WE CAN SAVE THE PLANET BY TURNING IT INTO A COMPUTER

A vision of the future

It's the year 2200, and you've just arrived at Yellowstone National Park.

Well, what *used* to be Yellowstone National Park. National parks and forests have become obsolete since nature merged with machines. Such places made sense when we could only preserve nature by quarantining it from industry, but now the two are inextricably entangled. Each benefits from the other to such an extent that destroying any natural place for its raw materials is as absurd as destroying a luxury car for its bumper sticker. Ever since the forest became more economically valuable than the lumber, humanity stopped putting protective fences around the forest. All that remains now is the old "Welcome to Yellowstone!" sign, left in place as a historical oddity. You take a quick picture of the sign, grab a compass, and walk into the wilderness.

As you walk, you encounter a very familiar placard, like thousands of others that you've seen in cities and towns across the globe. "Please remain on the path, this natural environment is engaged in computation." These placards used to amuse you, but they're so commonplace anymore that you barely even glance at this one. It just leaves you with a subconscious gratitude. It is a small reminder of the epiphany which saved the natural world from human destruction only a century ago. Humanity finally realized that these natural systems offer a different (and more valuable) set of "natural resources" intact than they do disassembled. When disassembled, natural places only offer raw materials. But when intact, they offer computers, repositories for data, and mechanisms for moving data. Humanity became symbiotic with nature by finding and using these "natural computers." As you walk, the wild around you includes naturally and artificially engineered systems so intertwined that you pity the future archeologist who may try to disambiguate them.

The trail carries you up a volcano which only recently stopped leaking molten material. Trudging along the hard, igneous ground, you glance at your compass and notice that its twitching back and forth. Of course! You've stumbled upon Repository Mountain. 50 years ago, engineers built a bridge which stretched across the river of lava that has become the trail beneath your feat. As it flowed underneath, this bridge generated large magnetic fields which toggled one direction and then the other, reorienting the tiny magnetic materials in the lava like so many little compass needles. As the lava cooled, these needles became locked in place. Your twitching compass retrieves this data one bit at a time. You chuckle as you wonder how much time it would take for you to recover every bit and decode it into the text which it represents: the entirety of Wikipedia as of the year 2150. Concerned about another solar flare which might destroy electronically-stored data, humanity created Repository Mountain as a resource from which it could recover knowledge. There are no legal protections for this mountain, because it doesn't need them. Everyone values the data that it holds much more than the raw materials that it offers, and thus it will remain pristine for generations.

Glancing into the gorge off your right, you see a strange looking boulder just underneath the surface of a sparkling blue river. Only its right angles betray it as being the product of human engineering. This strange monolith is *covered* with life, as it has become an artificial reef in and on which fish, plants, and crustaceans proliferate. You've read about these! It's a reef computer, powered by the water which flows through it and affected by the life which inhabits it. Liquid computers existed long before the digital electronic computers which dominated the previous century, and engineers resurrected them as special-purpose devices for performing Monte Carlo analyses. Humanity realized that it needn't spend energy on generating random numbers in digital electronic computers if it instead engineered computers which allowed for the intrusion of nature's randomness. As tiny apertures open and close in the reef computer, the water itself becomes the computational medium.

You round a bend to encounter a small detour which takes you around a section of trail. A plaque explains the reason for the diversion:

> *Computational naturalists have discovered that the crack patterns on this section of trail approximate the street patterns in lower Manhattan. A slime mold is currently running an optimization over these cracks, which will be used to inform a redesign of the city subway system. Please do not disturb.*

You chuckle. How many millions of dollars would have been spent in previous centuries on optimizations and calculations of this variety? Why did it take so long for people to realize that nature offers computers that will solve problems of such complexity and value? Nobody dares destroy any natural places anymore, for fear of the unrealized computational wealth that they may be destroying in the process.

At the rim of the sleeping caldera, you're met with an astonishing view of what appears to be an unbroken wilderness out to a distant horizon. These vistas still confuse you, because you *know* that the city from which you drove exists in your field of view, but it's so intertwined with nature that it's difficult to discern. You see large herds of migratory megafauna on their thousands-of-kilometers march. In previous centuries, people nearly hunted these animals to extinction for their furs. Now, they've become mechanisms for moving data. They carry tiny memory cards on their fur, like the seeds stuck to your own jacket, along with them on their journey. In the process, a single herd will move petabytes of information in a fraction of the time that it would take to move that information via the Internet. They're far more valuable as an information transport network than they are as jackets and blankets. The same is true for rivers, ocean currents, and the trade winds. Nature's incredible ability to move *matter*, long used only as a source of energy, is now used to move information. In a few more years, engineers anticipate storing that information in the matter itself. The rivers won't carry memory cards, the water molecules themselves will hold the information.

The world around you has become a computer. Storing information, moving information, and processing information. It always was this way, of course, but you thank God and the universe that humanity started using it as such. Machines that exploited and abused nature generated the environmental crisis of the previous century, and machines for which healthy natural systems are critical components solved it in this one. When humanity unlocked the latent computational potential in nature, it unlocked the incredible economic potential of healthy, intact natural systems. The explosive growth of the economy improved everyone's quality of life, and guaranteed nature's preservation for generations to come.

From preservation by quarantine to preservation by value realization

We can make meaningful progress toward this vision of the future in our lifetimes. All that it requires is that we open our eyes to the unrealized natural resources that healthy natural systems offer, and that we shift our perspective toward those of us who destroy natural places. People who destroy natural places don't do so because they hate nature, they do so because those natural places generate more economic value disassembled than they do intact. The lumberjack doesn't think "I hate this tree!" before cutting it down, and neither does the contractor think "I hate this forest!" before replacing it with a mall. It's just the case that the lumber generates more value than the tree, and the mall generates more value than the forest. Most people love nature, they just need to make a living, often at nature's expense.

For as long as it's the case that natural places generate more value "deconstructed" than they do intact, the only kind of preservation which is possible is "preservation by quarantine." We put up fences, both physical and legal, around these natural places to prevent people from extracting their deconstructed value. The problem with quarantine preservation is that it lacks multigenerational longevity. When times get tough, rules will change and folks will hop those fences to extract that value. And they won't do so because they're bad people, they'll do so because they're trying to survive. One of the unfortunate consequences of quarantine preservation is that we vilify the fence hoppers.

But there is alternative! One which can guarantee that natural places will be preserved for generations to come.

As soon as it's the case that natural places generate more value *intact* than they do *disassembled*, we never need to worry again about nature falling victim to changing rules or to times of trouble. We will have removed any incentive to ever destroy it. As soon as the tree generates more value than the lumber, we no longer need fences around the tree. This isn't preservation by quarantine, it's "preservation by value realization." Nature's economic potential, which will be its salvation, lay in its untapped potential for **computation**, **data storage**, and **data movement**. By incorporating healthy natural systems into our *computers*, we can both increase global computational availability and improve the relationship between nature and machine. If machines that exploit or abuse nature got us into this environmental crisis, then machines for which healthy natural systems are critical components may help us out of it.

Natural creates computers

A computer is *anything* which usefully transforms one quantity into another. From anthill construction to raindrop trajectories, nature abounds in processes which can be described *algorithmically*, or in accordance with a set of rules to be followed in calculations. To the extent that these algorithms are *useful* (and many are), then these natural processes are computers. Nature also offers repositories for information, and mechanisms for moving that information *en masse*. The similarity to conventional computers, which have their own mechanisms for computation, data storage, and data movement, is tantalizing. If we can affect the inputs to these natural systems, comprehend the transformations that nature performs on those inputs and ingest the outputs, then we can deploy these "natural computers" on problems of interest to humans. This is not biomimicry, as the objective is not to replicate nature. Instead, the objective is to find computers that the universe herself has engineered, and to symbiotically interface those natural computers with our own. Success in this endeavor will unlock nature's latent computational potential and incentivize its preservation.

"Natural computers" will develop similarly to conventional digital electronic computers, which started special-purpose and became general-purpose. The first digital computers just computed ballistic trajectories, the first analog computers just computed high-tide and low-tide times, and the first natural computers will be similarly special-purpose. They will interface with our conventional computers (by way of sensors and actuators) so that those conventional computers can offload a single algorithm to that natural system. A general-purpose computer working alongside a special-purpose computer is common in high-performance computing applications, where the special-purpose computer "accelerates" a certain algorithm. To date, however, none of those special-purpose accelerators have been engineered by nature and "found in the wild." The algorithms best suited for "natural acceleration" are those which are *difficult* for conventional computers and *easy* for nature. Random number generation is a low-hanging example of such an algorithm. But low-hanging does not mean low-impact! Natural random number accelerators may reduce energy consumption associated with Monte Carlo analyses.

Monte Carlo analysis is one of the most useful and ubiquitous techniques for high-dimensional problem solving in modern science and engineering. A Monte Carlo analysis solves a deterministic problem by overwhelming it with random trials. Rather than searching analytically for the "right answer" in an ocean of possible answers, a Monte Carlo analysis instead uses a computer to randomly generate and test a *huge* amount of possible answers. By design, it requires generating an epic quantity of random numbers. This is not a simple task for a conventional digital electronic computer with its deterministic internal environment. Every random number that it generates costs that computer time and energy. But it's an easy task for nature.

One could imagine designing our computers such that nature can inject a bit of its randomness into that computer's internal environment. We might design computer memory that is particularly susceptible to "single-event upsets" from galactic cosmic rays or other forms of radiation, so that high-energy particles can randomly flip 1's and 0's in our computer. Or alternatively, one might use the approximately uniform-random distribution of raindrops from a storm, water molecules in a river, or photons from the Sun to perform mechanical or electrical Monte Carlo integration of complicated curves and shapes. Eventually, we will offload other algorithms to natural processes. Nature offers timers in the form of periodic systems and optimizations in the behavior of insects and other organisms. Life itself rearranges its environment in an algorithmic fashion, and may be used as a natural accelerator. We already have evidence that natural computational acceleration works, at least in principle.

Our own brains provide evidence that natural acceleration works. We often think of our phones and laptops as being computational aids to our brains, devices into which we can offload some "thinking." But, in fact, this relationship goes both ways. Our brains remain better than our computers at certain algorithms. When we interface our brains with digital electronic computers by means of keyboards, mice, screens, etc., we also allow for our computers to use our brains as natural accelerators. Our computers offload work to our brains by providing an input via screen, and then prompting for an output via keyboard or mouse. Similar processes are observable elsewhere in nature, where organisms use the natural environment to facilitate their own computational processes. One resource which facilitates these processes is *memory*, or repositories for data. Nature offers memory by the zettabyte, and we may eventually make use of that memory without adversely affecting any life or natural processes.

Nature offers repositories for data

One model for life is a *function* which takes its environment as an input, and provides a reorganized version of its environment as an output. We humans reorganize our environment in a particularly visible way, but even earthworms and phytoplankton modify their environment as they push dirt aside or adjust the temperature of nearby water molecules. These environments contain huge number of "degrees of freedom," or numbers that you would need to write down to fully specify the state of that system. For example, you'd need to write down nearly 6000 billion numbers to specify the position and orientation of every grain of sand in just one cubic meter of beach. Many of those degrees of freedom are *invisible* to the life which inhabits those environments. The earthworm doesn't mind if we rotate a few pieces of dirt, and the crab doesn't mind if rearrange some grains of sand. We are free to store data (a lot of data) in those invisible degrees of freedom without having any effect on local life. One could imagine storing data in the magnetic polarization of iron-bearing minerals in igneous rock. We might store data as electromagnetic waves bouncing back and fourth between receiver/transmitters on Earth and Moon, or acoustic waves bouncing back and forth in a cavern. One could imagine storing data in DNA, and indeed much progress has already been made in this direction. It is worth noting that every degree of freedom is available for information storage in environments that contain no life, like the Moon and asteroids. Eventually, we may store data in the organization of the atoms themselves. And excitingly, some of these repositories for data *move*.

Nature moves information

Nature excels at moving tremendous quantities of matter over tremendous distances. Examples include animal migrations, ocean currents, water and carbon cycles, and the movement of celestial bodies. **Anytime that matter is moving, information is moving too.** Humanity has a long history of using this moving matter to generate energy, but has underutilized these processes for data transfer. There is some precedent for doing so in the form of homing pigeons and sailing vessels (among a few others), but we've yet to approach the channel capacity for these systems. There exist both near-term opportunities and long-term possibilities for injecting information into these epic movements of matter.

In the near-term, we can add matter in the form of conventional data storage devices to these systems, such that they are swept along from origin to destination. This method for data transfer makes the communication channel "bursty" in the sense that the information arrives all at once rather than bit by bit, but it enables a shockingly high average data transfer rate. It's worth pondering, for instance, that the data rate for a single humble homing pigeon carrying 1TB SD cards from New York City to Boston is approximately 3 GB/s. And there exist natural migrations of matter with far more capacity for excess mass than pigeons (e.g. ocean currents, trade winds, and whales). In the long term, it may be possible to embed the information in the matter itself, by looking for and modifying the invisible degrees of freedom discussed previously. Humanity must begin asking itself questions like "what is the information channel capacity of the Nile?"

How this starts, and where it leads

Developing natural computers will occur in phases, the first of which resurrects the naturalists of previous centuries. Like those naturalists, the natural computing researcher will go into the wilderness to look for new things. Rather than searching for new plants and animals, this person seeks natural computational processes, natural repositories for data, and natural movement of information. These processes will be studied and modeled to gain an understanding of their algorithmic qualities, and then the researcher will design and build devices which make these evolved systems components of a larger machine.

Humanity has a long history of using natural processes to produce power, but it has underutilized these processes for computation. Unlocking the latent computational potential in nature could increase total global computational availability and fundamentally change the relationship between nature and machines. This is how we move from preservation by quarantine to preservation by value realization. This is how we ensure multigenerational conservation of natural places. Very earnestly, I think this is how we save the planet. We must stop insulating nature from industry, and instead incorporate *healthy, intact* natural systems into our machines. Natural computing is how we become fully symbiotic with the natural world.

In a few more years or decades, one may encounter signs in natural parks which read "please remain on the trail, the trees are engaged in computation." Vast swaths of wilderness will be protected for the computational utility that they contain. We will save the planet by turning it into a computer.