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WHAT ET WILL LOOK LIKE AND WHY SHOULD WE CARE

Seth Shostak
SETI Institute
515 N. Whisman Rd.
Mountain View, CA 94043
sshostak@seti.org

ABSTRACT

Our experiments to find extraterrestrial life are predicated on the assumption that it is most likely to be found on so-called "habitable worlds." These are planets and moons where surface liquid water exists, and atmospheres of light gases are found. Our searches presume that life on other worlds has a biochemistry at least somewhat similar to our own.

While these postulates might be our best guide for finding biology, they could be misleading us in the search for extraterrestrial intelligence (SETI). Timescale arguments suggest that shortly after a sentient species invents the technology for communication, it develops synthetic intelligence. Consequently, SETI's targeted searches of star systems that might have habitable planets in the conventional sense may be chasing a very short-lived prey.

In this paper, we discuss what the implications of post-biological intelligence might have in directing our SETI experiments.

INTRODUCTION

SETI experiments of the last 50 years have assumed that sentient extraterrestrials will be fashioned in our own image. Our current efforts to eavesdrop on artificially constructed signals reflect this. We do not insist that the broadcasters be biochemically identical to terrestrial life, or even that they be carbon-based. But SETI observers have almost always chosen target stellar systems that are deemed likely to include rocky worlds, with liquid seas and thick atmospheres [1]. The only routine exception to this are the sky surveys that give all patches of celestial real estate equal *a priori* weight.

The Drake Equation [2], the logical scaffolding for discussing the chances of finding sentience elsewhere, assumes that SETI's prey will arise as biology on a planet, and will have progressed to intelligence and long-lived technical capability. But this same formulation also makes clear that the chances of finding a signal rely strongly on a value for *L* – the technological lifetime of a sentient society. Typical estimates of L range from 10^3 to 10^6 years [3].

Therefore targeted SETI searches make two strong, implicit assumptions about the type of beings they could detect: (a) they are the outgrowth of biological processes, and (b) they are – even thousands of years after achieving technical ability – still inhabiting their natal world (or are émigrés to another world of similar type).

This anthropocentric reasoning lies behind the enthusiasm of SETI practitioners for NASA's Kepler mission [4], an experiment that, by 2012, will establish the fraction of stellar systems that have Earth-like worlds – planets roughly the same size as our own, and orbiting their sun in the so-called "habitable zone", where water remains liquid. The expectation is that such terrestrial clones will not be rare.

For SETI, the detailed construction of the aliens is seemingly of no consequence: if these putative beings are capable of building powerful transmitters or lasers, then that is all we require. Their appearance, physiology or motivations, are obviously speculative and – judging by the scarce attention given the matter – of small interest to SETI practitioners.

However, this indifference to the true nature of the extraterrestrials may be adversely affecting the search.

WHY WE MIGHT CARE

The necessity for considering the nature of extraterrestrial sentience can be gleaned from an historical example, namely our changing conception of Martians.

Only a century ago, mostly thanks to the inventive mind and supple writing of Percival Lowell, we imagined that the inhabitants of Mars were both intelligent and capable of planet-wide engineering [5]. There was, we were told, a vast, hydraulic society on Mars. By the 1930s, our expectations had diminished, as astronomers found that the Red Planet possessed only a very thin, carbon dioxide atmosphere. But even as late as the mid-1970s, we still expected some plant life, or at least pond scum (if not ponds) on the Martian surface, thus prompting the elaborate experiments carried out by the Viking Landers. At least one embryologist had speculated that finding life on Mars required no more than landing a mousetrap and a camera on the surface [6]. However, the Viking landers – which did include cameras – failed to find any signs of a martian biota. The Biology Team concluded that the landscape was barren [7]. (Note, however, that at least one member of the Viking team maintains that this conclusion was marred by misinterpretation of the data [8]).

For those who expected to find life on Mars, Viking was a disappointment. It wasn't the last. In 1996, we were told that Martians – dead ones – had been found in a meteorite, ALH 84001 [9]. This claim remains contentious, but has led most researchers to the current, modest view of Martians: if they exist at all, they're likely to be bacteria-like creatures in underground aquifers.

In a century, we went from Martians engaged in planet-wide civil engineering, to cryptic microbes a few hundred feet below the planet's dry, sterile surface. Clearly, there's been an evolution in our image of these putative neighbors, and similarly an evolution in our techniques for discovering for them. We once sought Martians using modest-size refractors in Flagstaff, Arizona. Today we contemplate a search using robotic drilling rigs, sent to the surface of the Red Planet. Perhaps this is a necessary, and salutary, warning for SETI. As our perception of the Martians changed, so too have our techniques to hunt them down. But our search for ET hasn't changed in anything like the same degree.

THE USUAL ASSUMPTIONS

Our anthropomorphic bias about extraterrestrials is occasionally justified on the basis of convergent evolution. Simon Conway Morris [10] has argued that the body plan of *Homo sapiens* is near-optimal for intelligent beings, and consequently non-terrestrial sentients might be – on a dark night and from a distance – indistinguishable from ourselves. But even those who dispute the idea that the extraterrestrials will be a physically close approximation to ourselves make the usual assumptions about their habitat: (a) on a planet with liquid water, having a (b) non-negligible atmosphere, and (c) of an age of at least a billion years or so (to allow time for the evolution of intelligence).

So our targeted SETI experiments, beginning with Project Ozma in 1960 [11] scrutinize star systems that are assumed to be of the type likely to host Earth-like planets. Until recently, this meant stellar cousins of the Sun: F, G, or K-type stars. Recent work [12] has enlarged this small range of types, by noting that even closely orbiting planets – tidally locked worlds – could have habitable zones. Consequently, modern SETI target lists also include the very numerous M-dwarfs.

An additional evolution in our ideas of habitability has been theoretical work showing that double-star systems might also be suitable homes for long-lived planets [13]. So multiple star systems, which had been *personae non gratae* for targeted SETI searches, are now in the candidate race.

Today, roughly 90% of all star systems seem plausible homes for the type of protoplasmic aliens that we've always pictured. That's an evolution in our strategies, but does not include any evolution in our picture of the extraterrestrials. However, with the overwhelming majority of stars now tallied as possible environs for technological societies, what more could we do in deciding where to point our telescopes?

Well, here's something both obvious and tangible: We still have little idea of the planetary complement of these stars, at least as far as habitable worlds are concerned. That is, we still have yet to find a demonstrably Earth-mass – let alone, Earth-like – exoplanet. Presumably, this will happen by 2012, as NASA's Kepler mission completes its planetary inventory. At that point, we can sharpen our target lists by narrowing in on the types of solar systems where we, ourselves, might feel at home.

All of this is either history or is in the easily predicted near future. When Frank Drake pivoted his 85 foot antenna at Tau Ceti and Epsilon Eridani, he was checking out cousins of the Sun, where he assumed he might have the best chance to find cousins of us. And truth be told, we still engage in the same experiment, albeit fattened on the feed of some good astronomy and excellent improvement in search hardware.

A DIFFERENT SORT OF EXTRATERRESTRIAL

Our searches continue to hunt for the same sort of extraterrestrial we've imagined since the days of Percival Lowell. However, a well-established truism of SETI might serve to enlarge the range of our vision.

That truism is this: should a SETI experiment detect a signal, it's most probably coming from a species far in advance of our own. This is easily understood by recalling the Drake Equation, and its last, important term: *L*, the average lifetime of a technological society. If this term is not large – at least 10^3 or 10^4 years or more – then the chances of stumbling across a signal are small. Ergo, if we find a signal, then *ex post facto* we've demonstrated that *L is* large. Consequently, the chance that we've heard a society within, say, a century or two of our own level is clearly very small.

So detected extraterrestrials will be millennia or more beyond our own level of development. This fact motivates the usual approach to answering the question "what will the aliens be like?" We simply extrapolate our own existence a few thousand years into the future. Perhaps, as is so often depicted by fiction, our descendants of the forty-first century will have taken our own physical development farther down the road we've trod so far. We'll have less body hair, fewer teeth and only minimal olfactory sense. Our continuing social drift toward a meritocracy may endow our descendants with larger brains and less muscled bodies, since the latter are no longer essential. This is the way that many aliens of the phosphor and silver screens are depicted.

Another scenario for our future development is that we'll become bionic. The first steps in putting engineered appliances into our bodies have already been taken. In some cases this is just to remedy physiological defects – such as cochlear implants. In others, such as RFID devices, implants offer a convenience (and a possible loss of privacy). But if you could encode even one bit of information into every atom of a memory device (a number which is surely too conservative), then all the information on the internet could be kept on something far smaller than a grain of sand. If some chip could make this accessible to your brain, then a serious enhancement of both knowledge, and possibly even your ability to think would be achieved. Such off-loading of information and, presumably, cognitive power is frequently estimated to be no more than a few decades away.

However, while these speculative scenarios about our own near future – and by extrapolation, the extraterrestrials' past – are interesting, they wouldn't cause a shift in our SETI experiments. We'd still be looking for carbon-based chemistry on rocky, watery planets.

REPLACEMENT AND IMPROVEMENT

However, another extrapolation of what lies in store for humanity leads down a different road. That's the path to artificial intelligence. Perhaps we're only here to invent our successors.

This has become a popular theme of late. While artificial intelligence, or AI, is an endeavor many decades old, the continued exponential growth in computer power, typified by Moore's Law [14], implies that even consumer grade computers will have the processing power of a human brain (and much more memory) by the year 2040 [15]. This headlong and accelerating rush towards technology that can cognitively outpace its creators is often called "the singularity" [16, 17].

Today, if you go to conventions on AI, the discussion seems to have moved beyond the question of "could we ever make a thinking machine" to such questions as "can we ensure that it has moral behavior" – which is surely just a euphemism for "could we pull the plug, if necessary?"

While not everyone agrees that it's possible to construct a functional replacement for what Philip Morrison [18] called "a slow-speed computer operating in salt water" – namely our brain – the AI community remains sanguine. They also point out that their lack of success to date shouldn't be confounded with a lack of progress.

If this occurs, if we succeed in producing an artificial sentience able to think as deeply as we can, then we will be quickly outpaced thereafter. We will have lost the race, and will have no hope for a rematch. Moore's law for computational machinery describes a doubling time for performance (at a given cost) of 18 months. The exact numbers aren't important. What *is* important is that this rate of improvement is enormously speedier than any we could expect from Darwinian evolution – even making the less-than-certain assumption that such evolution would move us in the direction of greater cognitive ability. The thought that we'll keep up because we're going bionic is wishful thinking, and akin to believing that improved running shoes will allow you to beat out a race car. If we build a machine with the intellectual capability of one human, then within 50 years, its successor is better than all humanity *combined*.

Assuming that our own technical timescales are not grossly atypical, this implies something important for SETI: once any society invents the technology that could put them in touch – once they reach a level that's comparable to our own, and become detectable with our listening experiments – they are at most only a few hundred years away from changing their own paradigm of sentience to artificial intelligence.

It's possible, of course, that the development of AI won't substantially affect the continued existence and activities of its biological ancestors, in which case the living extraterrestrials could still be there to find. But it seems reasonable to suppose that the artificial sentience will inevitably outlast and outperform its predecessors. Making this assumption, we can conclude simply on the basis of "technological lifetimes" that the aliens – at least, any we hear – will be machines.

THE BEHAVIOR OF ADVANCED SENTIENTS

To understand how a shift in our conception of sentient extraterrestrials from biological to technological might affect our SETI searches, we would be well served to understand their motivation and behavior. What is it that they would find interesting to do?

While there has been speculation – mostly in the sci-fi literature – about what would be important to a thinking machine, there are only three things that seem sufficiently plausible that we might call them likely:

(a) High speed computation requires a compact configuration. Consequently, the machines are unlikely to spread out over vast distances – either by using distributed computing via a widespread array of central processors or a swarm of nanobots. An optimal computer would be functionally malleable, and compactly packaged – made up of (still hypothetical) "computronium" [19]. In other words, the principal artificial sentients will be localized.

(b) Because of the very short timescale for improvement, a "winner take all" situation would probably obtain for thinking machines. That is, the first one to arise will dominate, at least within a volume of space through which communication (to its competitors) is still small enough that a "second genesis" wouldn't get ahead.

This point can be simply understood. Suppose a technological society arises in the Galaxy at point A, and eventually produces machine intelligence. That device locates another machine – one that may have been around a long time – at point B, which is 100 light-years away. Machine B downloads its capabilities and knowledge to A, and both machines continue to improve, although machine A is clearly 100 years behind its predecessor B (the download is old, delayed by the time-of-flight). If, however, machines have as much as a 10% variation in speed of improvement, then within 1,000 years, machine A could overtake B, and become the "alpha male" of that part of the Galaxy. In other words, the lead machine could shift around.

But if there is any limit on the variation in improvement speed, then there's also a limit on how far from the first successful machine a competitor could arise able to surpass its elder. The also-rans might never be able to catch up. So it may be that the oldest machine cultures (and a culture may consist of one machine) could successfully remain in advance of all the others indefinitely, at least within a volume of space that might be thousands of light-years across.

(c) Space is dangerous, even for machines. So some sort of Darwinian selection will inevitably take place. If a machine exists now, it's because its mode of existence has kept this device from natural disaster – or possibly even from deliberate disaster, if such a phenomenon exists for machines. Perhaps it makes lots of copies. Or at least a few copies, updating as necessary. It does *something* to withstand inevitable catastrophe.

CONSEQUENCES FOR SETI STRATEGY

What consequences might the scenario described above have for our SETI searches? We first consider the advantages AI would have over biological intelligence:

- Far more intellectually capable
- Immortal, or at least amenable to indefinite repair
- Capable of Lamarckian evolution: the individual could improve
- Not dependent on biological environments
- Any new instance of an artificial intelligence could be preloaded with knowledge, and "born smart"

One of the many sequelae of this laundry list of selling points is that these "intelligently designed" aliens can undertake interstellar travel. After all, when you're immortal, all trips are the same length. But it's also true that they needn't live on planets. What they require for existence is rather simple:

- Energy on which to operate, and
- Some material from which to fashion new parts (either replacements or improvements)

In other words, the restriction to watery worlds is not one that such intelligence is required to heed. Indeed, it's unclear that they need be situated on planets at all. The interstellar flux in our part of the Galaxy is roughly a watt per square kilometer of collector. Consequently, it's not inconceivable that efficient machines could be situated anywhere, not just in the immediate neighborhoods of stars.

While low-power machinery might eke out an existence between the stars, the intellectual giants of the universe – machines able to expand their computational activities far beyond what we can conceive – might be prodigious consumers of energy. That suggests that these alpha male sentients might repair to regions of high energy density, for instance the center of the Galaxy. For the machines, for whom the trip to the center is only an inconsequential inconvenience, and for whom the bad environment would be tolerable, this might be a desirable place to set up shop.

Stellar black holes are another locale offering abundant energy. Neutron stars, or simply high-luminosity O and B stars might also be seductive locales for high-metabolism machinery. Cirkovic et al. [20] have suggested that AI would prefer the outer regions of the Galaxy, where the gelid cold could permit greater thermodynamic efficiency. On the other hand, the obvious shortcoming of such rural locations is the diminished availability of matter, as the stellar density is low.

We suggest that locales that have the thermodynamic advantages of the galactic nether regions but still lie in regions of high matter density should also be considered as stellar targets. Bok globules, incompletely understood dark clouds of interstellar gas and dust, are examples of a target that seems to accord with the requirements of high-powered computing machinery. While the kinetic temperature in the interstellar medium is typically 100 K, Bok globules often have temperatures < 10 K. In addition to offering high thermodynamic efficiency, they are also rife with interstellar matter. As a practical matter, they also are conducive to observation: being typically a few to a few hundred light-years in diameter, and at distances of hundreds to tens of thousands of light-years, they are nicely congruent with the beam sizes of many radio telescopes.

CONCLUSIONS

Timescale arguments suggest that the bipedal biological creatures of yesteryear may be a provincial concept for extraterrestrial intelligence. Since, on the basis of our own anticipated future, the development of artificial intelligence follows the invention of radio by only a few centuries, it seems likely that the majority of aliens that are beyond our level are not merely another species; they are of an entirely different construction altogether.

The nature of our SETI experiments ensure that any sentience we detect will at least as technically advanced as we are, and the requirement that such sentience be long-lived (the *L* in the Drake equation) suggests that anything we find will likely be centuries or millennia (or more) beyond our level of development, and therefore will sport artificial intelligence. The three factors noted above, namely a compact configuration, a Darwinian imperative, and an extreme hierarchy, seem likely for machine intelligence, and thus for alien intelligence we might find.

On the basis of what seem like obvious long-term requirements for any deliberate intelligence – matter and energy – we suggest that regions of high energy density and/or low temperature should be included in future SETI targeted searches. These include the neighborhoods of hot stars, black holes, neutron stars, and the cold molecular clouds known as Bok globules.

The question for SETI is, would such intelligence produce signals we might detect? That is unclear. Perhaps such machines have curiosity and/or altruism. The former might cause them to seek out worlds where intelligence may have arisen, including worlds like our own. The latter might encourage them to bring other intelligence into their fold.

Such possibilities provide scant clues for focusing our search. But continuing to hunt for our analogs – technically competent biological sentients – may be an enterprise with less than promising prospect, as it focuses on a highly transient prey. Machines have no obvious limits to the length of their existence, and consequently could easily dominate the intelligence of the cosmos. Perhaps we should expend some effort in trying to establish their presence. To paraphrase Cocconi and Morrison [21], we can only succeed if we try.

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