Aliens Are Likely to Be Smart But Not "Intelligent": What Evolution of Cognition on Earth Tells Us about Extraterrestrial Intelligence

Anna Dornhaus

Abstract

How likely is it that we will find aliens like the ones in so many science fiction stories–people who possess self-awareness and cognitive ability comparable to ours, but who arose from an independent evolutionary origin? Here I make the argument that if life has evolved on other planets, it may well eventually acquire complexity equivalent to that found on Earth. The resulting lifeforms may be good problem-solvers, including predicting their environment and the behavior of social partners, using tools, learning, and otherwise flexibly and adaptively responding to information: these are all traits common among organisms on Earth. However, on Earth, human-like intelligence is unique. No other animal appears to have the same level of cognitive complexity, ability to use abstract and endlessly flexible communication, and ability to capitalize on social division of labor as humans do. Surprisingly, we do not know why this is the case: why are we the only ones with this level of intelligence on our own planet? This is not an unsolvable question in principle: we know the answer to many evolutionary "why" questions when it comes to animal intelligence. In the case of humans, however, natural selection to increase individual reproduction seems insufficient as explanation. Perhaps it is: sexual selection, the evolution of an exaggerated trait unnecessary for survival but impressive to potential mates, much like a peacock's tail or a nightingale's song, may be the most plausible explanation for the evolution of the human brain. If this is true, then we should expect cognitive ability, i.e. learning, memory, abstraction, and many other elements of intelligence to be commonplace in the galaxy as they are among organisms on Earth; but exaggerated intelligence as in humans may be a rare accident of chance, as rare as a peacock's tail.

Introduction

When we finally discover life on another planet (or moon), will it be an alien civilization with which we can have an intellectual exchange of ideas, or will it be something we study in a test tube? Here I discuss what we know about how likely it is, given that life has evolved on a planet, that this life will develop into something like humans. I'll first mention different aspects of what might be called ‘intelligence’, and where and why we find them on Earth. Then I’ll discuss what is unique about human intelligence, and why it appears to be unlikely to evolve.

Intelligence that is not human

What is intelligence? There is no generally agreed-upon definition, but intuitively the concept refers either to advanced cognitive ability or to consciousness. Cognitive ability, roughly, is the ability to solve problems with a nervous system (although there are exceptions, e.g. in collective (Reid et al. 2012) or artificial intelligence (Lindley 2013), or when referring to microbes or plants (Trewavas 2016); see particularly (Baluška and Mancuso 2009) for a broader perspective). For example, this might include specific skills such as navigation, recognition of social partners, or counting, or general abilities such as generalization, learning, ability to solve novel problems by insight, etc. ((Shettleworth 1998); I discuss consciousness below). Many of these skills imply that information is received through sensory organs, processed in some way, and a motor response generated. Generally ‘more intelligent’ is thought to imply more complex such information processing (not simply learning speed, (Chittka et al. 2012)); in terms of the observed outcome, generally more flexible behavior and more generalized problem-solving skills are considered more ‘intelligent’ (Matzel and Kolata 2010, Gould 2004).

There is abundant evidence that intelligence, in this sense, cannot be reduced to a binary present/absent distinction. Biology and psychology have a history of attempting to define human uniqueness in terms of some specific cognitive skill that non-human animals are simply not capable of: this approach has repeatedly failed (rev. in (Gould 2004); e.g. with regard to tool use (Goodall 1964, Krützen et al. 2005, Weir, Chappell, and Kacelnik 2002); theory of mind (Call and Tomasello 2008, Dally, Emery, and Clayton 2010) although see (Penn and Povinelli 2007); use of communication signals that are abstract representations of their content (Frisch 1967, Seyfarth, Cheney, and Marler 1980, Janik 2013, Slobodchikoff et al. 1991, Ausmus and Clarke 2014); episodic memory (Griffiths, Dickinson, and Clayton 1999, Dere et al. 2006); or metacognition (Dornhaus and Franks 2008, Liu et al. 2016, Sayers et al. 2015)). In addition, many cognitive skills which we realized were present not only in humans but also in non-human primates have now been demonstrated in animals that are much more distantly related to humans, and sometimes even been shown to be common in arthropods (rev. in (Dornhaus and Franks 2008, Greenspan and van Swinderen 2004); e.g. social learning and teaching (Dunlap et al. , Richardson et al. 2007); generalization (Wehner 1971, Liu et al. 1999); tools (Morrill 1972); cognitive maps (Menzel et al. 2000); individual recognition (Tibbetts 2002); planning or latent learning (Franks et al. 2007, Tarsitano and Jackson 1997); analogical reasoning (Giurfa et al. 2001, Zhang et al. 2005)). However, it is clear that while we find a variety of such cognitive skills present across different species of animals, we also find many species that lack some or all of these skills, and the presence of one specific cognitive ability is not a good predictor of other such abilities (Gingins and Bshary 2016).

The probability of non-human-like intelligence

The field of behavioral ecology, or more specifically cognitive ecology, studies what conditions promote the evolution of intelligence generally or with regard to any of the specific skills listed above (Dukas 2004, 2008). In other words, under which conditions is the gain in individual reproduction[1] achieved with a cognitive

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[1] How evolution works: A defining characteristic of life is that it evolves (Mix 2014); one might argue this is the only definition of life we need (I would). Evolution is the logically necessary consequence of reproduction with inheritance and variation: any heritable variant of a trait that increases the chance that more individuals in the next generation will have the same heritable trait variant will increase in frequency over time. This is why a lot of biological articles on evolution of cognition focus on demonstrating variation and heritability. That variants producing more offspring will be more frequent in the next generation sounds obvious, but has non-obvious implications. First, all that matters for evolutionary optimization is individual reproduction, not any other performance measure such as survival or harmony with others. Although what is considered an individual can be tricky (essentially it is the unit that is reproducing with variation and inheritance), it is generally not the species (i.e. traits do not evolve because they promote the survival or spread of a particular type of animal, but do so because they promote the reproduction of the particular individual, or gene, that carries them). In an extreme example, biological species can and have evolved themselves into extinction ("evolutionary suicide", (J. Rankin and López-Sepulcre 2005); this is possibly the reason for the extinction of sabertoothed tigers, for example (Van Valkenburgh, Wang, and Damuth 2004)).

This is relevant for the discussion of intelligence primarily because evolved intelligence is intelligence that serves to maximize reproduction. There is no process that promotes open-ended increases in intelligence (within evolution by natural selection, see discussion for humans below). Second, intelligence serves to reach goals, but these goals are not defined by it. Organisms may, for example, evolve to be highly cooperative or not, independently of whether they evolve to be more or less intelligent. Interestingly, this actually implies that the motivations and goals of humans may be more aligned with those of living beings on other planets than their physical similarities warrant: every system that evolves, including humans, cares a lot about reproduction, and thus for example about gathering resources and possibly mating partners. Differences may lie in the degree to which sexual reproduction of some kind plays a role, and to which cooperation between genes, cells, individuals, or larger units exists and is enforced. But this is a topic for another book.

skill worth the costs of this skill? Answering this question requires understanding both the costs (e.g. (Johnston 1982, Mery and Kawecki 2003)) and the benefits of intelligence or cognition. “Constitutive” costs are those that are paid up-front, whether or not a skill is used. This might include the cost of building neural tissue, elaborate sensory organs, etc., and the costs of maintaining them even when not used. “Induced” costs are those that are paid when a cognitive skill is used, such as the energy costs of firing neurons (Mery and Kawecki 2004). Importantly, some of the most important costs of behavioral flexibility and learning may not be physiological, but include opportunity costs (e.g. spending time to collect information instead of food) and costs of mistakes (when something has not yet been learned) (Shettleworth et al. 1988). To illustrate this, think of bees. Bees eat only nectar and pollen, and thus have to find flowers to extract their food. Some bees, like solitary cactus bees in the Southwestern US, are specialized on a single species of cactus (McIntosh 2005). They thus need no flexibility, but are genetically preprogrammed to identify exactly what their food sources look like and how to handle them. Bumble bees, on the other hand, are typically generalists: they can learn to extract food from any type of flower as well as many contraptions built by scientists, such as tunnels and mazes. A naive bumble bee or honey bee, however, may spend quite a while learning what a flower is (Gil, De Marco, and Menzel 2007, Menzel and Giurfa 2001), and how to handle a particular type (Raine and Chittka 2006, Muth, Keasar, and Dornhaus 2015). Which is the better strategy long-term? In a long-term fixed environment, preprogrammed behavior is better– cactus bees may have a neural system that is optimized for the single function of finding cactus flowers, and that is likely highly efficient at this (Bernays 1999, Laverty and Plowright 1988). The cactus bee does not waste time with things that are not cactus flowers or flowers at all, and makes very few mistakes. However, bumble bees, because of their ability to use a much broader spectrum of nectar and pollen sources, are able to populate much more diverse environments, and presumably will thrive more easily in environments that are changing (Stephens 1991).

Why then do some animals become like cactus bees, and others like bumble bees? And what can we conclude about possible organisms on other planets? Essentially, some environments and lifestyles promote the evolution of behavioral flexibility generally. First, organisms that are generalists with regard to food sources and habitats used tend to rely more on learning and plastic (i.e. not innately fixed) behavioral strategies; this is especially the case for extractive foragers, i.e. animals which have to manipulate their catch in various ways to extract food (Navarrete et al. 2016). Second, the frequency and predictability of environmental change over spatial and temporal scales has a strong impact on the potential benefits and costs of learning: environments that are fixed over many generations produce organisms that are hardwired for the best strategies in that environment (Stephens 1991). On the other hand, in some environments, within an individual's lifetime, the best strategy changes so fast, or the cues that allow a decision about which strategy to use are so unreliable, that learning does not evolve either, and individuals are better off choosing randomly (Dunlap and Stephens 2009). For example, stickleback fish living in the open water do not get reliable cues to orient to, and thus did not evolve this skill; other sticklebacks living near lake bottoms, however, have very good landmark learning and orientation skills (Odling-Smee, Boughman, and Braithwaite 2008). Thus, only in environments where the best strategy is somewhat predictable from sensory information, but not fixed over evolutionary timescales, do we expect organisms to evolve behaviors reliant on learning. These types of environments thus seem necessary for the evolution of intelligence.

It is important to point out, however, that a biologist's understanding of environment is sometimes better described as ecological niche (Peterson, Soberón, and Sánchez-Cordero 1999, Kerr and Feldman 2003): it does not necessarily refer to a geographic environment (e.g. certain temperature and weather), but to everything important to the organism, such as food sources, predators, availability of nest sites, etc. It is thus quite possible that the same geographic area contains species that live in a stable environment and species that live in a highly fluctuating environment, as determined by the temporal dynamics of their respective ecological niches. It is unlikely that we would be able to predict, from astronomically observable traits of planets, what types of environments (with regard to, for example, predictability etc. as above) any local organisms will encounter. In current biology, there is not even a consensus on how and why environmental variables and gradients affect species diversity (e.g. (Latham and Ricklefs 1993, Gaston 2000, Michalet et al. 2006)), something that is much easier to measure than temporal and spatial heterogeneity or the predictability of resources and other ecological factors for individual species.

More generally, cognitive ecology has provided abundant evidence that cognitive skills evolve to be finely tuned to their benefits and costs. That is, closely related species may repeatedly evolve or lose particular skills (Sherry, Jacobs, and Gaulin 1992, Gingins and Bshary 2016); even within the same individual organism, if local/current conditions change the benefits of a particular skill, that skill, and even the associated part of the brain, may disappear only to be rebuilt again later (Galea and McEwen 1999, Galea et al. 1994). In addition, animals may use fixed strategies or rules-of-thumb that generate approximately correct behavior in expected environments (Fawcett, Hamblin, and Giraldeau 2013, Fawcett et al. 2014). Similarly, many animals have evolved specific cognitive problem-solving skills, but not others: the reed warbler, a bird parasitized by another bird, the cuckoo, can discriminate cuckoo eggs from its own even though the differences are extremely subtle; but it is apparently fooled by the cuckoo chick, which looks nothing at all like its own chicks (in this particular case, the likely explanation is that a highly efficient first line of defense (egg recognition) prevents the evolution of an effective second line of defense (chick recognition) because that second line of defense is so rarely needed that it fails to exert significant selection pressure, (Kilner and Langmore 2011, Grim 2006)).

In summary, many cognitive skills have evolved repeatedly across a wide variety of organisms; we know something about when we expect them to evolve once we know what an organism's ecological niche is; and they can evolve and disappear quickly depending on how much they increase individual reproductive success in a given system.

A side note on "complexity"

A characteristic of life on Earth is high complexity compared to non-life. Without attempting to define this exactly, life is diverse (many types of life), made up of interacting units at several levels of organization (molecules interacting form cells, cells interacting form animals/plants, species interacting form ecosystems), and behaves in ways that are both less random and less predictable than behaviors of solids, liquids, and gases–all of this can be thought of as contributing to the complexity of life. Many complex systems are self-organized, in that their structure is not strictly hierarchical, but instead the problem-solving ability of the system is produced by the distributed actions and interactions of its parts–this is in essence also how nervous systems, and brains, work. The distributed nature of intelligence is sometimes more obvious than other times (see Sitvitilli and Gire in this volume), particularly when not referring to nervous systems but to collective intelligence such as that displayed by social insect colonies as a whole, which, for example, arrive at consensus decisions in much the same way as a brain does (Marshall et al. 2009).

Biologists have not made much progress understanding the evolution of complexity: that is, unlike for intelligence, we do not know which environmental conditions (biotic or abiotic) promote or prevent complexity. However, like non-human intelligence, complexity has emerged repeatedly in different lineages of life and in different environments. One might argue that, across Earth's history, complexity initially increased first slowly and then rapidly (e.g. the number of species has increased at the fastest rate in most recent geological records, at least until the advent of humans). Such a pattern suggests an exponential function, which is typically generated by a positive feedback; i.e. complexity may promote the evolution of more complexity. If that's the case, how common complex life is on other planets may depend a lot on how long it has been there.

Human-like intelligence

It has been surprisingly difficult to define cognitive skills that human brains can do that insect brains cannot, despite the fact that insect brains have around on the order of 100,000 (10^5) neurons and human brains have around 1 billion (10^9). This indicates that many aspects of 'intelligence' may not require a large brain, and that we understand little about what size brain is needed for particular cognitive skills (Chittka and Niven 2009). But it may also indicate that finding qualitatively different processes to define human intelligence is the wrong approach (Lindley 2013, Shettleworth 2010). Quantity matters, too: human brains are built from the same toolkit (cell types, genes) as other animal brains, but more cells, or more connections, may enable ultimately significantly different outcomes (Mashour and Alkire 2013, Roth and Dicke 2005). Non-human animals show the ability to generalize or learn concepts (Giurfa et al. 2001); but human capacity for abstract thought and behavioral flexibility is unmatched (Matzel and Kolata 2010, Penn and Povinelli 2007). Non-human animals communicate, including with symbols (Frisch 1967); but the human capacity for expressing complex and novel types of information with language is unlike the communication systems of any other species on Earth ((Hauser, Chomsky, and Fitch 2002), and see Ross in this volume). Non-human animals exhibit social learning, in that their behavior can be affected by the behavior of others (Leadbeater and Chittka 2007); however, the richness and complexity of information and training that humans are able to pass on to other humans is unrivalled (Tomasello, Kruger, and Ratner 1993).

Consciousness.

This chapter largely equates intelligence with cognitive problem solving. However, in common parlance, many people use the term ‘intelligence’ to imply consciousness, which is also often considered a quintessentially human trait. Consciousness, however, so far evades scientific study (although progress is, perhaps, being made, (Boly et al. 2013)). We don’t have an operational definition or know how to measure whether it is present (a practical problem for example for anesthesiologists; (Bayne, Hohwy, and Owen)). Some argue it ubiquitous, a necessary side-effect of any complex information processing (Trewavas and Baluška 2011); some argue that there is evidence for consciousness in non-human animals (Barron and Klein 2016, Griffin and Speck 2004, Greenspan and van Swinderen 2004) or plants (Trewavas 2016); others believe it entirely optional even for human-like brains (although see (Dennett 1995)). Evolutionary biologists argue from plausibility that if we have it, it must be good for something. We would also argue from homology that, since most cognitive traits we have also occur in non-human animals, at least some of them probably also have some form of consciousness. Empirical attempts to study it usually center on testing for self-awareness or episodic memory of some kind. No test for the benefits of consciousness, compared to an organism of similar intelligence but that lacks consciousness, has been developed. Given this, we can make no statements about what causes consciousness to evolve; therefore we can also make no statements about the probability that extraterrestrial organisms would possess it.

Intentionality is also sometimes used to distinguish human from non-human behavior. However, as philosophers typically conceive it, intentionality implies “free will”, the ability to make decisions and act independently of any physical or physiological processes in the brain. This essentially requires the assumption that we live in a dualistic (i.e. not merely material) world (or a purely spiritual one). If this is true, current science is fundamentally misunderstanding how the world works, and we certainly have no reason to think we can predict how other worlds work. Biologists, on the other hand, generally use the term “intention” as implying evolved goal-seeking, which we expect in any biological organism (Heisenberg 2014, Sayers et al. 2015, Barron and Klein 2016), including extraterrestrial ones.

The human characteristic of changing our environment.

If intelligent, civilized aliens were to visit Earth, the most obvious characteristic of humans is not their individual intelligence, but their impact on the whole planet. China’s Great Wall may be one of the only man-made individual structures visible from space, but the lights at night, the atmospheric composition, the fact that human-domesticated mammals on Earth outweigh wild land mammals about 10:1, and the ubiquitous covering of Earth surface with asphalt and buildings generally are all evidence that humans have changed their environment at a global scale. However, this is not clearly related to cognition; and again, it is the quantity rather than the quality that seems uniquely human. For example, social insects also change their local environments (from temperature-controlled nests to weeding plants that are in their way or interfere with the plant that functions as their host), and microbes may induce cloud formation, and generate locally toxic ocean water to increase food abundance. In fact, in one of the biggest organism-induced changes to the environment, when cyanobacteria first evolved photosynthesis, they generated free oxygen, thereby causing a major mass extinction (of other, oxygen-intolerant bacteria).

In summary, human-like intelligence is primarily not a specific, fundamentally unique faculty, but the exceptional degree to which humans can employ behavioral flexibility, abstract thought, and social learning; the latter two skills may well be tied to language use. This skillset has also enabled a cultural evolution, which includes, among other things, the development and use of tools to an (on Earth) unparalleled degree (Tomasello, Kruger, and Ratner 1993, Koops, Visalberghi, and van Schaik 2014), but also has enabled individuals to capitalize on trial-and-error learning, sensory information, and generally insights achieved generations before and miles away. It is this cultural evolution that makes us who we are today.

The probability of human-like intelligence

To estimate any probability, one usually relates the frequency with which something did happen to the number of chances it had of happening. The frequency of human-like intelligence evolving, to present knowledge, is 1. But how often could it have happened? Was there only one chance (one life, one Earth, assuming, perhaps, that once someone evolves human-like intelligence no other species will get a chance to evolve it)? In that case, it evolved in 100% of cases. This is not terribly informative statistically speaking, however, since we only have one sample. Moreover, if we hadn't evolved this kind of intelligence, we wouldn't be talking about it. If, on the other hand, we assume that each species on Earth could have evolved human-like intelligence (just like many did in fact evolve learning, or navigation based on landmarks, or communication of some kind), then we should conclude that the probability of human-like intelligence evolving is only one in 10 million or so (if one wants to calculate a more precise number, it would be necessary to take extinct species into account, but then only count the lineages that are sufficiently distinct to have had independent chances of evolving intelligence; this is however unlikely to give a fundamentally different answer). Of course the implications of this depend on what species richness we expect on other planets, should they harbor life; what causes species richness is an unsolved, but actively studied, question (Gaston 2000).

Another line of evidence also suggests that human-like intelligence emerges with low probability: it did not appear on Earth for a long time, perhaps only as recently as 50,000 years ago (estimates are typically 250,000 – 50,000 years ago, (Sterelny 2016)). The human lineage diverged from that of other chimpanzee species around 8 million years ago; hominids started walking upright roughly 4 million years ago, and started using fire and stone tools 2-3 million years ago; the human braincase significantly expanded over the course of the last 2 million years (although note that brain size may be a poor proxy for intelligence (Miller and Penke 2007). We don't see the truly human degree of innovation, e.g. in the variety of stone tools, or complex social interaction, e.g. in making jewelry or signs of ritual, until about 0.05 million years ago. Anthropologists conclude from this that human language did not appear until that recently, although clearly this is associated with a good measure of uncertainty. This means for (roughly) 99.9987% of Earth's history, life did not evolve human-like intelligence, despite the fact that many species have emerged and disappeared in this time (average species lifespan in mammals is thought to be about 1-10 million years)[2]. This is unlike other, similar traits: communication, for example, is present even in many bacteria (Ben-Jacob et al. 2004) and thus has presumably existed for more than half of Earth's history; navigation skills, i.e. the ability to find the way back to a specific place, is likely as old as animals, roughly 12% of Earth's history (Ma et al. 2012, Budd 2015). This implies that human-like intelligence seems a comparatively recent, and thus low-probability, event.

Why is human-like intelligence so improbable?

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[2] The Drake equation includes a term of how long intelligent alien civilizations are likely to exist (or at least signal into space). Essentially, we have no information on this, since we lack even a single example case of human-like intelligence, or life in general, appearing and disappearing. People speculate on this for Mars (perhaps life existed and disappeared) and Earth (perhaps life, or at least human civilization, will disappear due to technological disaster), but both are just that–speculation. No further insight on the average lifespan of life on a planet or even civilizations can be derived from this. However, it is worth noting that non-human-like intelligence may, and has, disappeared in any lineage whenever new ecological conditions changed the benefit-cost balance.

Evolutionary biologists constantly develop and test good hypotheses about why particular traits evolve in some species and not others; as discussed above, we understand fairly well which environmental conditions promote the evolution of behavioral flexibility, or spatial memory, or cooperation, for example. Generally, ‘why’-type explanations for biological traits are derived and tested using modeling, empirical measurements of fitness correlates, or comparative studies that identify which conditions, across species, are associated with the trait of interest (Krebs and Davies 1993). Such a ‘why’ explanation thus has to specify the environmental, social, or other factors that increase the probability that certain traits will evolve. Once such explanations are available, we can make predictions about the conditions under which an unknown organism may be thought to possess a trait. Scientists do not have such explanations for human intelligence. In other words, we do not know why human intelligence evolved. We can trace some of its history, and some of the consequences, but these are not sufficient to deduce *why* this trait evolved. Only a hypothesis from which predictions can be made about the expected level of intelligence in other, as-yet-unstudied, species can count a scientific explanation.

Did human intelligence confer survival benefits for living in the African savannah? Perhaps, but many large mammals live in the savannah, and none of them seem to have evolved anything near human intelligence. In addition, the radical expansion of the human brain, along with the ultimately radically different level of intelligence possessed by humans, did not go along with a corresponding increase in ecological success–early humans did not increase in population size and even may have gone through populations bottlenecks around the same time (Chen and Li 2001). Are primates particularly prone to exploiting the “clever social hunting” niche, thus predisposing only us, not other African mammals, to evolve intelligence? Surely they are, and this is why many of them have comparatively large brains and high intelligence: but no primates other than humans have human-like intelligence, despite the fact that there are many species, including in the African savannah. Another hypothesis revolves around the reproductive benefits gained by individuals with high social intelligence, particularly when living in large groups. Indeed primates in larger groups seem to have larger brains, and thus if humans are the only large primates to evolve larger group sizes, this may explain why only humans became as large-brained as we are (Dunbar 2003). However, there is considerable debate around the evidence for this hypothesis, and more generally, group size or social complexity seems a poor predictor of cognitive evolution (in carnivores (Holekamp et al. 2015), insects (Lihoreau, Latty, and Chittka 2012, O'Donnell et al. 2015)). Nonetheless, social intelligence in humans is one of our most distinctive traits (Herrmann et al. 2007, Tomasello, Kruger, and Ratner 1993, Call and Tomasello 2008).

There is one remaining hypothesis that by its very nature suggests why human intelligence may be a unique trait: sexual selection ((Miller and Todd 1998, Haselton and Miller 2006); see Miller, this volume). Sexual selection refers to a process by which traits may evolve that do not confer survival benefits and in fact may be detrimental to survival. If one or both sexes in a species are choosy about their mates, then any trait that becomes a mate-selection criterion can evolve to unique, exaggerated, and costly (to survival) levels. This process is well-studied in biology (Krebs and Davies 1993), and for good reason: it is incredibly common–essentially all bird coloring and song is explained by it, as well as extravagant horns, antlers and penis shapes (primarily in insects). It is inherent in this process that the exaggerated trait, such as a peacock's tail, a nightingale's song, or a deer's antlers, is essentially arbitrary: it does not have to have any use other than to impress mating partners or rivals and thus lead to more matings. What if human brains were such a trait? This would explain their fast evolution, distinctness from related species, unclear or absent survival benefits, and rarity as a trait for those same reasons (its arbitrariness and production cost). None of the other hypotheses advanced so far have comparable explanatory power. According to the "Mating Mind" (=human-like intelligence arose by sexual selection) hypothesis (Miller 1993), human-like intelligence is thus essentially an arbitrary trait, only somewhat influenced by the lineage-typical fitness-relevant traits (brains for primates, rather than antlers for deer or feathers for birds). The peacock's tail of primates.

Will aliens be intelligent?

Almost certainly, at least some lifeforms on other planets, if they exist, will be intelligent in the non-human sense. There are two main arguments for this. First, cognitive skills are frequent on Earth. Even bacteria on Earth show learning, chemotaxis, and social signaling (Shapiro 2007); even insects show tool use, navigation over longer distances including cognitive maps, and many other complex computations (Dornhaus and Franks 2008). Many animals show learned and spontaneous problem-solving abilities, and even sessile organisms, like plants, exhibit social interactions and sensory capabilities (Trewavas 2016). All of these skills are so ubiquitous in Earth's organisms that it is hard to imagine aliens "living" without them. Second, we understand something about when cognitive skills evolve: they provide evolutionary benefits exceeding their costs in many ecological conditions. They can provide some robustness to environmental change; they can enable the use of a larger variety of resources and larger home ranges; they enable targeted, short-term behavioral adaptation in a way that is not possible with genetic adaptation. Such behavioral flexibility and robustness to variable environments is likely to be adaptive in any, even an alien, ecosystem. In other words, if intelligence is understood as information processing, cognitive problem solving, or behavioral flexibility, we would predict it to be commonplace wherever life exists. However, we would also predict that its precise form, i.e. the specific cognitive skills present, will depend exactly on the balance of benefits and costs of such skills. However, human-like intelligence appears to be unlikely and rare. No matter the reason, this doesn't bode well for the prospect of finding human-like aliens.

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