claustrophobes who can't stand the thought of being cooped up in a single star system with only a few billion trillion cubic kilometers in which to roam. No, we want it all — and (by definition) that means the stars!

Unfortunately, when you set out to write an interstellar adventure, you immediately run into a series of practical problems. One of these involves astrogation — that is, navigation between the stars (The Art of Science Fiction, Volume 1, "Practical Astrogation."). The problem, of course, is that while the astronomers tell us where the stars appear in the terrestrial sky, they don't tell us where they are with respect to one another. No self-respecting science fiction writer (at least not one of the hi tech persuasion) would dream of misplacing a star in the sky. For these people, I recommend The Astrogator's Handbook, available for free download from Sci Fi - Arizona.

A second problem SF writers encounter when they let their imaginations roam among the stars is whether or not they are going to have aliens among their characters. With this decision they must take a stand on the question of whether there is "life as we know it" out there in the universe. Most people I know who have studied the question always answer in the affirmative when asked whether there is intelligent life out among the stars. The laws of probability would seem to require it. Whether such life exists anywhere close in either space or time is another question, and one that is much more difficult to answer.

Having taken the position that life exists elsewhere in the universe, a second question follows naturally. Just what form will that life take? Would they look like us as almost all the aliens on Star Trek do? (The better to fit human actors into the alien costumes.) Or will they be so different that we might not even recognize them as life forms? And even if they look like us, will they think like us, and what exactly does the phrase "think like us" mean?

Those then are the practical problems associated with writing an interstellar romance. Some writers choose to ignore the problem by populating their stories only with human beings (Isaac Asimov and his *Foundation* books spring to mind). Others people their work with wild shapes, alien forms, and even more alien philosophies, writers like Larry Niven and his *Tales of Known Space*. Both approaches are viable, but the second requires considerably more work unless you are merely going to make your aliens big versions of cats, rats, or some other familiar terrestrial life form.

That, then, will be the subject for this month. How do you go about constructing an alien life form?

Carbon, The Basis For Terrestrial Life

For several decades now, there has been an "organic" movement in the United States. These are people who insist on only eating "naturally grown" fruits and vegetables. Naturally grown produce is, by definition, that which has had no "artificial" chemicals or pesticides used on it. While the "organic" enthusiasts certainly have a point when it comes to pesticides, I have always been amused at their distaste for artificial chemicals, as though a nitrate molecule could tell whether it was produced in a chlorophyll-filled plant or in a chemical factory. Nitrate is nitrate, regardless of the source. The same can be said of nitrite, phosphate, sulfur, iron, or any of the hundreds of other things we put on our crops to get them to grow better. Personally, I would much rather think the strawberries I was eating had been bathed in nice clean white nitrate pellets than having been showered with what the Chinese euphemistically call "night soil," more commonly known by the vulgar monosyllable "shit!" This may be due to the fact that one of my father's favorite jokes was; "Did you know that farmers spread manure on their strawberries rather than milk and sugar?"

The Probability of Finding Intelligent Aliens in the Universe

Scientists have speculated for years on the probability that intelligent aliens exist out among the stars. They have even developed a formula for calculating the odds. Of course, since we don't know the values for most of the parameters that go to make up the formula, we can't really make an educated guess at how great a chance there is of other intelligent species Out There. Still, just understanding the formula allows us to hazard a few guesses as to whether or not we are alone in the universe. The following is a simplified version of the formula astronomers use to predict the existence of other intelligent races in the universe:

Parameter	Definition
N	Number of stars in the universe, approximately 10,000 billion billion, or 1×10^{22}.
P_{SOL}	Probability that a particular star will be close enough to Sol in output power and spectrum that life can exist around it [all Probabilities (P's) in the formula are positive numbers less than one; example 0.01 or 0.00001].
P_{EARTH}	Probability that an Earthlike planet will form around a given star.
P_{LIFE}	Probability that life will arise on a given Earthlike planet.
P_{INTEL}	Probability that life will develop intelligence.

P_{TIME} Probability that intelligence will exist in the same span of time that we do. (We have occupied a 50,000-year span out of the 15 billion years the universe has existed, making this probability for humans 0.000003.)

X Number of intelligent species in the universe.

The probability that intelligent life exists somewhere in the universe can be calculated by the formula.

$$X = N \cdot P_{SOL} \cdot P_{EARTH} \cdot P_{LIFE} \cdot P_{INTEL} \cdot P_{TIME}$$

No matter how improbable each of the factors is, the value of N is so large that it is likely that there are dozens (hundreds, thousands, or millions) of intelligent species in the universe at any given moment. Of course, whether they are close enough to us for us to find them is an entirely different question.

"Organic" Chemistry

Still, what exactly does the word "organic" mean anyway? To the great percentage of the public, organic means that the produce has been produced with no help from human chemistry. However, "organic" has a scientific meaning, too. An organic molecule is a molecule that takes part in the complex process known as "life." Organic chemistry is, by definition, the chemistry of molecules based on Element No. 6, Carbon.

If you have ever held a glass plate over a smoky oil lamp, you will note that it quickly turns an opaque black color. The soot that stains the glass is one of the "dirtiest" substances known to man. That isn't a value judgment, merely an observation. Stains produced by carbon black are some of the most noticeable in life. And though most of us haven't seen an oil lamp lit in decades, we have all been around the copy machine when the repairman was there. That fine black powder that floats through the air, stains the carpet, and gets all over hands and clothing, is basically the same element — carbon.

Carbon atoms are unique in that they have four electrons weakly held in their outer shell. When it comes to the atomic tug of war between carbon and oxygen, carbon hasn't a prayer. An oxygen atom can suck away two of a carbon atom's electrons just by being in the neighborhood. Since carbon atoms have four electrons to give up, they can play host to two oxygen atoms (which need two electrons each to complete their own outer shells), producing the common molecule CO_2, carbon dioxide.

If that were the only trick that carbon could do, then it would be a boring life (or rather, a boring non-life). However, carbon can grab electrons as well as give them up. In effect carbon atoms "swing both ways." They are effectively bisexual, having both a positive and a negative valence. (Carbon has a valence value of both +4 and -4, meaning it can either take 4 electrons or give up 4 electrons.) And best of all, carbon atoms can stick to one another. Men, that lump of sparkling rock on the third finger of your wife's left hand (right hand in parts of Europe) is merely a very pure lump of carbon atoms arranged in a highly organized matrix. We call this particular form of carbon "diamond," and it is much more highly valued than the more amorphous form we call "coal." Either way, however, it's still carbon.

And since carbon atoms stick together so readily, and because they also stick to hydrogen and oxygen atoms, a surprisingly large number of different molecules can be formed using the carbon atom. In fact, there are literally billions of carbon-based organic molecules already known, and probably a lot more that aren't yet known. This is good because the process we know as life is mind numbingly complex and it needs billions of different kinds of molecules to make the machine run efficiently.

This, then, is why science fiction movies often talk about "carbon-based life forms." They are, in effect, talking about us and our brethren, wherever they may reside out among the stars. And one thing we know about carbon-based life forms is that they all have certain characteristics in common. Most of these common factors are based on the relative strength of the carbon-carbon molecular bond.

If you think back to high school chemistry, you will remember that the subject of how well various atoms stick together came up in class, and that the strength of this bond has something to do with the gross physical properties of the resulting substance. As we also learned in school, temperature is merely a measure of how fast the various molecules in a substance are vibrating. If they aren't vibrating at all, then the substance is at that condition known as "absolute zero," which by human standards is very cold indeed. When the molecules are moving slowly, then most substances have a rigidity to them and we refer to them as "solid." Increase the velocity of molecular vibration sufficiently and most materials will take on a less rigid form that we know as "liquid." Heat them still more and the various molecules cease to associate with one another. The substance becomes "gaseous."

The temperature at which any particular substance changes from solid to liquid and again from liquid to gas is determined by how tightly the atoms of that substance bond to one another. For instance, when two atoms such as sodium and chlorine stick to one another, they do so very tightly. This results in a substance that has a very high melting point (several thousand degrees). Carbon atoms, on the other hand, have intermediate bond strength. They are relatively weak compared to the ionic bonding of sodium and chlorine (to form sodium chloride, or plain table salt), but very strong compared to the covalent bonding of oxygen and nitrogen. What this means is that carbon-based molecules are viable only below a certain temperature (which corresponds approximately to the boiling point of water under conditions that exist on Earth at mean sea level).

This, then, is the reason why our bodies have such elaborate temperature control systems. For human beings, the optimum temperature for our carbon-based biochemistry is 37 °C (98.6 °F), while for cattle and dogs, the optimum temperature is a few degrees higher. If any of these organisms are subjected to temperatures much higher or lower than these optimum ranges, the biochemistry essentially shuts down and the organism dies. [Many of you have probably seen the movie, *Titanic*. More than a thousand people went into the cold North Atlantic that night in 1912. Six of them survived, despite the fact that most passengers were wearing their life jackets. Why? Because the water they fell into was -2 °C (28 °F) and water that cold will suck heat out of you faster than your internal heat engine can replace it. Thus, in only a few minutes, the victims' internal temperature dropped below the point where carbon-based biochemistry operates, and they all died of hypothermia.]

Because the laws of physics are everywhere the same in the universe (this is the Universal Principle, UP, of science) that means that all aliens that are built using carbon-based molecules will have more or less the same limitations that we do. This is not to say that special environmental adaptations won't allow them to extend the range of temperature in which they live, just as our habit of wearing clothing extends the temperature range in which we live, but that their basic biochemistry will operate on the same principle as does ours.

This may not be good news, however, since it means that they will find the same kind of real estate attractive that we do. And at their heart, many (if not most) of the wars humanity has fought over the past 50,000 years have come about when two groups found the same piece of real estate attractive.

Thus, any carbon-based life form is likely to find the Earth an attractive sight against the ebon backdrop of space, which could make life exciting in the future.

Silicon, Hot World Building Block

There is one other atom that has a valence of plus 4 and minus 4, and you find it directly underneath carbon in the Periodic Table of the Elements. That is Element No. 14, Silicon. Theoretically, silicon could also be the building block of life since it can perform the same trick that carbon does, namely either give up or accept four electrons from its outer shell.

So why don't we see silicon-based life forms slithering around the surface of the Earth? Simple, really. It's too damned cold for them here!

Remember, carbon based life forms have an optimum temperature range based ultimately on the strength of the molecular bond between carbon atoms in organic molecules. The same is true for any hypothetical silicon atom bonds in a "silico-organic" molecule. The only difference is that silicon bonds are stronger than carbon bonds and therefore, the temperature at which silicon life form chemical reactions will take place is much higher than we are used to. Silicon, then, is the building block of life on hot worlds. How hot? Something approaching the temperature of Hell in the Old Testament.

Don't believe me? Then consider this. The molecule that results when two oxygen atoms latch onto a single carbon atom is carbon dioxide, a byproduct of our respiratory process. At room temperature, carbon dioxide is a gas, indicating relatively low bond strength between atoms. It should be noted that you don't have to get carbon dioxide too cold (relatively speaking) to make it freeze. You can buy this form of CO_2 in just about any large supermarket. We call it dry ice. And while carbon dioxide has a liquid phase, most people are unfamiliar with it because it doesn't exist at the low atmospheric pressures we find comfortable.

The molecule that results when one silicon atom is latched onto by two silicon atoms is silicon dioxide, and it is very far from being a gas at room temperature. In fact, silicon dioxide is most familiar to us in two forms: sand and glass. Stop what you are doing and look out the closest window. That transparent sheet of material is almost pure silicon dioxide, and was undoubtedly produced by melting pure, white sand in a furnace and then allowing it to cool down slowly. Sand is the crystalline form of silicon dioxide while glass is the amorphous form. As anyone who has ever watched a glass blower work knows, you can melt glass, but you have to get it very hot first. As for boiling it, you have to get it very, very hot — 2230 °C (4000 °F).

The much higher melting and boiling points of silicon dioxide compared to carbon dioxide is a direct measure of the relative strengths of the atomic bonds and the reason why you aren't likely to find silicon-based bug-eyed monsters running around loose any time soon. If such beings do exist, their spaceships will glow red-hot or white-hot just from the internal heat and their crews will freeze solid about halfway through "Take me to your lead..."

Because of this basic difference on a molecular level, we should have nothing to fear from silicon-based life forms, outside of their burning us if we ever try to shake hands with them. To their eyes, or whatever they use to perceive the universe around them, Earth is a cold, dark place covered with seas of liquid water. A silicon-based being would likely view a summer's day at the lake the same way we would view a giant vat of liquid nitrogen.

Is silicon really a viable alternative to carbon as the basis for living things? Could be. However, carbon isn't the only atom involved in living molecules. If it were, diamonds would be intelligent. Whether there are analogs of the other atoms (primarily hydrogen and oxygen) that go to make up living cells, I am not expert enough to know. Nor, I suspect, are the world's chemists.

We'll probably just have to go out and see for ourselves.

Nitrogen, Colder Than A Well Digger's Rear!

We've looked at hot world chemistry. What about cold worlds, say the gas giants Jupiter, Saturn, Uranus, and Neptune. Might there not be some form of life inhabiting these planets?

It's possible, of course. For one thing, there are spots in the atmospheres of each of those worlds where the temperature is the same as it is on Earth. If this seems counterintuitive, remember that the gas giants all radiate more heat out into space than they receive from the sun. In effect, they have internal heating mechanisms to keep them warm. Thus, so long as a carbon-based life form could float in the atmosphere and develop a system of altitude control, there is no reason why a gas giant couldn't be home to such beings.

But what about the really cold worlds, those where water is to be found perpetually in its crystalline form known as ice? There is one other atom that might conceivably be used to build complex molecules. This is Element No. 5, Nitrogen, directly to the left of carbon in the periodic table.

Nitrogen isn't as attractive as carbon as a building block for life because it has a valence of either +5 or -3. This means that it has five electrons in its outer shell that it can share with other atoms, or it can steal 3 electrons to form molecules such as NH_3, ammonia. The odd number of atoms that stick to nitrogen may be something that eliminates it as a life-giving molecule; or again, it might not.

However, where silicon is much stronger in holding its partners than is carbon, nitrogen tends to be weaker. This means that the temperature that nitrogen based creatures would prefer are considerably colder than we human beings find comfortable.

Still, it is possible to conceive of an alien with ammonia running through his veins who is a pale, translucent blue and who would perpetually live in a deep freeze while performing his diplomatic duties on Earth.

Where silicon-based life forms would find the Earth much too cold, these nitrogen-based beings would view New York as another version of Dante's Inferno. Indeed, nitro-mothers would probably scare their squid-like offspring by telling them horror stories of what it is like to live on the surface of that cauldron that circles third out from the sun.

Really Exotic Aliens

From time to time there have been attempts in science fiction to postulate very exotic life forms. These range from intelligent patterns of plasma living deep inside the sun to the thermoelectric based "Outsiders" in Larry Niven's *Tales of Known Space*. Then there are the vacuum-based life forms with which writers populate space, including Starseeds (again Larry Niven), space whales, and other fantastic creatures.

From what we know of life, all of these seem utterly fantastic, but then that is what science fiction is about, isn't it? Who knows, perhaps there really are four-dimensional beings living outside of our universe, and if we knew what to look for, we could see the amorphously changing shapes of their legs where they intersect our three-dimensional space as they walk about their four-dimensional world. There is even one story (I think Isaac Asimov wrote it) in which there is a war going on between beings who are fighting across the galaxy. Their war involves creating and killing stars over a billion-year span of time.

Would A Carbon-Based Alien Look Like Us?

More than thirty years ago someone wrote an article in *Analog Science Fiction/ Science Fact Magazine* where they speculated on what an alien would look like. Interestingly, he concluded that they would look more or less like us. Personally, I found his logic to be persuasive. On the other hand, those were the days when John W. Campbell ruled the roost at *Analog* and Campbell had some fairly rigid ideas on the subject, so maybe the author was merely stroking the editor's prejudices in order to make a sale. In any event, I will attempt to reproduce his logic for you.

Have you ever wondered why the human brain is in your head? It seems a less than optimum place for it. After all, your head sticks up where just about anyone can bounce a stone off it. It's also precariously balanced on the end of your neck, which means that any slight twisting motion can sever the nerve connections that attach your thinking machine to the rest of the body. [Most people don't realize that the primary cause of death in air crashes comes when the plane decelerates at 20-gees on impact. Suddenly all the passengers heads, which formerly weighed 3 kilograms (6 pounds) now weigh 60 kilograms (120 pounds), thereby breaking the neck. This is the reason for putting your head down and between your knees in what is known as "crash position." It's to protect your neck to the greatest extent possible.]

Wouldn't it be better if people carried their brains in their chest cavities where they have all the other vital organs protected by the bulk of the torso and rib cage? Actually, no it wouldn't.

People carry their brains in their heads because that is where all the primary sense organs are and it is important to keep transmission times between senses (eyes, ears, nose) and brain to a minimum. When you see a tiger charging at you through the brush, you don't want it to take five seconds between the time your eyes see the danger, your brain perceives the danger, and your legs begin to run. So to keep transmission times to an absolute minimum, Mother Nature has placed all of the sense organs and the brain in very close proximity.

But why in the head? Because in an animal that has one primary direction of movement, it is a survival factor to place the sense organs primarily facing in that direction and as high up as you can get them. You've all seen films of prairie dogs frolicking in the grass. What do they do? Every few minutes, one of them will stop, get up on his hind legs, and look around for danger. We humans have an advantage over prairie dogs. We live our lives on our hind legs, with our eyes and ears up high to perceive the onset of danger.

If perceiving danger is so important, why don't we have eyes in the back of our heads? Apparently because Mother Nature determined that a third eye is more trouble than it is worth. There are animals with 360 degree vision, but they are all insects, indicating that Mother Nature found the moveable neck a simpler solution to the problem of keeping aware of one's surroundings than adding the complexity of a third vision organ and the associated circuitry to interpret the signals.

So if there are intelligent aliens, and if they evolved under similar conditions to ours, it is likely that they will have some kind of an appendage on top of their body in which they carry their primary sensory organs and their brains, and that the brain will be inside some type of an armored box. In other words, they will likely have heads, with eyes, noses, and ears mounted such that they give preference to their primary direction of movement. Their eyes will tend to face front, or at least be on the sides of their heads, but highly mobile, possibly even mounted on stalks.

How many legs would an alien have?

This is a harder question to answer since on Earth we have animals with two legs, four legs, six legs, and eight legs. However, on closer examination, the situation isn't as complex as it first appears.

The six- and eight- legged animals on this world are confined to the very small — basically insects and spiders. These animals live on a scale that is utterly alien to us, which has been the subject of numerous movies from *The Fly* ("Help me, help me, help me!) to *Honey, I Shrunk The Kids!*. Obviously, then, on this mini-macroscopic scale, there are advantages to having the complex wiring associated with having six- or eight- legs. On a larger scale, say everything bigger than a rat; however, there appears no advantage. We know this because there are no land dwelling, six- or eight-legged animals larger than a large tarantula.

(This isn't strictly true, since some of the insects native to New Zealand can get as large as small dogs. This is an evolutionary curiosity brought about by the fact that New Zealand has been isolated from the rest of the planet for a very long time. Since humans have introduced small mammals in the form of rats and dogs, the big bugs have been disappearing at a rapid pace, indicating the relative superiority of four legs to six in that particular size class.)

So four legs appear to be the optimum number in the size range human beings tend to be interested in. (And, of course, this rule doesn't hold in the ocean.) Will aliens tend to have four legs? Probably, but with a caveat. We often forget that we humans are also quadrupeds, as anyone who has lived with a baby less than a year old can testify. In fact, we get around fairly well on hands and knees, graduating to two legs only when we need our hands free to better explore the wide world and cause our mothers nervous breakdowns.

Of all the two-legged mammals, we are the most optimized for standing erect. Our pelvises are shaped like buckets to hold our internal organs in place when we stand erect and our spinal columns have four bends in them to give us some lateral stability. Even so, we still suffer from back problems because, while optimized for two legged locomotion, Mother Nature still has a work to do yet before the design is truly perfected. If you look at the skeleton of a monkey or ape you will find a single parabolic curve to the spine just as you find in a dog. A monkey, then, is a four-legged animal that just happens to live a great deal of its life in a vertical position.

What about intelligent aliens? Would they be descended from quadruped animals that over time stood erect to free their hands for grasping? It seems logical, based on our sample of one. And remember, the same basic design worked for *Tyrannosaurus Rex* as works for humans, and we don't overlap one another by 65 million years.

There are, of course, other two-legged animals on the planet — the ostrich, for one. But birds too are descended from quadrupeds. Instead of developing arms and hands, they developed wings.

But why not have a four-legged animal with two arms, essentially a centaur-like alien? After all, that was what I used in my book *The Sails of Tau Ceti*. The reason is that the additional limbs require additional brain capacity and a more complex nervous system, and evolution appears to favor the simpler approach when it is viable. As Albert Einstein put it in another context, "Things should be as simple as possible, but no simpler!"

Now if conditions on the planet in question are much different than they are here on Earth, say the gravity is much stronger, then it is possible that a larger number of legs than four might turn into a survival factor. Here on Earth, and likely on any similar sized planet in the universe, four is the number of legs that are the best compromise between mobility and simplicity of design.

So, your average intelligent alien is liable to have a central torso out of which spring one pair of locomotive appendages and another pair of manipulator appendages, and atop which is some sort of brain case and sensor housing. They will likely be axially bisymmetric (mirror images left and right of their centerlines). They may or may not have tails.

In other words, our competitors among the stars will likely have two arms, two legs, and a head arranged in a familiar pattern. They are likely to look just like us — except with differences!

The End