**Title: The end of inquiry? How to overcome human cognitive limitations**

**Abstract**

The human brain is the only object in the universe, as far as we know, that has discovered its own origins. But what, if any, are the limits of our understanding? Epistemic pessimists, sobered by our humble evolutionary origins, have argued that some truths about the universe are perennial *mysteries* and will forever remain beyond our ken. Others have brushed this off as premature, a form of epistemic defeatism. In this paper we develop a conceptual toolbox for parsing different forms of cognitive limitation that are often conflated in the literature. We distinguish between *representational access* (the ability to develop accurate scientific representations of reality) and *intuitive* *understanding* (the ability to comprehend those representations). We also distinguish different modalities of cognitive limitation. If the scientific endeavor ever comes to a halt, will this feel like slamming into a brick wall, or rather like slowly getting bogged down in a swamp? By distinguishing different types and modalities of human cognitive limitation, we soften up the hypothesis of ‘cognitive closure’ and ultimate ‘mysteries’. Next, we propose specific mechanisms and strategies for overcoming our innate cognitive limitations. For a start, it is uninformative to think of the limits of a single, bare, unassisted brain. One of the central features of human intelligence is the capacity for mind extension and distributed cognition. We have developed various technologies for extending the reach of our naked brains and for pooling their cognitive resources, as witnessed by the history of science. We then discuss different cognitive mechanisms for overcoming the limits to our *intuitive* understanding, and argue that these are combinatorial and open-ended. In light of all these possibilities for extending the limits of our understanding, we conclude that there is no good reason to suspect the existence of an outer wall of human comprehension.

Keywords: cognitive limitation; intuitive understanding; representational access; epistemic pessimism; new mysterianism: mysteries; cognitive closure

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# Introduction

Human brains are the product of blind evolution. They evolved to deal with practical problems impinging upon survival and reproduction, not to unravel the mysteries of the universe. This, remarkably, is what human brains themselves have come to realize, after billions of years of unguided evolution. Among some thinkers, this line of thought has inspired pessimism about the epistemic prospects of the human race (Fodor, 1983; McGinn, 1993; Stich, 1990), and even led to a minor backlash against the naturalist worldview (Boudry & Vlerick, 2014; Nagel, 2012; Plantinga, 2011). Given our humble evolutionary origins, these epistemic pessimists have argued, we have no reason to suspect that (human) science will penetrate the deepest riddles of the universe. Indeed, it would be miraculous if the human brain were capable of any such feat . In fact, some of them argue, it is already surprising that science progressed as far as it did. We should take seriously the possibility that some questions are doomed to remain “mysteries” (Chomsky, 1988). Just as the minds of other animals are closed to mathematics, polyphony or humor, some mysteries will never yield to human inquiry. To think otherwise is a blatant form of epistemic *hubris*.

Not all evolutionary naturalists, however, share the epistemic pessimism of these so-called “New Mysterians” (Flanagan, 1992). According to Dennett (1991a, 1991b) the mysterians have rushed to their conclusions after only a “paltry canvassing of the opportunities” and have thus forfeited their intellectual responsibilities. Humphrey (1999, p. 218) has lamented the “continuing despondency” of the mysterians in the face of our advancing knowledge, and Flanagan (1992, p. 9) has speculated that they are motivated by their desire to “drive a railroad spike through the heart of scientism, the view that science will eventually explain whatever is natural”.[[1]](#footnote-2) Independent from the arguments offered by the new mysterians, other naturalists have developed a much more optimistic view of our epistemic prospects, starting from the same evolutionary outlook. For example, Rescher (1990) has argued that the intelligibility of the world by the human is exactly what one should expect, given that the human mind has involved *in* that world: “A world in which intelligent creatures emerge through the operation of evolutionary processes must be an intelligible world” (Rescher, 1990, p. 65)

Both parties in this debate agree on the purely natural origins of the human brain and all its faculties, as well as the mechanism that is (largely) responsible for them, but they end up with radically different conclusions about our epistemic prospects. How is this possible? In this paper, we introduce an enriched conceptual framework for thinking about the limits of human understanding, and we discuss specific strategies for overcoming our innate cognitive limitations. While science has indeed produced theories that increasingly challenge our cognitive resources, we have also developed tools to overcome our cognitive barriers. In light of the availability of such mind-extension devices, and the combinatorial possibilities of networks of human brains, we argue that there is no reason to suspect that we will soon (or ever) reach an outer wall of understanding. Finally, we conclude that positive affirmations of ultimate mysteries and cognitive limitations are far less modest than they appear.

# Biological limitations

Given that our minds are natural and biological organs with functional specifications and limitations, some aspects and properties of the world must lie beyond our ken. This, at least, is the line of reasoning developed by Fodor (1983), Chomsky (1988, 2005, 2014), McGinn (1993, 2000; 1994) and, to some extent, Pinker (1997). In the arguments of the new mysterians, analogies with other species play an important role. Just as dogs or cats will never understand prime numbers, polyphony, the rules of chess, or the properties of electrons, human brains must be closed off from *some* of the world’s wonders. If you think that human beings, alone in the natural world, are free from any such cognitive limitations, you buy into the myth of human exceptionalism. Jerry Fodor strongly suspects that this notion of “epistemic unboundedness”, which states that the human mind has unlimited cognitive capacities, is just “incoherent” (Fodor, 1983, pp. 122-123). And even if it is coherent, such hubris seems to conflict with the naturalist outlook, in particular the notions of evolutionary gradualism and continuity. Darwin, after all, taught us that the difference between human beings and other animal species is but a difference in degree. For Noam Chomsky, therefore, the existence of such cognitive limitations is an obvious “truism” for anyone who accepts the central facts of modern biology, namely that humans are “part of the organic world” (Chomsky, 2014). In particular, Chomsky (2000, p. 83) has argued that all human scientific activities are undergirded by a “science forming faculty” – loosely defined as those cognitive capacities that “enter into naturalistic inquiry”. This innate faculty constrains our epistemic scope: the answer to some of our inquiries about the world are out of reach and will always remain mysteries.

Even the evolutionary psychologist Steven Pinker (1997), himself often accused of “scientism” and scientific imperialism (Wieseltier, 2013), is sympathetic to the pessimism of the new mysterians. Evolution by natural selection, according to Pinker, is an opportunistic and short-sighted *bricoleur*, which produces quick-and-dirty, satisficing solutions to adaptive problems in an organism’s environment. It is also a ruthless economizer, which tends not to endow organisms with any more brainpower than is strictly needed for their survival and reproduction. It is too much to hope for that such as an opportunistic tinkerer would produce an organ – the human brain – that is capable of comprehending all the mysteries of the universe. As Pinker rhetorically asks, “if the mind is a system of organs designed by natural selection, why should we ever have expected it to comprehend all mysteries, to grasp all truths?” (Pinker, 1997, p. 563).

# Kinds of limits

In this paper, we use the pessimistic pronouncements of the new mysterians as a jumping board for thinking about human cognitive limitations. But we need better concepts to think about human cognitive limitation. Mysterians typically present the question of cognitive limits in stark and black-or-white terms: either we are capable of solving a problem, or the answer will forever elude us. Either we have cognitive access or we are blocked from it. They also seem to be talking about the limitations of a bare, unassisted human brain. Finally, it is often not clear if their claim is that we will never possess the true scientific theory of some X, or rather that we will never fully *comprehend* that theory once we possess it. In other words, their framework is inadequate because it conflates various sorts of cognitive limitations, biases and challenges.

## Representational vs. intuitive limits

Our discussion will focus on cognitive limitations that are specific to the human species, arising from the architecture of the human brain. In other words, we are looking for problems which, even though they may be perfectly accessible to another type of cognitive being, will forever remain beyond human reach. By contrast, there are also epistemic limits arising from our spatio-temporal location in the universe, or from general computational or parametric principles. For example, some parts of the universe may be beyond our event horizon, and some problems might require more computational resources than are available in the universe. Fodor dismisses such limitations as merely “boring possibilities associated with parametric limitations of one sort or another” (Fodor, 1983, p. 121), which “even the most starry-eyed epistemic optimist” would be willing to accept (for a good overview, see Rescher, 2006). Fodor is right: even though our argument is optimistic, we are perfectly willing to accept such parametric limitations.

But the hypothesis of species-specific limitations is a stronger, and more fascinating one. What would such a cognitive limitation consist of? Suppose there is a domain or aspect of reality which, because of some insurmountable cognitive or perceptual barrier specific to the human brain, we will never be able to probe or penetrate. In other words, it is impossible for humanity to arrive at an accurate scientific representation of this part of reality. It might be accessible to other cognitive beings, but it is out of reach of the human mind. In this case, human beings lack *representational access*.

Now suppose that we find ourselves in a different predicament. We have succeeded in developing a scientific representation of some domain or aspect of reality, possibly with the help of sophisticated measuring devices, computer models, mathematics, or other sorts of cognitive scaffolds and mind extensions (see 4.1). There is only one problem: because of the way our brains work, it is impossible for us to *comprehend* or *grasp* our own scientific theory. No matter how hard we try, we just cannot seem to wrap our heads around it. Because of some species-specific cognitive limitation, these representations will forever bewilder and baffle human beings. In this case, we suffer from an inability to develop *intuitive understanding* of a certain theory or representation (Vlerick & Boudry, 2017).[[2]](#footnote-3)

Let us try to define this notion of “intuitive understanding” a bit more carefully. An agent possesses intuitive understanding of some concept or idea X if she manages to internally represent that concept in her mental workspace, and is able to perform basic mental operations on it (deriving inferences and predictions, analyzing its constituent parts, making comparisons with other representations).

An example from the domain of mathematics will serve to illustrate the difference between representational access and intuitive understanding. Mathematicians have developed accurate formal representations of four-dimensional objects such as a tesseract, the 4D-equivalent of a cube. Based on this mathematical characterization, they can calculate the number of faces, edges and vertices of a tesseract, and describe other geometric properties, such as its various symmetries, its intersections with other figures, and its projections in two or three dimensions, etc.

But can mathematicians also intuitively represent a tesseract, in the way that we visualize a cube before our minds’ eye? In principle, human visual imagination is limited to three dimensions, and it is notoriously difficult to develop an intuitive understanding of higher-dimensional objects. In section 5.2.2, we will discuss cognitive tools for transcending this intuitive limitation, but for now let’s suppose, for the sake of the argument, that this cognitive barrier to understanding higher-dimensional objects is insurmountable: no human being will ever be capable of intuitively representing a tesseract in the way that all of us represent a cube before our mind’s eye. In that case, human beings would have *representational access* to the idea of a tesseract, but no *intuitive understanding*.

For the sake of clarity, we chose a well-defined abstract entity such as the tesseract to illustrate our distinction. But the point can be easily transferred to objects and entities in the natural world. Take the theory of general relativity. Physicists conceive of the universe as a four-dimensional space-time continuum that can be curved by the presence of matter and energy. That is, they possess theories and equations to characterize the way in which matter and energy interact with the space-time continuum. Among the predictions falling out of general relativity theory is that time slows down in the vicinity of massive objects, that light passing close to the sun will be curved by its gravitational field, and that one twin making a space voyage close to the speed of light will be younger than his twin brother when he returns on earth. Physicists can accurately model these relativistic effects, and take them into account when making predictions, for example to calculate the location of my smartphone based on a GPS signal. It is clear that they have representational access to space-time curvature. Still, it remains to be seen if physicists can *intuitively* make sense of the strange phenomena of relativity theory.

Remember that were are not talking about simple parametric limitations. Intuitive understanding of X, as we define it, does not require that an agent develops an internal representation of X that is complete and fully detailed. For example, it is obvious that no human brain will ever be able to have a *complete* and fully detailed cognitive representation of the physical structure of the whole solar system, as described by general relativity. For our discussion, the question is not whether such a complete intuitive understanding of the solar system is possible, but whether human beings can develop an intuitive understanding of the physical laws and principles involved in the relativistic description of the solar systems (gravity, wordlines, speed of light, inertia, time-space curvature...). Is such an intuitive understanding possible, or is it ruled out in principle because of some insurmountable cognitive obstacle?

## Jumping from intuitive to representational limits

Representational access describes a relation between the world and our (scientific) representations of it, whereas intuitive understanding describes a relationship between our representations and our minds. It is important to distinguish between these two types of cognitive limitation, because in many pronouncements of mystery or closure, it is unclear exactly what form of limitation is intended, and often different cognitive limitations are conflated.[[3]](#footnote-4) McGinn, for instance, characterizes his thesis as one of “epistemic inaccessibility” (McGinn, 1993, p. 4), the impossibility of “convert[ing] the problem into regular science” (p. 40). About the mind-body problem, McGinn has written that “the correct *theory* is inaccessible to the human intellect” (1994, p. 145, our emphasis). But then McGinn only offers arguments that bear on the psychological difficulties human beings experience when trying to *grasp* the relevant scientific theories. Throughout, he uses experiential and phenomenological language to describe the state of perplexity and bewilderment of those who contemplate the problems. For instance, he writes that the mind-body connection is “numbingly difficult to make sense of”, that we suffer from a “feeling of intense confusion”, and that “[t]he head spins in theoretical disarray” when we try to think about it (McGinn, 1993, pp. 27-28). But as we previously argued, intuitive closure does not entail representational closure. It is perfectly conceivable that we succeed in forming a scientific representation of some domain of the world, without being able to understand our own representation on an intuitive level (XXX).

Noam Chomsky’s account of “mysteries” also seems to vacillate between representational and intuitive limits. According to Chomsky, there are certain problems in science which have perfectly natural answers, but those answers will forever remain inaccessible to our “science forming faculty” (Chomsky, 2000, p. 82). In other words, no scientific progress whatsoever can be made demystifying those mysteries. But in his latest publication on the subject, Chomsky characterizes mysterianism as dealing with “phenomena that fall beyond human *understanding*” (Chomsky, 2014, our emphasis). Now there seems to be a possibility that Chomsky overlooks: scientific progress without comprehension. It is conceivable that we developed accurate representations about some part of reality, without being able to wrap our heads around them. It is not clear whether this would qualify as a “mystery” in Chomsky’s sense.

# Overcoming limitations

## Extending our representational reach

It is undeniable that the human mind has certain biological specifications and limitations. The question is: what are our prospects for overcoming them? It is instructive to have a look at perceptual limitations first, as our cognitive predicament is partially analogous to it. Human senses cannot directly detect UV-light, ultrasound, X-rays, radio waves, CO2 molecules, gravitational waves, and so forth. In fact, only a narrow segment of the electromagnetic spectrum can be directly perceived by the human eye (390-750 nanometer wavelengths). But as our very awareness of all these phenomena attests, these are merely the perceptual limits of a bare, unassisted, isolated human brain. In order to enhance our perceptual limits, we have developed X-ray film, Geiger counters, radio satellites, UV spectroscopy, laser interferometer gravitational-wave detectors, and so forth, all of which translate unobservable stimuli into some format that is accessible to our human senses. Perceptual limitations of the human brains are real and verifiable, but they are not very informative when it comes to finding the limits of our understanding. If we think about the limits of human knowledge, we have to take into account not just the direct perceptual input provided by our biological senses, but also all the possible perceptual extensions that we can develop.

In the same way that technological instruments have drastically expanded our perceptual range, other forms of technology have broadened the class of things we can *represent*. Ever since the invention of writing, and possibly language itself, human beings have been using “external memories”, vastly extending the storage capacity of our naked brains. Indeed, according to the “extended mind” hypothesis (Clark & Chalmers, 1998), the human mind can quite literally extend beyond the skin/skull boundary, encompassing notebooks, computers screens, maps, file drawers, etc. Mathematics and logic are also mind-extension technologies, enabling the representation of things that our unaided minds would never be able to represent. Probability theory and statistics are tools for extending our natural understanding of chance and probability. Most importantly, perhaps, human cognition can also extend to *other* minds, as in Giere’s theory “distributed cognition” (Giere, 2002), Tomasello’s account of the cultural origins of human intelligence (Tomasello, 2001), and models of cumulative cultural evolution (Henrich, 2015; Richerson & Boyd, 2005). Modern science is the epitome of such a collaborative cognitive endeavor, in which minds extend to other minds and pool their cognitive resources (Boudry & Pigliucci, 2016; Longino, 2015), enabling them to collectively develop representations that would be unattainable to each individual human mind (Campbell, 1997; Goldman, 1999; Thagard, 2012). The mind of a scientist extends “horizontally”, to the brains of his academic colleagues, but also “vertically”, to minds of scientists of past generations, as in Newton’s metaphor of “standing on the shoulders of giants”.[[4]](#footnote-5)

## Extending our intuitive reach

Representational access does not entail intuitive understanding. It is one thing to extend our representational access to the world, but can we also enhance our intuitive understanding? We defined intuitive understanding as the ability to develop an internal mental representation of some theory or idea, along with the ability to perform some mental operations on it. For this type of understanding, it seems more difficult to pool cognitive resources. Groups of human brains can collaborate to solve a problem or develop a theory that would be out of reach for each of them working in isolation, but groups of brains have not reached the level of interconnectedness that would justify our attributing some sort of collective ‘understanding’ to them. Some people have speculated, with the arrival of the internet, that humanity will develop a sort of ‘superbrain’, which will eventually become conscious in its own right. For the sake of the argument, however, let us assume that intuitive understanding is not something that can be distributed over a group of people, but can only be attributed to single human brain. If no single scientist intuitively understands quantum mechanics, then neither can a group of scientists. People can help each other to grasp some bizarre phenomenon on an intuitive level, but at the end of the day, intuitive understanding is something that happens (or not) in their *own* minds.

Fodor has argued that there are “constraints on the class of beliefs that the mind can entertain” (Fodor, 1983, p. 125). Because any kind of cognitive system has an “endogenous structure”, there are bound to be “thoughts that we are unequipped to think” (1983, p. 125). But is this endogenous structure fixed and unchangeable, a prison of understanding? With regards to intuitive understanding, cognitive psychology teaches us that the innate “endogenous structure” of our minds consists of a number of “intuitive ontologies”, cognitive systems for dealing with various sorts of entities: physical objects, living beings, agents, abstract categories. Each of these ontological categories (Boyer, 2000; Boyer & Barrett, 2005) is associated with a number of core principles, inferential principles for dealing with the class of objects in question. In the case of physical bodies, for example, this includes the principles of cohesion, continuity and contact. In the case of the living world, this includes hierarchical taxonomy and essentialism.

If these intuitive ontologies were fixed and informationally encapsulated, that would be the end of the story. The limits of our imagination would coincide with the limits of respective intuitive ontologies which evolution has endowed us with. But this is not the case. We can train our minds to apply the core principles of one cognitive system to the set of entities of another system, thereby enriching or overriding our intuitive grasp of the world. Carey and Spelke (1994) have called this process “mapping across domains”. Importantly, this process of mapping across domains is open-ended and combinatorial. It allows us to redeploy our innate set of intuitive ontologies in a wide variety of novel combinations, thereby radically extending our intuitive reach (Vlerick, 2012).

Here we explore two general strategies for extending our intuitive understanding of the world, and show how they apply to some outstanding scientific problems: (1) metaphors and analogies (2) representations in a perceptual medium.

### Analogies and metaphors

The most important strategy to extend our intuitive understanding of the world is through the use of analogies and metaphors. Analogies allow us to understand something new, unfamiliar or alien in terms of something we already know. Analogies and metaphors work by pointing to structural similarities between a source domain and a target domain, and transferring our understanding from the former to the latter. Many everyday analogies are “near analogies”, in which source and target domain are relatively close, but scientific breakthroughs are often made by the use of “distant analogies”, in which the boundaries of intuitive ontologies are crossed (De Cruz & De Smedt, 2010). In the context of our argument, it is not necessary that metaphors have played a formative role in the development of new scientific theories (Brown, 2003). Even if they play they only a secondary role in the *development* of theories themselves, it suffices that they enable us to comprehend some scientific theories that would otherwise be incomprehensible and bizarre.

Metaphors are not a part of the conceptual structure of scientific theories themselves: they do not have predictive power and have no explanatory content. Instead, they can be seen as interfaces for making the structure of a scientific theory digestible to its human consumers. In this sense, they have a subjective dimensions. Metaphors only work for human beings because our minds have a certain “endogenous structure”, as Fodor put it, and because we have a certain range of prior experiences to draw from as possible source domains. If extraterrestrial beings have developed science, we could expect that they have developed some theories that are conceptually equivalent to relativity theory or quantum mechanics and evolution, but we should not expect that they makes use of the same metaphors (if they are capable of metaphorical thinking at all).

Metaphors and analogies are used in every domain of science, but for the purposes of this paper, it is instructive to look at the scientific theories which provide the most substantial challenge to our intuitive understanding. When it comes to sheer incomprehensibility , quantum mechanics has the most solid reputation. It is one of our most impressive scientific achievements, in terms of predictive success and explanatory power, but it is also notoriously hard to wrap one’s head around, even for people who have spent a lifetime trying to understand it. Still, since the early days of quantum mechanics, metaphors have been used extensively to make sense of what seems incomprehensible at first. Planck’s notion of a “quantum” uses our everyday experience with discrete bundles or packages of matter. Rutherford’s model of the atom draws an analogy with the structure of the solar system, with electrons orbiting the nucleus (Brown, 2003, pp. 74-99). Quantum “superposition” is a metaphor exploiting our spatial imagination, which invites us to think of quantum states as discrete entities stacked on top of each other.[[5]](#footnote-6) Quantum “entanglement” draws an analogy with strands or ropes that are inextricably intertwined with each other.

Analogies are always imperfect: atoms are only superficially like the solar system, and different physical states are not really stacked on top of each other.[[6]](#footnote-7) Different analogies and metaphors can be used to form an intuitive understanding of quantum phenomena, each providing a partial understanding of the quantum world. For our argument, we do not need to assume that metaphors provide a perfect understanding of quantum phenomena. To soften up the limits of intuitive understanding, it suffices that metaphors allow us to get *some* intuitive purchase on otherwise incomprehensible phenomena.

The important think to notice is that there are no clear limits to analogical thinking. Not only can we compare anything to anything, but a target domain of one metaphor can become the source domain of a different metaphor. For instance, Rutherford’s model of the atom uses the analogy of the structure of the solar system, with planets (electrons) orbiting the sun (nucleus). But the heliocentric model was itself a relatively recent invention, which was intuitively hard to make sense of when initially proposed. Newton explained how planets can be orbiting the sun by using the thought experiment of a cannonball that is being shot horizontally on top or a large mountain (Newton & Cohen, 2004).

The recursive nature of metaphors and analogies can be gleaned from the fact many of our most abstract concepts are rooted in metaphors and analogies, which are in turned based on different more basic analogies, all the way down to our most fundamental everyday concepts (George Lakoff & Johnson, 1980; G. Lakoff & Johnson, 1999). For instance, even our concept of time, which is a constitutive part of everyday reality, is structured by analogy to space – e.g.: he arrived *at* 1:30, worked *through* the night, is looking *forward* to tomorrow, leaves the past *behind*, etc. (St. Clair, 2007). Gentner & Jeziorski (1993) have argued that higher-order cognition is the product of our capacity for analogical thinking. Given the combinatorial possibilities of metaphors and analogies, it becomes very difficult to delineate the limits of our intuitive understanding.

### Representations in perceptual media

Metaphors and analogies work by projecting one abstract representation unto another, more familiar one, so that one can hold it in one’s mind and perform some mental operations on it. But it is also possible to project abstract representations onto some physical medium that can be perceived by our senses. Because vision is our dominant sense, the overwhelming majority of such perceptual representations in science make use of our visual imagination. Graphs, charts, diagrams, schemas and other visualizations of abstract representations provide interfaces to make complex information vivid to human minds, allowing us to directly see certain patterns and structures, and to perform some mental operations. By looking at a graph of a normal distribution, for example, one can ‘see’ what a standard deviation is. By plotting information on two or more axis, correlations become salient to human understanding.

*Higher dimensions*

In principle, human vision is limited to three spatial dimensions, and most visual representations of models are two-dimensional. But there are workaround ways to make sense of abstract information that involves a higher number of dimensions. Mathematicians and scientists have developed formal tools for handling higher-dimensional entities (equations, models…), but also for partially representing them in a way that is intuitively digestible by the human mind.[[7]](#footnote-8) In fact, there is a whole range of techniques for pictorial or schematic representations of multidimensional objects. Let us return to our example of the tesseract.

Mathematicians can project the "shadows" of a tesseract, in the same way in which three-dimensional objects project a shadow on a two-dimensional surface. We can also visualize how a tesseract moves ‘through’ our three-dimensional world, analogous to the way in which a cube can pass through a two-dimensional surface. Mathematicians also use stereographic projections, in which a 4D objects is projected onto a three-dimensional sphere, or the so-called Schlegel diagrams (Ziegler, 1995), which project the tesseract through a single point. Another strategy to visualize 4D objects is to use the color spectrum as the extra dimension. For instance, by color-coding the fourth dimension on a three dimensional projections, one can get an intuitive feel of how to untie knots in four dimensions. Most of these strategies become clear when you understand how you move from 1D to 2D and from 2D to 3D, and how people in a two-dimensional Flatland would conceive of our third dimension. Once you intuitively understand that, you can extrapolate from there (by analogy) to an extra dimension. Mathematicians argue that you can train your intuitive ability to make sense of 4D objects. In biology, higher-dimensional fitness ‘landscapes’ are represented by singling out one or two phenotypic traits as horizontal (X and Y) axes, while representing the fitness value on the vertical Z axis. It is not possible to visually represent 20 dimensions at the same time, but it is possible to plot several of them separately, and to extend our understanding of higher-dimensional fitness ‘landscapes’ from there.

## Wading through the swamp

Pronouncements about mysteries and cognitive closure typically evoke the image of suddenly hitting an impenetrable outer wall of understanding. We suddenly reach an impenetrable boundary, hard-wired into our biological constitution, and impossible to overcome. We hit upon an ineffable mystery, and stare forever in blank incomprehension. But considering the possible technologies for mind extension – both representationally and intuitively – such hard and impenetrable limits of understanding seem unlikely. Somehow we always seem to be able to work our way around a mystery, to probe it from different angles, to partially understand it by comparing it to something else that we already understand.

If there really is a limit to intuitive understanding, it is unlikely that it will feel like slamming up against a wall. It is more likely that we will just experience increasing difficulties in our attempts to comprehend some part of representations. More and more cognitive effort is exerted, with ever diminishing returns. Max Planck envisaged such limits: “with every advance [in science] the difficulty of the task is increased; ever larger demands are made on the achievements of researchers […]” (quoted in Rescher, 2006, p. 51). Reaching the limits of human knowledge, to use a contrasting metaphor, might be compared to gradually getting bogged down in a swamp, rather than slamming into a brick wall. As you sink deeper in a swamp, you have to exert more and more effort to keep forging ahead, but there’s no discrete point at which further progress becomes impossible altogether.

In the case of the wall-like limits envisaged by the new mysterians, we would expect little or individual variation in cognitive abilities. Some people may be better at understanding difficult subjects, of course, but all of us are bound by the same hard-wired biological limitations. New mysterians are talking about “mysteries” for the human species at large, not just for particular individuals or groups. In the case of soft, swampish limits, however we would expect to find more individual variation. Some people who are unusually smart or imaginative, or have received extensive training, may be able to progress further than others.

In the history of science, such individual variation is of course precisely what we observe. Most member of the human species will never understand quantum mechanics or population genetics or even heliocentrism, but some will. ­Given sufficient education and training, and of course a certain level of cognitive talent, some people are capable of understanding these theories (though perhaps not all of them at the same time). And some exceptionally gifted individuals will be pioneers of understanding, blazing the trail for others. As Planck noted, however, it is undeniable that that our scientific theories have become more intuitively challenging, and fewer and fewer people are able to comprehend them. The low-hanging fruit has long been harvested by our predecessors, and the remaining problems in science will prove to be very challenging indeed.

It is possible that in the future only a few people, and eventually no-one at all, will be able to wrap their heads around some scientific theories, but it is also possible that we will just become better and better at wading through the swamp. In order to see what metaphors, analogies and visual representations can accomplish in terms of mind extension, it is instructive to look back at the history of science. There is an important line of evidence for the claim that scientists become better over time at intuitively grappling with their theories: we seem to have forgotten how bizarre some ideas and theories were when initially proposed. They have lost some of their counterintuitiveness as scientists – but also the public at large – have grown accustomed to them. Being immersed in a scientific culture, we no longer recognize how bizarre the germ theory of disease and heliocentrism were when first proposed. They have lost some of their original ‘shock value’. In his book on the counterintuitive nature of science, McCauley makes this point obliquely:

When first advanced, the suggestions that the earth moves, that microscopic organisms can kill human beings, and that solid objects are mostly empty space were no less contrary to intuition and common sense than the most counterintuitive consequences of quantum mechanics. (McCauley, 2000, pp. 69-70)

This suggests, indirectly, that both scientists and the public at large have become better at wading through the “swamp”. And this provides grounds for what we may call ‘optimistic meta-induction’ about the history of science. Ideas and theories which seemed bizarre and incomprehensible at first, have finally yielded to intuitive understanding. This process of familiarizing continues today. The old rumor, possibly apocryphal, that there were “only three people” in the world who understood relativity theory, including Arthur Eddington and an unknown third physicist (Waller, 2004), is no longer accurate (if it ever was). Experts working in the field of relativity physics today, after years of exposure and familiarity with the subject, have acquired a more intuitive feel of time dilations, space-time curvature and higher dimensions (Goldberg, 1984; Mermin, 2009).

## A thought experiment

In order to see the danger of drawing premature inferences about cognitive limitation, it is instructive to contemplate the epistemic prospects of humanity as they might have appeared before the arrival of modern science. Imagine that hyper-intelligent extraterrestrial observers had visited the earth around 15.000 BC and had taken stock of our species, trying to make an assessment of our cognitive potential. They would have noted our modular brain organization, our capacity for meta-representation, our linguistic skills and logical reasoning, our gregarious nature and capacity for communication, and so forth. But they would also have noted our hard-wired intuitive ontologies: our folks physics, folk biology, etc. Suppose that some mysterians among those extraterrestrial visitors had followed this line of reasoning:

Evolution on this planet has equipped the minds of human beings to deal with environments characterized by only slight gravitational curvature, and for traveling at relatively slow speeds. None of these earthlings has ever traveled close to the speed of light, or spent time in the vicinity of truly massive objects, or escaped from the grip of the earth’s gravitational field. Because conditions on the surface of the earth approximate zero-curvature geometry, evolution by natural selection has very usefully hard-wired this local ecology into their brains, ineluctably condemning human thought to flat geometry. Alas, this means they have no innate capacity at all for understanding space-time curvature. Barring a fundamental future change in their biological constitution, the wonders of space-time curvature will forever remain beyond their ken.

But those extraterrestrials would have been wrong. Our biological constitution did not alter significantly since 15000 BC, but we still managed to develop an understanding of non-Euclidean geometry and space-time curvature. Even though we might still have trouble intuitively *grasping* how space itself can be curved, we do have the science. This thought experiment is a counsel for prudence when it comes to pronouncements of representational limits. Even when it *seems* that a cognitive system is bounded or limited in a particular way, as it would have seemed to extraterrestrial visitors around 15000 BC, it is almost impossible to foresee all the possible combinations of mind-extending devices, and it is tempting to draw conclusion that later turn out to be premature. We think this is an important lesson for the alleged “mysteries” that Fodor, Chomsky and McGinn are talking about.

# Discussion

Intuitive understanding is a matter of grasping a representation on an intuitive level. Representational access, by contrast, is a matter of devising representations in the first place. As we argued before (XXX) representational limits do not follow from intuitive limits. It is conceivable that human beings succeed in accurately *representing* some aspects of the world, by way of collective scientific labor powered by various other mind extensions, but then fail to wrap their heads around the representations themselves.

By distinguishing these different forms and modalities of cognitive limitation, and exploring the different strategies for mind extension, we have arrived at a more optimistic assessment of our epistemic prospects. Not only have scientists gained representational access to many exotic parts of the universe, as witnessed by our impressive predictive and technological successes, but they have also slowly gained an intuitive understanding of even the most bizarre theories. By bending, twisting, stretching, and pumping up our imagination – all metaphors in their own right of course – it is possible to acquire an intuitive understanding even of phenomena that our minds have not been designed by evolution to understand.

In light of all the possible ways (and combinations of ways) to expand our cognitive reach, we should be wary of resolutely affirming that some aspects of the world will never make sense to the human mind. If, for example, you want to claim that the mind-body nexus will forever baffle human reasoners, you have to demonstrate that no possible combination of metaphors, mappings, thought experiments and analogies will lead us any closer to understanding this presumed mystery. That, we claim, is a taller order than the new mysterians have acknowledged.

Similar points about epistemic modesty apply to the question of representational limits. It is logically possible that certain aspects of the universe are so incredibly complex, or so remote to our senses, that scientists will never be able to represent them. Much as for intuitive understanding, however, admitting defeat with regards to representing these properties of the world seems premature, and indeed far from epistemically modest. In order to demonstrate *representational limits*, we would have to show that no possible combination of mind extensions (future technology, advanced mathematics, etc.) and collaborative arrangements between scientists would enable us to represent a certain aspect X of the world. Granted, the problems of science that remain unresolved to this day, such as quantum theory of gravity, promise to be mind-bogglingly difficult. But we see no principled reason to suspect that the outstanding problems of today will forever remain inaccessible to *any* form of representation.

Of course, we should never completely rule out the possibility that human inquiry will one day come to an end. To assume otherwise would be epistemic hubris indeed. There might be areas of reality which we will never be able to represent, and there might be theories which we will never wrap our heads around, no matter how hard we try. But if human inquiry ever comes to a halt, it is unlikely that this will be sudden and abrupt, like slamming into a brick wall. It is far more likely, in light of our arguments about mind extensions, that the end of inquiry will feel like getting bogged down in an increasingly dense swamp. As our continued progress become more and more laborious, we asymptotically approach the limit of human knowledge, though we would never be quite stopped dead in our tracks.

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1. For a discussion of the problem of 'scientism' and the limits of science itself, as opposed to the limits of human inquiry in general, see Boudry & Pigliucci (2017). [↑](#footnote-ref-2)
2. In previous work we called these predicaments, respectively, “representational closure” and “psychological closure”. After some reflection, we have decided that “psychological” as a construct is too broad to contrast with “representational”. Bear in mind, however, that “intuitive” in this context has nothing to do with ‘gut feelings’ or unreflective ‘instincts’, but with *intuitive apprehension*, i.e. the mental ability of an agent to grasp or understand a given representation. This is admittedly still vague, but it will suffice to disentangle the different stands in the new mysterianism, and to soften up the closure thesis. [↑](#footnote-ref-3)
3. In his original formulation, McGinn wrote that “A type of mind M is cognitively closed with respect to a property P (or theory T) if and only if the concept-forming procedures at M’s disposal cannot extend to a grasp of P (or an understanding of T)?” (McGinn, 1989, p. 350). By adding these parenthetical asides, McGinn suggests some rough equivalence, or a mere terminological difference. But there is a huge difference between the claim that we cannot form a representation of some property P, and the claim that we cannot understand or grasp the representation itself. [↑](#footnote-ref-4)
4. Letter to Robert Hooke, February 5, 1675: http://digitallibrary.hsp.org/index.php/Detail/Object/Show/object\_id/9285 [↑](#footnote-ref-5)
5. In superstring theory, space-time is 10-dimensional, in supergravity theory it is 11-dimensional, and in bosonic string theory space-time even has 26 dimensions. [↑](#footnote-ref-6)
6. Sometimes misleading metaphors can lead the public and even scientists astray (Boudry & Pigliucci, 2013). But even if we decide to get rid of some bad metaphors, we have no choice but to replace them with new and better ones. [↑](#footnote-ref-7)
7. In superstring theory, space-time is 10-dimensional, in supergravity theory it is 11-dimensional, and in bosonic string theory space-time even has 26 dimensions. [↑](#footnote-ref-8)