

How Our Biology Constrains Our Science

Michael Vlerick
Tilburg School of Humanities (The Netherlands)
Department of Philosophy
michaelvlerick@gmail.com
m.m.p.vlerick@uvt.nl

Abstract Reasoning from a naturalistic perspective, viewing the mind as an evolved biological organ with a particular structure and function, a number of influential philosophers and cognitive scientists claim that science is constrained by human nature. How exactly our genetic constitution constrains scientific representations of the world remains unclear. This is problematic for two reasons. Firstly, it often leads to the unwarranted conclusion that we are cognitively closed to certain aspects or properties of the world. Secondly, it stands in the way of a nuanced account of the relationship between our cognitive and perceptual wiring and scientific theory. In response, I propose a typology or classification of the different kinds of biological constraints and their sources on science. Using Boden's (1990) notion of a conceptual space, I distinguish between constraints relating to the ease with which we can reach representations within our conceptual space (which I call 'biases') and constraints causing possible representations to fall outside of our conceptual space. This last kind of constraints does not entail that some aspects or properties of the world cannot be represented by us – as argued by advocates of 'cognitive closure' – merely that some ways of representing the world are inaccessible to us. It relates to what Clark (1986) and Rescher (1990) have framed as 'the alien scientist hypothesis' (the possibility that alien scientists, endowed with radically different cognitive abilities, could produce representations of the world that are unintelligible to us). The purpose of this typology is to provide some much needed clarity and structure to the debate about biological constraints on science.

Keywords Cognitive Constraints, Sensory Constraints, Scientific Scope, Cognitive Scaffolding, Conceptual Space, Cognitive Closure

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1. Introduction

Darwin's (1859) theory of evolution by natural selection has profound consequences for epistemology. It sheds a whole new light on the origin and therefore the scope and limits of the human mind. Not only are our cognitive faculties the outcome of a contingent evolutionary path, they are also shaped to promote survival and reproduction in the particular ecological context ancestral Homo sapiens encountered. A far cry from the traditional view of the human mind as the God-like organ, partaking in universal Rationality. To make matters worse, Darwin (1871) insists that the difference in mind between human and non-human is but a difference of degree. What then are we to make of our epistemic prospects? Darwin himself was not optimistic. In a letter to William Graham, he expressed the following concern:

"With me the horrid doubt arises whether the convictions of man's mind, which has been developed from the mind of the lower animals, are of any value or at all trustworthy. Would anyone trust in the convictions of a monkey's mind, if there are any convictions in such a mind?" (Darwin 1871).

Since Darwin, a great deal more has been discovered about the human mind. The picture that is emerging is that of a highly structured amalgam of cognitive sub-systems, each evolved to deal with a set of particular, recurring problems in our ancestral environment (e.g. Fodor 1983; Barkow, Tooby and Cosmides 1992; Pinker 1997; Carruthers 2006). While the extent to which the mind is 'modular' or carved up in domain-specific, informationally encapsulated, autonomous and specialised sub-systems is still heavily debated, it is unanimously accepted that the human mind is an evolved, natural organ with its concomitant structure and limits. Epistemic pessimists – such as Fodor (1983), McGinn (1994), and Chomsky (2000) – have argued that this entails that our best epistemic endeavours, science, must be limited in scope. That, in other words, some aspects and properties must in principle remain unknown

to us, given the biologically imposed limits of our evolved minds.¹ This is the so-called ‘cognitive closure’ or ‘epistemic boundedness’ thesis.

In previous work I have argued against the view that biological constraints entail cognitive closure (Author’s ref). The fact that our biology constrains our epistemic activities does not entail that some aspects and properties of the world must remain unknown or unrepresented by us. Arguing that it does, conflates *representations* (the ways in which we represent the world and which are constrained by our biological makeup) and *objects of representations* (the aspects and properties of the world which are represented). It is not because there are constraints on the way we represent the world that we cannot represent everything there is in the world. Moreover, deriving cognitive closure from genetic constraints also ignores the myriad of ways in which we scaffold our thinking with so-called ‘mind extensions’ (see section 2). We cannot, therefore, gauge the scope of our sciences by looking at the limitations of our unassisted senses and minds (as the advocates of cognitive closure do).

This however does not mean that our biology does not *constrain* our sciences (merely that it does not in principle *limit* what our sciences can represent). Conflating constraints and limits is exactly the fallacy committed by the advocates of cognitive closure. By ‘constraints’ I refer to the fact that our biology steers and frames scientific enquiry (see section 2). ‘Limits’ on the other hand refer to a principled inability to represent some aspects of the world. The view that our biology limits our science is defended by the advocates of the cognitive closure thesis. The view that our biology constrains our science – in the sense defined above – follows from a naturalistic perspective on human cognitive abilities (and is commonly accepted by philosophers of naturalistic ilk). Our genetic constitution, meaning the makeup of our senses and cognitive faculties, is not irrelevant to our epistemic activities. How our biology affects our science, however, is not clear from the extant literature.

¹ To be fair, only Fodor (1983) and Chomsky (2000) derive cognitive closure from the premise that our mind is an evolved organ with its accompanying structure and limits. McGinn (1994) does believe the natural, evolutionary origin of our mind makes it very likely that some aspects and properties of the world will elude us, but does offer other arguments to support his claim, (such as a mismatch between the way our mind works and the structure of allegedly unsolvable problems).

The aim of this paper is to remedy this by proposing a conceptual framework or typology of biological constraints on scientific representations. Such a framework, I hope, will both facilitate the systematic study of cognitive and perceptual constraints on human scientific representations of the world and ward off hasty and ultimately unfounded (pessimistic) conclusions regarding our epistemic prospects. In section 2, I look at the ways in which we extend our cognitive scope by using external resources. These external levers greatly amplify the conceptual space of our (scientific) representations. In section 3, I propose a new conceptual framework to think about biological constraints on science. In section 4 and 5, I flesh out this framework. And in section 6, I conclude.

2. Extending Our Cognitive Scope

In the same way as for any other species on this planet, our genetic constitution determines to an important extent the representations we form of the world.² More precisely, it determines the kind of input we gather from the world and the way we process this input (Fodor 1983, Barkow, Tooby and Cosmides 1992, Carruthers 2006, Boyer 2000). We come equipped with a number of senses – each with their particular scope and resolution – and a set of intuitions or innate reasoning principles underlying the interpretation of this input. This yields a humanly shared set of intuitive representational frameworks we impose on (the input we gather from) the world, often referred to as ‘folk sciences’ (e.g. folk physics, folk biology, and folk psychology). Boyer (2000: 277) calls these hard-wired representational frameworks ‘intuitive ontologies’, which he describes as ‘a series of category-specific intuitive principles that constitute an evolved natural metaphysics’.

The fact that these intuitive (and often implicit) theories about aspects of the world are innate is supported by two strands of research. The first is developmental psychology. Infants show some basic appreciation of physical laws which they could not have gathered from experience. This

² By this I do not mean that we can map specific genes to (kinds of) representations we form of the world, but rather that cognition is grounded in our biology. Much like the hardware of a computer determines the way that computer is going to process information, the human genetic constitution determines the way our minds process information.

conclusion emerges from the research of Spelke (1991) and Baillargeon (1991) who have designed experiments on 3 to 8 month old children, to test their concept of objecthood and the laws that govern their interaction. In order to test this, they measure the looking time of the infant when confronted with either a possible or an impossible physical event (such as, for instance, an object passing through another or an object disappearing after being veiled). When infants consider something as an impossible physical event, their looking time will be considerably longer than when confronted with a possible event, which bores or ‘habituates’ them much faster, making them look away (Baillargeon et al, 1995:81). In other words, infants reveal their innate representations of the world by looking much longer at scenarios that violate their intuitions about how the physical world behaves.

The conclusions that emerge from this research is that infants possess the concept of objecthood – whatever moves together is considered an object – and that they expect these objects to behave in certain ways. Infants expect objects to be impenetrable by each other, to move along continuous trajectories and to be cohesive. Furthermore, they already ‘know’ that objects can only move each other by making contact. As Pinker (1997) points out, infants see objects, remember them and expect them to obey several physical laws. They have an understanding of a stable, lawful world, which they could never have acquired by simple induction (they are barely able to manipulate objects, they don’t see them very well, etc.) or through feedback from anyone else (they obviously can’t communicate). Therefore, they must be endowed with an innate predisposition to understand physical entities in a particular way (319).

The second strand of research that points at our possession of innate theories about certain aspects of our environment is comparative anthropology. People everywhere have deep-rooted intuitions about natural kinds, such as animals, plants and minerals. According to Atran (1995, 1998), we are endowed with a predisposition to think about fauna and flora in a highly structured way. We intuitively classify the organic world in a complex taxonomy, based on a hidden trait or essence that members of the same group share with each other. Based on these intuited essences we divide the natural world into a complex taxonomy which incorporates different groups, each further defined in different levels of

subgroups (e.g. a lion is an animal, a mammal and a cat). Atran argues that these taxonomies are widely shared across all cultures and eras, and are therefore much less arbitrary than the assembly of, for instance, entities in cosmology, artefacts or social groups (1998: 547).

Taken together, the senses and innate reasoning principles we have evolved endow us with what Uexküll (1909) has called an ‘Umwelt’. A particular realm of awareness in which every species is encapsulated as a result of the outcome of its evolutionary history. Humans, nevertheless, have transcended their Umwelt (see Author’s ref). Modern science has parted ways with most of our intuitive understanding of the world and has radically extended the scope we have on the world, as provided by our unassisted senses and minds (Wolpert 1992, McCauley 2000). Indeed, in science we make use of instruments to observe otherwise unobservable macro- and microscopic entities such as, for instance, distant galaxies or the cells making up organic tissue. Furthermore, scientists postulate the existence of unobservables – like atoms and electrons – and grasp the causal structures of the physical world by means of complex quantitative systems (mathematics), yielding radically different representations (e.g. relativity theory) than those produced by our ‘bare’ sensory and cognitive faculties³.

In this regard, Sterelny (2010), following Clark and Chalmers (1997), argue that humankind’s impressive cognitive feats are primarily the product of our ability to extend our minds’ capacity through interacting with our environment, rather than being the product of our internal computational engine. Our minds, according to Sterelny (2010: 480), are ‘scaffolded’. They are supported by external, environmental resources that radically enhance their cognitive capacity.

These external resources ‘scaffolding’ human science can roughly be divided into three major categories. The first is the social aspect of human knowledge in general and science in particular. The impressive

³ By sensory faculties, I mean the five senses and the brain processes that interpret the input we gather from these senses. By cognitive faculties, I mean the brain processes that generate knowledge and understanding. I use the term ‘faculties’ interchangeably with ‘wiring’ ‘mechanisms’ and ‘apparatus’ – as in cognitive and perceptual wiring or mechanisms and cognitive and sensory apparatus.

bodies of knowledge science produces are not the result of the work of isolated individuals, but are accumulated over generations. Tomasello (2001), in this context, argues that the key cognitive adaptation accounting for human culture is humankind's ability to understand conspecifics as intentional agents just as the self, endowing human beings with 'joint attentional skills'. This endows us with 'powerful forms of cultural learning, [...] allowing human beings to pool their cognitive resources both contemporaneously and over historical time in ways that are unique in the animal kingdom' (135).

The second kind of scaffold refers to the 'cognitive artefacts' we develop. Such artefacts include logic, a system of formal principles of accurate inferences, and mathematics, a system to represent and compute quantitative information. Together those artefacts form the backbone of our modern sciences. Furthermore, as Dennett (2000: 22) argues, the natural languages humankind developed, provide us with the necessary tools to 'think about thinking'. They enable us, in other words, to represent our own representations – i.e. to form metarepresentations.

The third kind, finally, refers to the external devices we make use of. Notation enables us to store huge amounts of information we could never retain by memory. Furthermore, it assists our reasoning, enabling us – for instance – to rapidly work out mathematical equations. But it doesn't stop at writing. Over time we produced a plethora of technological detecting and measuring instruments (e.g. telescopes, barometers and the like) providing us with data we could never gather from the world by means of our unassisted senses, as well as computing instruments, enabling us to process data in ways we could never do with our unassisted mind.

This endows us with a radically different cognitive relation to the world than any other species on earth. In contrast to all other species, we are not bound to represent the world in a fixed set of ways (given that we have the ability to override our intuitive perspectives on the world – our so-called folk sciences), nor can we derive from our possession of biological constraints on cognition that some aspects and properties of the world must in principle remain unknown to us (given that we cannot predict what cognitive scaffolds we might in principle 'construct', enabling us to overcome cognitive limitations), as do advocates of the cognitive closure thesis.

This open-ended cognitive relation to the world (given that we are able to overcome innate species-specific representations and ‘freely’ construct new representations with new scaffolds) endows us with a conceptual space containing an infinite amount of possible representations of the world. This however does not mean that science is not affected by genetic constraints on perception and cognition. The fact that science is constrained by our biology has been pointed out by a number of influential authors. Ruse (1986, 1995) claims that science is firmly rooted in our biology. Our scientific endeavours, he explains, still flow through ‘biologically channelled modes of thinking imposed on us by evolution’ (Ruse 1986: 149). Lumsden and Wilson (1981: 13) refer to this as the ‘leash principle’. ‘Genetic natural selection’, they state, ‘operates in such a way as to keep culture on a leash’. Rescher (1990: 95), finally, claims that we are endowed with a particular ‘cognitive project’ which is ‘the intellectual product characteristic of one particular sort of cognitive life-form’.

It is however not clear what exactly those biological or genetic constraints on knowledge in general and science in particular are. This vagueness plaguing much of the literature dealing with this important issue, is problematic for two reasons. Firstly, it leads to hasty and unfounded conclusions, as the ones made by the advocates of the cognitive closure thesis, who bluntly assert that given the obvious genetic constraints on our cognitive activities, some aspects and properties of the world must elude us. Secondly, this vagueness prevents us from forming a nuanced account of the relationship between our biological makeup and the scope and form of our scientific theories (and the ways in which the former constrains the latter). To remedy this, I propose a conceptual framework, drawing from Boden’s (1990) notion of a ‘conceptual space’. This is the subject of the next section.

3. Conceptual Framework

A conceptual space, as Boden (1990: 89) defines it, is a space of computational possibilities a system can generate, based on the particular set of data (input) it receives and the set of action-rules it can perform on these data. Chess, for example, allows for a number of possible

board-positions based on a particular set of data – i.e. the different pawns and the structure of the board – and action-rules – the rules by which those pawns can be moved across the board. Based on these data and rules, all possible board positions can be generated. Similarly, the conceptual space containing the representations of the world we can in principle generate – i.e. the totality of representations that we could in theory form of the world – is based on the input we could in principle draw from it (the input we gather by means of our senses and the artificial aids we could in principle produce) and the ways in which we could in principle process this input (generated by our cognitive faculties, assisted by all the cognitive artefacts and other external resources we could in principle develop and use to scaffold our reasoning).

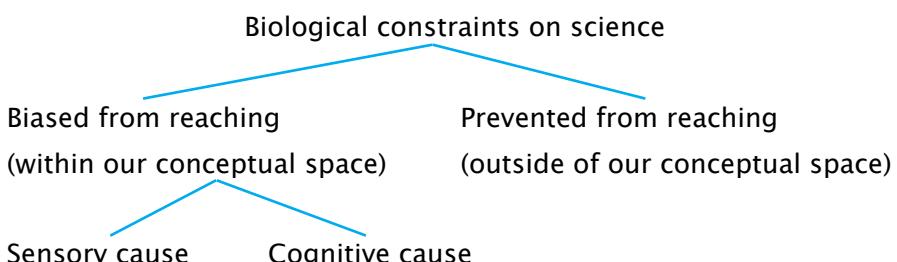
Every location being determined by a particular input and a particular action-rule performed on this input, the ease with which our mind zooms in on a location (i.e. a representation in our conceptual space) depends both on the ease with which the particular input can be drawn from the world and the ease with which a particular action-rule can be performed on this input. Regarding the input we can draw from the world, the nature of our senses – as I will discuss below – makes some data from the world easier to gather than other data. With regards to processing this input, our minds – as I will discuss – are predisposed to apply certain reasoning patterns (action-rules) to certain subject matters (data) and are therefore drawn towards certain locations within the conceptual space while typically – or at least initially – ignoring other locations.

To return to our chess example. While the combination of a fixed set of data and action-rules generates all possible board-positions, some board-positions are more likely to be generated than others. Chess players (or at least human chess players) will use certain guidelines – such as, for instance, ‘protect the queen’ – and will not try any permissible move at random. Similarly, our minds do not wander blindly in their conceptual space but selectively, yielding particular locations. Boden (1990: 89) refers to these guidelines as heuristics. They enable any cognitive system to move ‘insightfully’ through the conceptual space generated by the system. While the various scaffolds that support science enable us to overcome these predisposed representations of the world to an important extent, our genetically wired heuristics (Boyer’s (2000: 277) ‘cate-

gory-specific intuitive principles' that make up our intuitive ontologies) can nevertheless be expected to continue to play a role in our (scientific) reasoning and therefore bias us against 'zooming in' on certain representations within our conceptual space. Similarly, as pointed out, the way that our senses operate, biases us towards certain representations within our conceptual space (makes these easier to reach than others). I develop both kinds of biases in the following section.

Next to the first kind of constraint that our biology imposes on our science – making some locations within our conceptual space easier to reach than others – our biology constrains our sciences in another way. This second kind of constraint refers to the points located outside of our conceptual space. The fact that our conceptual space contains an infinite amount of representations (given the open-ended nature of forming representations) does not mean that there are no locations (possible representations) which are outside of our conceptual space. (Much in the same way that the fact that there are an infinite amount of numerical values between the number 1 and 2 does not mean that there are no numerical values outside of that numerical space). Locations outside of our conceptual space cannot be reached.

This yields the following typology of biological constraints on science:



This, I want to emphasise again, does not mean that some aspects or properties of the world must remain unknown. Our conceptual space may very well cover everything there is to know in the world, or – at least – there is no principled reason why our conceptual space could not cover everything there is to be represented. Nor does it mean that we are trapped in a subjective, tainted and therefore somehow deformed

perspective on the world. As Stove's (1995) famous rejection of 'the worse argument in the world' goes, it is not because we have to know the world through our conceptual schemes that we cannot know the world in itself. We just have a particular way of accessing the world. The fact that there can be different ways of knowing the world, is no more problematic than the fact that there are different ways of locomotion (compare birds, snakes, fish and humans). Much as it wouldn't make any sense to argue that we can't move because our locomotion is constrained by our bipedal makeup, it doesn't make any sense to argue that we can't know because our cognition is constrained by our genetically wired sensory and cognitive faculties.

What it does mean is that different ways of knowing the world may be possible and that some ways of knowing could be inaccessible to us given our biological makeup (much in the same way that some ways of locomotion are inaccessible to us given our biology). This point has been framed as the 'hypothesis of the alien scientist' by Andy Clark (1986) and Nicholas Rescher (1990). I discuss it in section 5. In the next section, I look at the way that our perceptual and cognitive makeup biases our sciences. In other words, I look at the way our genetic makeup makes some points easier to reach within our conceptual space than others.

4. Bias from Representing the World in Particular Ways

4.1 Bias Caused by Our Sensory Apparatus

Through the senses that we have evolved, we receive input from the world. However, only a small part of the available stimuli trigger our senses. We perceive stimuli only within particular ranges (e.g. our visual receptors are sensitive to a narrow portion of the electromagnetic spectrum and our auditory receptors to frequencies above 20 Hz and below 20 kHz), and endowed only with a certain level of resolution⁴; and, most importantly, there are vast realms of potential data in the world for which we simply have not evolved the appropriate sensory receptors (e.g. we

⁴ The same goes of course for our other senses: taste and smell as well as somato-sensory sensation or touch. We only perceive certain kinds of stimuli and only endowed with a certain level of resolution.

do not perceive magnetic fields as some migrating birds are known to do). This leaves us with a narrow scope on the world (Levine and Shefner 1991).

Nevertheless, as pointed out, we extend the reach of our senses (i.e. scaffold our perceptual abilities) through artificial detecting devices, allowing us to gather input from the world that falls beyond the scope of our ‘naked’ senses. We create telescopes, microscopes, antennas and stethoscopes, enabling us to detect otherwise unperceivable entities both in the macro- and microscopic realm. Furthermore, rather than just increasing the resolution of our senses, we possess devices that detect ranges of phenomena we cannot perceive, such as, for instance, the invisible part of the electromagnetic spectrum, and the inaudible frequencies of sound. Finally, we even detect phenomena for which we have no sensory receptors at all, such as air pressure through barometers and magnetic fields through compasses.

In this regard, we are ever increasing our perceptual scope on the world through a process of cumulative cultural evolution which leads to ever more powerful sensory extensions. Assuming that the physical world is causally closed – i.e. that all entities leave traces on other entities which again leave traces on others in an endless chain of causal connections – and that there are no epiphenomena – i.e. that there are no phenomena which do not exert a physical effect – we could, in principle, detect every entity and property in the world. While we might not be able to observe some aspects of reality directly, if these aspects exert a causal influence on other aspects, which again change others ad infinitum, all elements in the world could – in principle – eventually ‘surface’, leaving a trace that we can gather through observation and its mechanical extensions. The narrow scope of our evolved senses do not pose a principled limit to what we can detect, since physical entities do not have to be detected by a particular sense ‘designed’ to detect it. Light, for instance, can yield auditory stimuli, just as sound can be translated into graphs by a computer.

Nevertheless, some entities or properties of the world are easier to detect than others. The existence of the sun is much easier to detect than the existence of Jupiter’s moons, since we are able to detect the former with the naked eye and the latter only with telescopes. Similarly, the existence of Jupiter’s moons is easier to detect than the existence of

the radiation caused by the big bang, since the latter cannot be detected by a ‘simple’ telescope, but requires high-tech radar equipment and the proper scientific hypothesis – i.e. the birth of the universe in a big bang – to explain the particular recording. Therefore, while it might be the case that no physical entities are impossible to detect in principle, the detection of some entities is rendered much easier than the detection of others by the nature of our particular senses.

Detecting instruments, in this sense, are better described as extension devices of existing senses than radically new and different artificial senses. In discovering data from the physical world, we start from what we gather through our unassisted senses, and extend our reach from there. We do not delve into completely different realms of data with these instruments at once, but gradually work our way up to more and more inaccessible data. Indeed, how could we construct a mechanism that detects something of which we are totally ignorant? We can only direct our gaze to entities we know or at least have reason to suppose exist. This ‘sharpened gaze’ through mechanical detection devices then opens us up to the existence of new entities, which again enables us to focus our gaze, providing us with a new set of bearings to further direct our detection of aspects of the world.

This provides us with a perceptual bias: some elements will be (relatively) easy to discover, because of their proximity to elements we already observe, while others might be extremely hard for us to gather. Different senses, in this regard, would provide us with a different set of input that we gather through our senses and, therefore, a different perceptual bias, making different elements of the world more accessible. Since locations within our conceptual space are reached by applying a set of action rules to a set of input data, we are biased against reaching those locations which require input data from the world we are unlikely to gather because of the nature of our sensory apparatus.

4.2 Bias Caused by Our Cognitive Apparatus

Modern sciences – as pointed out in the introduction – are to an important extent at odds with our intuitively based folk theories, such as for instance folk physics, mistakenly ascribing an ‘impetus’ to moving objects or, folk biology, ascribing an immutable essence to natural spe-

cies. Indeed, throughout its history, human science has gradually parted ways with our intuitive understanding. While Aristotelian physics is still in line with our intuitive grasp of physical happenings, Newtonian – let alone Einsteinian – physics contradicts our intuitions. In this context, De Cruz and De Smedt (2012) show through an analytical model that cultural transmission of scientific knowledge leads toward representations that are increasingly more truth-tracking, even when our intuitions on the matter are seriously off the mark. Human science, in this regard, has gradually scaffolded its way from the often erroneous, uncritical representations we hold in virtue of our cognitive wiring to more truth-approximating representations of the external world.

Nevertheless, as De Cruz and De Smedt (2007) point out in another article, although science has parted ways with what Boyer (2000) dubbed our ‘intuitive ontologies’, we can nevertheless expect that they will continue to play a (distorting) role in scientific enquiry, since the human mind has evolved to understand objects in the world according to these intuitive ontologies (351). Considering the case of scientific theories about human evolution, De Cruz and De Smedt (2007) argue that not only do intuitive ontologies shape intuitions about human evolution, they also guide the direction and topics of interest in the research programs.

In exploring the relationship between intuitive ontologies and the scientific discourse surrounding human evolution, De Cruz and De Smedt (2007) point at palaeoanthropology, which retraces human evolution based on fossil findings. It is, as they point out with Tattersal (2000), a discovery rather than theory driven science. The lack of an explicit theoretical framework, makes it particularly vulnerable to the distorting effect of those so-called (implicit) intuitive ontologies. What indicates that palaeoanthropologists have succumbed to those tacit intuitive notions in interpreting the fossil record is because their assumptions departed from standard evolutionary theory (the scientifically validated framework) and became more compatible with such intuitively guiding notions.

More particularly, the intuitive notion to which palaeoanthropologists have succumbed to, according to De Cruz and De Smedt (2007), is the human–nonhuman distinction (358). Making a stark distinction between human and non-human is an innate psychological feature natural selec-

tion endowed us with – as well as most other species – in order to distinguish conspecifics from nonconspecifics. This is an important adaptation enabling organisms to recognise potential mates, among other things. The human–nonhuman distinction, according to De Cruz and De Smedt (2007), leads us to exaggerate the difference between humans and non-human animals and consequently consider human evolution as exceptional (358). It has led paleoanthropologists to a unilineal view of human evolution.

Mayr (1950: 115–116), for instance, argued that all hominids can be grouped in a single lineage from australopithecines through *Homo habilis* to *Homo sapiens*. This is in sharp contrast with the usual branching pattern of evolution, and was explained away by Mayr by invoking the fact that hominids did not speciate because, possessing culture, they occupied more ecological niches than any other species (De Cruz and De Smedt 2007: 359). This is inconsistent with the finding of *Homo floresiensis*, a small hominid with the brain size of an australopithecine dated at 18.000 years B.C., and many more genera within the hominid linea in the last decades (most recently *Homo naledi* in a South-African cave – Berger et al 2015). Nevertheless, paleoanthropologists still attempt to prune the tree of human evolution (De Cruz and De Smedt 2007: 361). While there might of course be other non-biological reasons for this apparently systematic bias in palaeoanthropology – cultural reasons, such as the influence of cultural anthropology, stressing the pivotal importance of culture in explaining all things human on Mayr (De Cruz and De Smedt 2007: 360) and Mayr's influence on the next generations of researchers – it is likely that implicit intuitive notions were (and to some extent still are) at work.

Therefore, while we are able to transcend our commonsense representations or ‘folk sciences’ – i.e. go beyond and in some cases against these representations – the intuitive ontologies at the core of these representations still seem to play a role in the scientific representations we produce. As suggested by De Cruz and De Smedt (2007), intuitive ontologies are pervasive in scientific discourse, directing research and biasing the interpretation of experimental results. In this sense, much as our senses bias us against detecting certain elements of the world and therefore bias us against zooming in on certain representations of

the world, our cognitive nature biases us against interpreting the data in certain ways. In terms of the framework introduced above: we are biased against forming representations which would require pathways through our conceptual space we are not likely to take, still guided as we are by the heuristics natural selection provided us with.

5. The Alien Scientist Hypothesis

Science, I have argued above, has radically transcended our default or natural view of the world, extending our cognitive scope way beyond its humble origins: the Uexküllian ‘Umwelt’ we were endowed with much like any other species on this planet. The key drivers behind sciences’ extension of our cognitive scope beyond the human Umwelt, are the various scaffolds discussed in section 2. Those instruments and cognitive artefacts however do not materialise out of thin air. In this regard, whereas those artefacts enable us to radically transcend the intuitive representations we hold in virtue of our cognitive makeup, they are themselves constrained by our genetically wired cognitive mechanisms. Ruse (1986), in this context, argues that while the products of science (i.e. the representations or theories it produces) transcend their organic origin (the functions our cognitive faculties were ‘designed’ to carry out by natural selection), the methods science employs and the principles it adheres to are still firmly rooted in our biology. Our scientific endeavours, in other words, as far as they can take us away from our uncritical commonsense representations, still flow through ‘biologically channeled modes of thinking’ imposed on us by evolution (149).

Ruse (1986) refers to these innate reasoning patterns underlying all human thought as ‘epigenetic rules’. This term, borrowed from Lumsden and Wilson (1981), designates the biological constraints on human cognition and behaviour which have their origin in evolutionary needs (Ruse 1986: 143). A good example of such rules is the universal human classificatory schema into which colours are broken up (143–144), or the incest barriers we find in all human cultures (145–146). Culture, Ruse argues, is not some special disembodied phenomenon but ‘the flesh on a biological skeleton’, where the bones of that skeleton are epigenetic

rules, controlled by our genetic constitution and fashioned by the hand of natural selection (147).

Those epigenetic rules include the cognitive ingredients at our disposal; the building blocks of human reasoning. According to Ruse, they are the basic logical principles we adhere to in our reasoning, such as the law of the excluded middle and of non-contradiction, or the rule of modus ponens and alternation (Ruse 1986: 156–157).⁵ Furthermore, they include the basic premises and principles of mathematical thinking, our ability to draw causal relations, inductive and deductive reasoning, and so on (158).

All human thinking, from the uncritical folk sciences we produce to the most advanced and counterintuitive scientific conjectures, employs these basic ‘cognitive building blocks’. In other words, the cognitive artefacts we develop and which radically increase our conceptual abilities, are nevertheless still constructed out of a set of conceptual tools, which are ultimately the product of our genetically determined cognitive apparatus. In the same way, we cannot experience the world other than through our particular senses; we cannot think other than through those reasoning patterns evolution has provided us with. Being the products of a natural, unguided process, the cognitive building blocks at the basis of human reasoning are contingent in much the same way as the experiential realms yielded by our senses. In this regard, just as we could perceive the world differently, we could – in theory at least – conceptualise it differently.

The way we represent the world is highly dependent on the particular evolutionary path we have taken. While this is trivially true on an intuitive, hard-wired ‘Umwelt’ level (the underlying physical intuitions of a water born fish can be expected to be radically different than ours, given that

⁵ I am aware that this is a controversial point. Many philosophers, most notably Frege (1884), have argued against this so-called ‘psychologism’. Logic (and by extension mathematics) cannot, according to Frege, be explained by psychology. In other words, the foundations of logic and mathematical are not cognitive in nature. Quine’s (1969) naturalism has famously taken a diametrically opposed stance. According to Quine, epistemology is to be a ‘chapter of psychology’ (1969). This paper is rooted in the latter, naturalistic tradition. It takes a cognitive (and evolutionary) perspective on epistemology. Defending such a naturalistic approach (or even reviewing the arguments in favour of such an approach) is, however, beyond the scope of this paper.

they evolved to cope with a radically different environment than ours), it also holds for our scientific representations. Let us suppose, in this regard, that we did not possess the innate faculty to represent numerical information. According to Spelke (2003) there are two distinct innate systems at the basis of our ability to represent numbers. With respect to small numbers (up to about 3) we are endowed with the innate faculty to represent the numerical identity exactly, as well as the effects of adding or subtracting one. With respect to larger sets of numbers, we represent their approximate numerical magnitudes, enabling us for instance to gauge that a set of 50 is larger than a set of 25 (but not that a set of 31 is larger than a set of 30) (297). Spelke argues that these two distinct systems of representation are then combined by the human mind, underlying our ability to represent larger numbers exactly and therefore to count and engage in more complex mathematics (302)⁶. Without these innate faculties underlying our sense of numeracy, it is likely that we could never have developed mathematics. Lacking this powerful cognitive artefact, in turn, most of the scientific representations of the world we now hold, would be unreachable.

Conversely, a creature that would be endowed with more or different cognitive building blocks, could possibly construct radically different representations that are inaccessible to human beings. A creature with such extra reasoning patterns could look upon us in much the same way as we would look upon those numeracy-lacking humans: as blinded to some ways of representing the world. Grounding our cognitive faculties in a natural process, we must indeed admit to the theoretical possibility of radically different cognitive faculties.

This point was eloquently framed by Clark (1986) and Rescher (1990) as the hypothesis of alien scientists or epistemologists. According to Clark, an ‘interesting consequence’ of an evolutionary take on cognition

⁶ This innate number sense does not mean that human will automatically develop a full-fledged numerical system. It is a necessary condition, not a sufficient condition. Famously, the Pirahā (an Amazonian tribe) only have the number 1 and 2 and a term to designate small quantities and one to designate large quantities. Moreover, when cultures do develop full-fledged numerical systems they can differ. Mesopotamians did not have a decimal number system, but one centered on 60. Nevertheless, I would argue with Spelke (2003), that despite the cultural differences in constructing numerical systems, they are all rooted in an innate sense of number.

is that we must accept the possibility of alien epistemologists, working successfully with a different and – to us – possibly unintelligible model of our ‘common reality’. Indeed, he continues, ‘the ideal limit of human scientific enquiry is still not the only possible ‘correct’ representation of reality even if relative to our cognitive constraints and observational access there are no visible alternatives’ (158).

Similarly, Rescher (1990) argues that ‘there is no categorical assurance that [alien] intelligent creatures will think alike in a common world, any more than they will act alike – that is, there is no reason why cognitive adaptations should be any more uniform than behavioral adaptations’ (his italics, 92). Sciences, he continues, ‘are bound to vary with the cognitive instruments available in the physical constitution and mental equipment of their developers’ (95). Our sciences, in this regard, are but the intellectual product of one particular sort of cognitive life-form. They are ultimately species-relative (95).

Rescher concludes that ‘it would be grossly unimaginative to think that either the journey or the destination must be the same – or even substantially similar’ and that ‘unless we narrow our intellectual horizons in a parochially anthropomorphic way, we must be prepared to recognize the great likelihood that the ‘science’ and ‘technology’ of a remote civilization would be something very different from science and technology as we know it’ (94).

In reference to the framework developed in this paper, some theoretically possible ways of representing the world can be expected to be located outside of our conceptual space. Such hypothetical alien scientists could yield representations which are irremediably beyond our ken. Denying this – I believe with Rescher (1990) – would be hopelessly anthropocentric. Nevertheless, this would still not entail that they would represent objects and properties of the world which we cannot represent. Those objects and properties might indeed very well be representable in more than one way. Some ways may not be accessible to us, but others might. Representational closure therefore does not entail cognitive closure. Compare this with language. The fact that we only master one or a few languages does not necessarily entail that we cannot express certain ideas, merely that in expressing them we are constrained to the particular language we happen to speak.

6. Concluding Remarks

While an increasing number of naturalistic authors point out biological constraints on human science, it remains unclear how exactly we should understand these constraints. In this paper, I have proposed a typology of those biological constraints. There are two ways in which our biology constrains our sciences. The first way is by making some representations within our conceptual space easier to reach than others. The second way is by defining a conceptual space and consequently preventing access to representations outside of that space. This classification and the implications I have outlined for each kind of constraint will, I hope, both ward off possible confusion and unfounded conclusions regarding our epistemic prospects by lumping all relevant issues together as constraints or limitations.

In this regard, briefly coming back to the issue of cognitive closure – the thesis that some aspects and properties of the world must in principle elude us given the constraints imposed on science by our perceptual and cognitive faculties – it should be clear that this is neither established by the fact that we are biased towards certain representations within our conceptual space, nor by the fact that humanly possible representations are contained within a conceptual space. Bias, by its very nature, is not an unsurmountable obstacle, and containment within a conceptual space and the possibility of radically different – and to us – unintelligible representations of the world, let's say by Clark and Rescher's alien scientists, does not entail that some aspects or properties of the world fall outside of our cognitive scope (merely that some theoretically possible ways of accessing those aspects or properties are outside of our reach).

Finally, I dare hope, the typology I propose could facilitate the systematic study of cognitive and perceptual constraints on human scientific representations of the world. This project should be of interest to philosophers and scientists alike. It is squarely rooted in the age-old epistemological quest to gauge the scope and limits of human knowledge in the face of sceptical threats. But it is also relevant for scientists, who deal with these constraints on a daily basis in their constant strive to further knowledge and expand the boundaries of our scientific scope.

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