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Darwinian Domain-Generality: The Role of Evolutionary Psychology in the Modularity Debate

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DARWINIAN DOMAIN-GENERALITY:
THE ROLE OF EVOLUTIONARY PSYCHOLOGY IN THE MODULARITY DEBATE

by

MICHAEL LUNDIE

Under the Direction of Daniel A. Weiskopf, Ph.D.

ABSTRACT

Evolutionary Psychology (EP) tends to be associated with a Massively Modular (MM) cognitive architecture. I argue that EP favors a non-MM cognitive architecture. The main point of dispute is whether central cognition, such as abstract reasoning, exhibits domain-general properties. Partisans of EP argue that domain-specific modules govern central cognition, for it is unclear how the cognitive mind could have evolved domain-generality. In response, I defend a distinction between *exogenous* and *endogenous* selection pressures, according to which exogenous pressures tend to select for domain-specificity, whereas the latter, endogenous pressures, select in favor of domain-generality. I draw on models from brain network theory to motivate this distinction, and also to establish that a domain-general, non-MM cognitive architecture is the more parsimonious adaptive solution to endogenous pressures.

INDEX WORDS: central cognition, connectome, domain-specific, encapsulated, endogenous selection pressure, exogenous selection pressure, domain-general, hub core, rich club

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by

MICHAEL LUNDIE

Committee Chair: Daniel A. Weiskopf

Committee: Neil Van Leeuwen

Andrea Scarantino

David Washburn

Electronic Version Approved:

Office of Graduate Studies

College of Arts and Sciences

Georgia State University

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DEDICATION

I am grateful to my wife, Nancy, who with great patience and support has stood by me through the great trials and challenges of academic life.

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LIST OF ABBREVIATIONS

EP – Evolutionary Psychology

MM – Massively Modular/ Massive Modularity

1 INTRODUCTION

Biological systems and mechanisms are putative products of evolutionary processes. A guiding principle of the theory of evolution by natural selection is that the emergence of such products is explicable in terms of adaptive advantage and fitness-enhancement (Boyer 2015: 186; Buss 1995: 2; Cosmides and Tooby 1994: 86). By reverse engineering the functional properties of, say, claws and wings, it is possible to locate the etiology of these adaptations in selective pressures that recurred throughout a species' phylogenetic history (Sober 1984: 211) – for example, claws for protection and predation, and wings for foraging and escape. This analysis accordingly identifies not only the emergence of adaptations, but also their stability across generations in phylogenetic history. Adaptations build upon one another to create more complex structures conducive to survival and reproductive viability (Sperber 2004: 53-4). In evolutionary psychology (EP), this research paradigm gets applied to the functional analysis of the cognitive mind, including the properties, structures, and general architecture of human thought (Buss 1995: 2; Cosmides and Tooby 1994: 86). The explanatory scope of EP encompasses the processing that takes place in lower-level sensory systems like vision and audition, which I will refer to as *perception*, as well as higher-order systems that mediate conceptual reasoning, belief formation, and other facets of distinctively human thought, a cluster I will call *central cognition*.

The primary question I will address here is: what sort of cognitive architecture follows from the principles of evolutionary psychology? Practitioners of evolutionary psychology usually argue in favor of a massively modular (hereafter, MM) architecture (Carruthers 2006; Sperber 2002; 2004).¹ My aim is to challenge this thesis, and argue that evolutionary psychology supports a non-MM cognitive architecture.

¹ Some philosophers regard massive modularity as a cluster of views bound together by a family resemblance relation, rather than a narrowly defined thesis (Weiskopf 2010: 28). The construal of massive modularity I treat here

To argue for my claim, I start in section 2 by elaborating on the MM thesis and why EP theorists tend to favor such cognitive architectures. In section 2.1, I sketch the *selection pressures argument*, attributable to Cosmides and Tooby (1997), which makes the claim that a non-MM cognitive architecture possessing domain-*general* functional properties could not have evolved. In section 3, I set the background for my defense of non-MM architecture against the selection pressures argument. I will show how the term ‘selection pressure’ is open to various interpretations, which differ with respect to the cognitive architecture that EP should favor. It will be argued that some selection pressures – call these *endogenous* pressures – lead to adaptive solutions that are candidates of domain-general processing in central cognition. Section 4 covers a response from MM theorists, highlighting how adaptations to endogenous pressures would still count as modules. This response would render superfluous domain-general mechanisms posited by non-MM architectures. In section 5, I attempt to undermine the MM thesis by drawing on findings from neural network topology (Bullmore 2012; Sporns 2010, 2012) to illustrate why endogenous pressures selected for domain general mechanisms. By these lights, EP should adopt the non-MM framework in virtue of its supplying the more parsimonious hypothesis, compared to the MM framework, of how the cognitive mind evolved to overcome endogenous selection pressures. I conclude by sketching possible directions for further development of the non-MM account of cognitive architecture.

2 EVOLUTIONARY PSYCHOLOGY AND MASSIVE MODULARITY

The evolutionary psychologists David Buss (1995) and Tooby and Cosmides (1994; 1995; 1997) described the methodology of evolutionary psychology (EP) as subsuming, integrating and

represents a distillation of claims attributable to committed modularists, a group that includes Carruthers (2006), Sperber (2004), and Cosmides and Tooby (1994).

uniting the disparate psychological theories of the human mind under a single set of paradigmatic principles. The paradigmatic principles supply an explanatory framework that places central importance on the concepts of *Environment of Evolutionary Adaptedness*, *fitness*, *adaptation*, and *selection pressures*, all cornerstones of evolutionary theorizing.² These concepts map onto features of the Environment of Evolutionary Adaptiveness (Boyer 2015: 189; Buss 2005; Tooby and Cosmides 1987: 5, 1994: 87) in which ancestral organisms encountered recurring threats to survival and reproduction and gradually developed adaptive mechanisms that overcame these threats. It is in the sense of locating selection pressures in the external environment that some theorizers, particularly Cosmides and Tooby (1994; 1995; 1997), adopt an *externalist* orientation to elucidating the fitness advantages afforded by adaptations.

The Environment of Evolutionary Adaptiveness most relevant to forming hypotheses about human psychology corresponds to the Pleistocene era, spanning a period between 1.8 million to 10,000 years ago (Buller 2005: 9; Tooby and Cosmides 1994: 87). Prehistoric hunter-gatherers struggled against an array of adaptive problems relating to resource acquisition, avoiding dangerous predators, overcoming conspecific rivals, securing shelter, finding mates, and raising offspring (Buss 1995: 9-10). These adaptive problems would tend to threaten the reproductive viability and survival of ancestral humans. Such problems imposed a selection *pressure* in favor of cognitive mechanisms, so-called “mental organs,” that were suited to overcoming each adaptive problem (Pinker 1997: 21). If the evolving minds of hunter-gatherers lacked the inference rules and problem-solving capacities to find resources, secure shelter, establish and follow norms, and avoid predation, the survival and reproduction of those hominid ancestors would have been jeopardized. Variations lacking such capacities would be less fit, and therefore

² Additional concepts distinctive to evolutionary approaches to the study of cognition and behavior are “function,” “regulation,” “computational architecture,” “organization,” “design,” “entropy,” “replication,” “by-product,” and “task environment” (see Cosmides & Tooby 1987: 8).

less likely to reproduce. This pattern would have led to the retention of fitness-enhancing traits in subsequent generations. That is, organisms that were able to overcome selection pressures were more likely to survive, reproduce, and pass genes encoding for those traits on to the next generation.

Some theorists propose that natural selection tends to favor specialized adaptive traits (Sperber 1994; Carruthers 2006). Specialized solutions to selection pressures are tailored to address a particular *type* of threat to the organism's survival.³ One of the defining characteristics of specialized adaptations is that they carry out specific, well-circumscribed functions that are ultimately conducive to survival and reproduction (Godfrey-Smith 2013: 51). There are sundry examples of specialization documented throughout biology. Examples of such mechanisms include lungs for breathing, hearts for pumping blood, and so on. Identifying a mechanism's specific functional role and its attendant fitness enhancement correspond to its *raison d'être* from the perspective of evolutionary theorizing. A sketch of specialized functionality is the starting point for describing why externalist approaches to evolutionary psychology (which I will continue to shorten, for brevity, to EP) favor modular mechanisms.

The term *module* carries a strict definitional usage in explanatory framework of EP. In order to evaluate the inference from principles of EP to a well-defined cognitive architecture, we must further clarify which necessary and sufficient conditions a mechanism must satisfy in order to be called a module. At the most general level, think of modules as computational mechanisms,⁴

³ The strength of this claim notwithstanding, cases of multifunctional mechanisms and traits arising by means other than selection have been known since Gould and Vrba (1982: 6). For instance, there are so-called *exaptations*, which are adaptations that are coopted to serve additional functions, as well as *spandrels* that emerge as developmental byproducts of adaptations (ibid. 6).

⁴ Describing modules as computational mechanisms equivocates between two senses of *computation* (Samuels 1998: 579). Modules may be computational under either the *hardware conception* or the *algorithm conception* (Ibid. 579). In the hardware sense, modules are specialized computers identical to specific neural networks. On the latter interpretation, modules as specialized sub-routines or mental programs – on this account, modules could be

specialized sub-routines or sub-systems within the overall cognitive architecture (Fodor 1983: 36-38; 2000: 91). There is not much consensus on how many conditions there are or how many must be met before any mechanism qualifies as modular (Carruthers 2006a: 3). Consider that in *The Modularity of Mind*, Fodor proposed nine distinct features that typify modules (1983: 47-101).⁵ It will suffice for present purposes to regard modular mechanisms as distinguished only by the subset of three properties that Carruthers (2006a) and Sperber (2004) are respectively committed to in their massive modularity frameworks. The three basic properties of modules are (1) domain-specificity, (2) encapsulation, and (3) mandatory operation (Fodor 1983: 36-7, 47, 52, 64).

Starting with (1), modules are *domain-specific* insofar as they process either a specific type of input (Carruthers 2006) or deliver a specific output to perform a function further downstream in central cognition (Cosmides and Tooby 1994: 94). If I perceive a cat, for instance, the relevant transducer or perceptual apparatus, in this case the cones and rods in my retinas and the axonal connections extending therefrom, relays information to the relevant cortical regions that take these perceptual data as inputs. The deliverances of these cortical processing regions produce a mental representation of the observed environmental feature as output (e.g. a mental representation of the perceived cat).⁶ The representational output is then available as a discrete, manipulable component in central cognition (e.g. enabling the formation of beliefs and inferences about the cat).

implemented across disparate neural networks (Samuels 1998: 579). I will assume the algorithmic conception that the evolutionary psychologists Tooby and Cosmides (1997) explicitly endorse in their account of modularity (81).

⁵ According to Fodor's original formulation (1983), modules are: (1) localized, (2) subject to characteristic breakdowns, (3) mandatory, (4) fast, (5) shallow, (6) ontogenetically determined, (7) domain specific, (8) inaccessible, and (9) informationally encapsulated.

⁶ For purposes of exposition, I provisionally adopt the representational theory of mind (RTM) in the present analysis. The basic idea is that the outputs of perceptual processing are representations whose role is to enter into cognitive processes like abductive inference, deductive reasoning, and other facets of central cognition.

Perhaps it's uncontroversial to state that the mind contains input-specific processors acting on databases – that sense of domain-specificity could hold true for many models of cognition, even on the non-modular accounts (cf. Fodor 2000: 58). The more contentious claim is that each module is an *adaptation* that evolved independently as a “mental organ” that is a universal feature of human cognition, each module suited to solving a specific adaptive problem (Buller 2006: 92; Pinker 1997: 21, 49). Recall that perceptual inputs are supposed to determine which modules upstream in central cognition end up getting activated. By adding the qualification about adaptive value to the mix, the revised order of operations approximates to: ‘different modules get activated based on whether the perceptual information meets the specific input conditions that characterize the *actual* and a *proper* domain of any given module’ (Sperber 2004: 55). The proper domain corresponds to bodies of knowledge and functional properties that have special evolutionary significance (Sperber 2004: 55). In other words, a module's *proper* domain refers to the inputs and functional properties for which the module was selected: that is, whatever carries out the function for which the module emerged as an adaptation (Buller 2005: 57). On the other hand, a module's *actual* domain extends far beyond its proper domain, and refers to any perceptual feature that may trigger the module (Ibid. 55). For example, the ‘face-recognition device,’ itself putatively a module with adaptive value, responds to perceptual cues beyond what is exhibited by *real* human faces. For instance, a jagged rock formation on the side of a mountain may exhibit structural properties sufficiently similar to a human face such that it activates the face-recognition device. To summarize then: the perceptual features of actual faces correspond to the module's proper domain, and recognizing faces carries adaptive value, plausibly by assisting in nonverbal communication and inter-personal, cooperative behavior among conspecifics (Green 2016: 2).

A corollary of the foregoing is that perceptual cues falling outside the parameters of a module's actual domain will not activate it. Suppose I perceive a doorway or a computer instead of the jagged rock formation. The perceptual features of the doorway and computer are sufficiently dissimilar from those of faces so that the face-recognition module is unlikely to play any part in subsequent cognitive processing. Rather, the respective modules that get recruited would process information proper to, say, SHELTER or TOOL-USE, modules with proper or actual domains responsive to the available perceptual inputs (Pinker 1994: 420). To clarify further, the perceptual cues that activate the SHELTER module may correspond to the door handle and oblong, hinged doors, and in other instance the TOOL-USE module may get activated by keyboards and monitors. To sum up, the boundaries of modules are defined over different categories of perceptual inputs.

Moving on to feature (2), modules are *encapsulated* in the sense of being computationally impenetrable by other modules and sub-systems, and are capable of accessing only their own proprietary databases. Put more succinctly, higher-order cognitive systems cannot penetrate the information stored in each module, and from the standpoint of any one module the operations of the cognitive systems outside its own database are opaque (Weiskopf 2010: 8). The PREDATOR module, for instance, would access its own database, presumably containing information about threats in the external environment. How the PREDATOR module runs its computations to determine what counts as a predator is inaccessible to higher-order cognitive processes. By parity of reasoning, the PREDATOR module cannot access the data or computational processes contained in the SOCIAL EXCHANGE module (presuming of course that the latter modular system, dealing with cost-benefit analysis in conspecific relations and reciprocity, is a discrete modular system). By regarding modules as isolable computational systems, the flow of information through

cognition is restricted only to modules whose actual or proper input domains are sufficiently relevant to the on-going task (Sperber 2004: 60-1). If my perceptual system delivers inputs that cause me to form a mental representation of a lion crouched in front of me, predictably followed by lion-related thoughts and inferences (e.g. THE LION IS DANGEROUS, therefore, I SHOULD RUN TO SAFETY), this should be a consequence of the relevant PREDATOR module consulting only its own proprietary database.

There is less convergence on whether the third feature should count as necessary for *all* cognitive modules, but I include (3), *mandatory operations*, following Sperber's architectural framework (2004: 60), one of the more influential exponents of the MM thesis, which posits modules that function accordingly. We may define this feature as a form of automatic processing with two conditions: the appropriate perceptual input (i.e., cues that activate the module's actual or proper domain) sufficiently triggers processing procedures that (a) cannot be interrupted by other sub-systems, so that the modular operation will run its course and 'ignore' other cognitive systems during processing. The modular operation is also mandatory in the sense of being (b) involuntary in operation once input conditions are satisfied, akin to a "cognitive reflex," hence the cognitive procedure cannot be consciously willed or blocked by the agent (2004: 60-1). Regardless of the thoughts I entertain, the perceptual information automatically triggers the module whose output results in my perceiving a cat in front of me. Optical illusions serve as a useful illustration of this phenomenon of mandatory operation. The persistence of the Müller-Lyer illusion – where two lines appear to be of different lengths, even though they are actually equal in length – shows how conditions (a) and (b) may be true of the mechanisms that mediate the perception of the figures in this illusion (see Zeman et al. [2013] for an in-depth analysis of the computational mechanisms behind the illusion).

Having covered the three basic features of modular mechanisms, we return to the inferential link from EP to massive modularity. The inference from the adaptive problems identified in the Environment of Evolutionary Adaptiveness of hunter-gatherer ancestors to an ensemble of modules in cognitive architecture should now be straightforward. The pattern of assigning specific functions that impart survival advantages should apply as well to the structures of cognition as it does to the other organ systems; each component, or module, of the human mind emerged as an adaptive solution to a specific problem, eventually resulting in a collection of modules that together facilitate central cognition in cognitive architecture (Carruthers 2013a: 8; Sperber 2004: 54).

How, then, did all the cognitive faculties like memory and executive function, including even individual databases like TOOL and SHELTER, evolve to become the constitutive modules of the overall cognitive architecture? If cognitive modules gradually arose throughout phylogenetic history in the Environment of Evolutionary Adaptedness, then it should be possible to reverse engineer the mind in terms of the relevant selective pressures and adaptations that locate the etiology of each cognitive module (Cosmides & Tooby 1997). EP generates hypotheses about the selective pressures that recurred in the Environment of Evolutionary Adaptedness and induced the emergence of each module. Sperber (2004) observes that MM in the maximal sense follows from EP only if each (or almost every) mechanism comprising perception and central cognition counts as a module. And it helps to reiterate the qualification that modules' *proper* conceptual domains correspond to bodies of knowledge, databases, and functionality that have special evolutionary significance (Sperber 2004: 54-56). Returning to the face-recognition device, EP hypothesizes that the recognition of conspecifics' faces carried with it the adaptive benefit of tracking rivals and mates, friend and foe, family and outsider, etc. A specialized module that we

call the face-recognition device gradually evolved to solve this adaptive problem, and was retained as a universal feature of human cognition due its fitness benefit.

To give an example of how even individual databases, construed as ‘micromodules’ on some MM accounts (Sperber 1994: 48), could manifest modular properties, Boyer (2015) specifies OWNERSHIP as the prototypical case of the EP paradigm in action:

The proposal here is that intuitions and motivations concerning who uses what resources constitute [...] a coordination tool for humans – and evolved from less efficient coordination strategies in the course of human evolution. In this perspective, the complex of intuitions generally called *ownership* are the outcome of largely tacit computations concerning the relative costs and benefits of using, guarding, or poaching resources, as well as collaborating with others in these diverse courses of action (190).

On Boyer’s understanding of adaptive advantage, the OWNERSHIP module arose to meet decision-making challenges regarding the coordination of resource allocation. Notice, though, that if OWNERSHIP is a module, it should be (1) domain-specific and (2) encapsulated, and (3) mandatory in operation. For x to recognize that y owns F , the occurrent perceptual features must (1) fall within the actual domain of x ’s OWNERSHIP module, (2) process only its own proprietary database while being impenetrable by other modules, and (3) carry out its mandated process automatically. Note that mandatory automatic processing need not entail inflexible responses though (Sperber 2002: 2). A cascade of modular activations may underlie the computations involved in decisions of ownership, where modules further downstream in central cognition determine whether to cooperate, reciprocate, or share a resource. Even if x recognizes that y owns F , modularists like Sperber (2002: 3) and Carruthers (2006: 6) account for the many permutations of behavior (e.g., cooperation, reciprocation, and sharing) that relate to ownership-

related circumstances by distinguishing between lower-level perceptual modules and higher-order central cognition modules. The lower order modules deliver representations in a typically mandatory fashion, still like cognitive reflexes. Meanwhile, the higher-order modules that govern central cognition correspond to different processors that integrate representations in higher-order thought processes like reasoning. The MM proposal is that this line of reasoning, *mutatis mutandis*, can be run for each module in the cognitive architecture until the final result is a mind maximally (or almost entirely) composed of specialized processors and databases. Mithen (1996) helpfully compares this architecture to a Swiss army knife, with each tool in the kit analogous to the modules of the cognitive mind.

To summarize, the unifying claim of MM is that human cognitive architecture is exhaustively composed of a plurality of modules, all working in concert to mediate perception and central cognition. I take Carruthers (2006a) and Sperber (2004) as representatively holding the strong thesis that both perception and central cognition, or at least almost every aspect of both,⁷ fall under the purview of modular processing. Indeed, everything from lower-level perception to higher-order conceptual reasoning and belief formation as being governed predominantly by an ensemble of modules (Tooby and Cosmides 1995: xiii; Samuels 1998: 576; Sperber 2004; Carruthers 2006). The diagram below illustrates the MM schema.

⁷ Some proponents of the MM thesis, including Carruthers (2013: 10371), as well as Cosmides & Tooby (2000: 1260), regard their thesis as compatible with there being some systems, such as working memory, that exhibit domain general features. That concession is still compatible with the overarching MM claim that the central cognition is predominantly outfitted with domain-specific modules and specialized problem-solving circuits (Cosmides & Tooby 2000: 1261). More precisely, the MM thesis denies that central cognition is constituted by a domain-general central system (Tooby & Cosmides 2000: 1171).

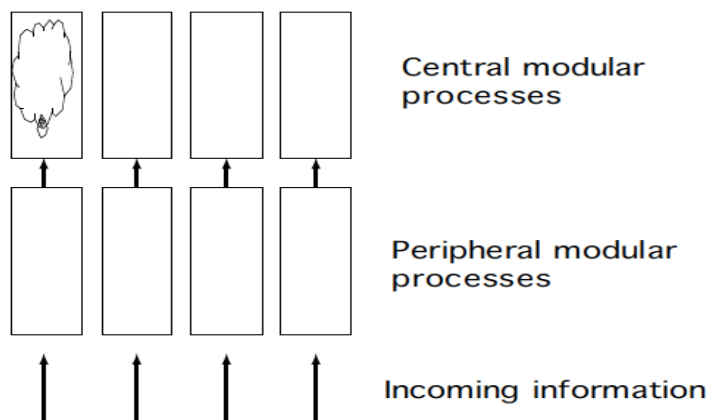


Fig. 1: Theoretical Schema of Massive Modularity

Diagramed above is a simplified model of the order of information processing within the MM cognitive architecture. What makes the above *massively* modular is ascribing modular systems to perception (the peripheral processes) as well as central cognition (cf. Sperber [2004], and Carruthers [2006]). Diagram taken from Nettle (2007: 261).

Fig. 1 summarizes the theoretical framework. First, peripheral modules process incoming perceptual information, as when processors take a retinal image from the eye and produce a visual representation as output. These representational outputs are then relayed to central modular processes, also called ‘higher-order modules.’ Higher-order modules convert the representational feed into concepts that enter into the more complex reasoning tasks of central cognition, namely inference and deduction, belief formation, or analogical reasoning – and each of these higher-order cognitive processes are modular systems as well (Carruthers 2013: 143).⁸ The key point to clarify is that MM architectures regard both perception and central cognition as governed primarily by modules.

EP and MM, therefore, go hand-in-hand. EP supplies a systematic way of identifying selection pressures in the Environment of Evolutionary Adaptedness. MM describes a cognitive architecture wherein each mechanism’s proper domain corresponds to adaptive solutions to each

⁸ MM theorists differ on what counts as higher-order modules. For instance, in Carruthers’s MM framework (2006) the *language content-integrator* is the higher-order module, and on Sperber’s account (1994, 2000) the *metarepresentation* module plays this role.

selection pressure. Conjoining EP with MM suggests how modules alone could facilitate every aspect of cognition.

2.1 SELECTION PRESSURES ARGUMENT AGAINST DOMAIN-GENERALITY

Accepting the precepts of EP seemingly entails that the human mind is exhaustively constituted by a collection of *specialized* modules, specialized in the sense of being domain-specific with respect to adaptive activation conditions and representation outputs (Cosmides and Tooby 1997: 81). A corollary of this claim is that each selection pressure found in the Environment of Evolutionary Adaptiveness calls for a *specialized* solution. What this precludes is the possibility that any domain-*general* mechanisms, such as a general-purpose learning system or problem solver, evolved to constitute a major part of the overall cognitive architecture. According to Cosmides and Tooby, “domain-specific cognitive mechanisms, with design features that exploit the stable structural features of evolutionarily recurring situations, can be expected to systematically outperform (and hence *preclude or replace*) more general mechanisms that fail to exploit these features” (1994: 90, my emphasis). In what follows, I describe what is meant by a domain-general cognitive mechanism, and then sketch Cosmides and Tooby’s argument – hereafter called the *selection pressures argument* – against there being such mechanisms comprising major aspects of human cognitive architecture, thereby reaffirming the inference from EP to MM.

First off, how do we define what is meant by domain-generality, setting aside for the moment its connection to modularity criteria? Buller (2006) describes this characteristic as any sort of reasoning mechanism that follows generally applicable rules and algorithms to form beliefs and inferences across various cognitive databases (151-2). Features diametrically opposed to that of a

cognitive module typify such a mechanism: it would be (a) *domain-general*, (b) *unencapsulated*, and (c) *flexible*.

Starting with (a), to describe the operations of domain-general processing, Buller (2006) draws on Popper's model of hypothesis testing and refutation, applied outside the context of evaluating scientific theories, as a helpful metaphor (153). Just as any observation from unbounded domains of knowledge may potentially be related to, or may either confirm or disconfirm, a given hypothesis, any given belief may likewise be related to any other belief in the cognitive database. Consider the flexible operations of central cognition that would result from this capacity. If I believe that the plants in my garden will grow more quickly if I plant them far from the shade cast by the tree in my backyard, I draw on my various databases, including my knowledge about botany (e.g. to identify the optimal growth conditions of the sort of plant I plan to grow), geography (e.g. to determine whether growing the plant outside the shade matches the hospitable climate conditions from wherever it's indigenous), and the intersection of physics and biology (e.g. to recognize that radiation from sunlight is a source of energy for inducing photosynthesis), to generate beliefs and propositional attitudes to which inference rules may subsequently be applied (Fodor 1983: 105). Some philosophers describe this relation holding among knowledge domains as being "inferentially promiscuous" in the sense that any one belief can be combined with any other belief in the database to form inferences in higher-order thought processes (Evans 1982; Brewer 1999; Hurley 2006). Because such processes draw on such a wide variety of databases to make inferential connections, it appears that general rules of reasoning govern central cognition.

To provide an example of one such domain-general rule of reasoning, I may reflect on my beliefs using the inferential structure of modus ponens – (1) $P \rightarrow Q$, (2) P , therefore (3) Q .

However, in order to form the necessary inferences about my beliefs, the mechanisms involved must be (b) unencapsulated in its access to my cognitive database. This gives access to an unbounded supply of inputs for modus ponens inference operations. The same goes for the other inference rules governing central cognition. By drawing on the various informational domains, and with unbounded potential inputs with respect to content, a domain-general processor can systematically and recursively generate beliefs, reasoning procedures, and plans of action (Fodor 1994). Just as I can reason that, *(1) if the sun shines, my plants will grow, (2) the sun is shining, Tf (3) my plants will grow*, I can also reason that, *(1) If the sun's light does not reach the plants, then there must be an obstruction blocking the sunlight (2) the sun's light is not reaching the plants, Tf (3) there must be an obstruction blocking the sunlight*. Rules of reasoning that govern central cognition need to have access to all cognitive databases to be effective.

By effective, what we mean is that the domain-general, unbounded mechanism should facilitate (c) flexible processing. If the mechanism operates in accordance to domain-general rules of inference, and if its access to cognitive databases is unbounded in scope, it would also enable the chaining of inferences, the combination of conceptual domains to form complex thoughts, and other characteristics of central cognition (Fodor 2000). Suppose that I discover that my plants are not growing. The next step would be to figure out whether there is an obstruction, or whether the plants are not getting enough water, or perhaps whether the soil is unsuitable for the plant species. The possible follow-up inferences are numerous indeed, unbounded in fact, and I may follow up on any one of these hypotheses in any order I wish, and either initiate or terminate a path of task-relevant inferences at will (see Fodor 2000: 60-2, for more on the characteristics of domain-general cognition).

One example of non-MM cognitive architecture with domain-general mechanisms governing central cognition is central systems theory (Fodor 1983). Although central systems theory posits modules that mediate perceptual processing (Fodor 1983: 40-1), it comports with the basic framework of non-MM architectures with respect to central cognition. To facilitate belief fixation, abstract and abductive reasoning, and other putative domain-general learning and cognitive tasks, this approach adduces a non-modular central processor to govern central cognition (for more on domain-general architectures, see Elman et al. 1996; Karmiloff-Smith 1992; Prinz 2006: 6-8; Quartz & Sejnowski 1997; Samuels 1998). See fig. 2 below for a simplified theoretical schema of non-modular cognitive architectures:

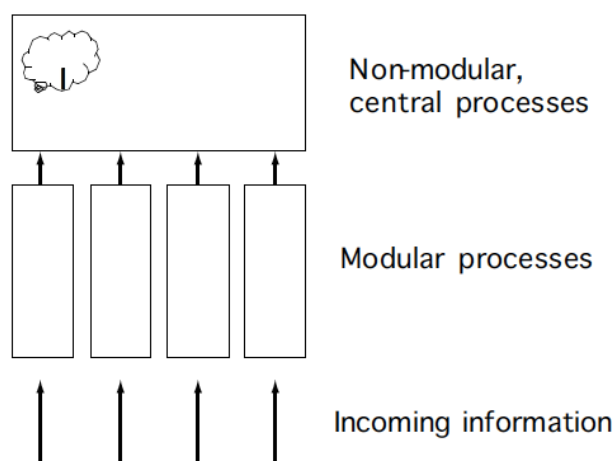


Fig. 2: Theoretical Schema of Domain General, Non-Massively Modular Cognition

Diagrammed above is a simplified schema of the order of information processing within the non-MM approach to cognitive architecture. Note that peripheral systems like perception may be governed by mechanisms that satisfy the conditions for modularity. So the alternative to massively modular architectures may concede that some mechanisms are modular, while reserving central cognition for non-modular mechanisms (cf. Fodor 1983, 2000). Diagram taken from Nettle (2007: 261).

Now, returning to the main thread of this paper, could some selection pressures, relevant perhaps to resource acquisition or threat avoidance, have induced the evolution of a domain-general mechanism in our cognitive architecture? Do the explanatory principles of EP favor

domain-general, non-MM architectures, such as a Fodorian central systems model (1983), or do they favor MM architectures?

We turn now to the *selection pressures argument* against the possibility that a domain-general mechanism governing central cognition could have evolved (Cosmides & Tooby 1997). They note that EP formulates hypotheses about highly specific selection pressures in the Environment of Evolutionary Adaptedness to explain the etiology of cognitive mechanisms. For a domain-general cognitive processor to emerge, there must have been a selection pressure our hunter-gatherer ancestors must have encountered via recurrent adaptive problems that would have selected for a domain-general solution. However, according to Cosmides and Tooby (1994), there are no *general* adaptive problems, only specific problems that call for *specialized* (i.e., domain-specific) solutions. As Symons put it, “There is no such thing as a ‘*general* problem solver’ because there is no such thing as a *general* problem” (1992: 142, my emphasis). For adaptive mechanisms to emerge in the cognitive mind the selection pressures must be stable environmental features, such that the investment costs associated with generating the new mechanism being offset by fitness-enhancing payoff makes the adaptation’s emergence and retention across phylogenetic history more likely (Tooby & Cosmides 1987: 53). Such stable selection pressures span across various domains, including the problems of resource acquisition, avoiding predation, and finding mates. For a domain-general mechanism to evolve, one must propose that the relevant selection pressure in question is something as general in scope as *survival*, something general enough to call for a *general-purpose* mechanism. But such an abstract category of selection pressure would be nowhere near fine-grained enough to constitute a recurrent environmental structure that would select for a particular adaptive structure (Tooby & Cosmides 1987: 53, footnote), nor is it tractable enough for incremental adaptive traits to

overcome it (Cosmides & Tooby 1994). Besides, Cosmides and Tooby show elsewhere (1992) how all (or nearly all) the facets of central cognition can be readily accounted for by specialized adaptations. The following are viable candidates:

A face recognition module, a spatial relations module, a rigid object mechanics module, a tool-use module, a fear module, a social-exchange module, an emotion-perception module, a kin-oriented motivational module, an effort allocation and recalibration module, a child-care module, a social inference module, a sexual-attraction module, a semantic inference module, a friendship module, a grammar acquisition module, a communication-pragmatics module, a theory-of-mind module, and so on. (113)

And that's just to name a few of the many hundreds of thousands of domain-specific modules that govern central cognition in our cognitive architecture (Cosmides & Tooby 1995: xiii). Sperber adds that even conceptual reasoning governed by logical rules of inference, including the putative exemplars of domain generality like modus ponens, should be considered modules (2004: 56, footnote). This makes a compelling case for the MM thesis, because modus ponens inference looks like a paradigmatically domain-general process. Would there be a separate modus ponens module for each cognitive database – one for resource acquisition, one for predator avoidance, another for mate selection – for how else could modus ponens inferences be regarded as domain specific? Here is the reply. Modus ponens inferences are still domain specific since the input conditions are narrowly constrained to pairs of premises that conform to the general structure $\{(1) P, (2) [if P then Q]\}$, and this procedure need not draw on the actual *content* of different databases. According to Sperber (2004),

[...] The difference between a wholly general and the number-specific modus ponens is one of inputs, and therefore of *domain-specificity*, not one of database, and therefore not

of encapsulation [...] In particular, they *ignore data* that might cause a rational agent to refrain from performing the modus ponens and to question one or other of the premises instead (Harman 1986). If there is a modus ponens inference procedure in the human mind, it is better viewed, I would argue, as a cognitive *reflex*. (56, footnote, my emphasis, to explicitly tie the passage to the three conditions of modularity)

Sperber has therefore clarified how a putatively domain-general process like modus ponens inferences could be (1) domain-specific, (2) encapsulated, and (3) mandatory in operation. *Mutatis mutandis* for the other inference systems that comprise central cognition. And if each module in central cognition corresponds to a selection pressure found in the Environment of Evolutionary Adaptedness, then MM is the most plausible cognitive architecture that conforms to the principles of EP. So goes the selection pressures argument.

3 ENDOGENOUS PRESSURES AND NEURAL NETWORKS

In this section, I will set the background for developing a rebuttal of Cosmides and Tooby's selection pressures argument. I will contend that the selection pressures argument crucially relies on an overly restrictive construal of the term *selection pressure*. To do so, I will introduce a distinction between *endogenous* and *exogenous* selection pressures, followed by an elaboration on the differences between each type. In short, selection pressures external to the organism count as exogenous, whereas selection pressures stemming from internal factors of the organism itself, including its physiology, count as endogenous.⁹ Next, I will argue that exogenous pressures tend

⁹ I hasten to acknowledge that this distinction is not completely novel. Godfrey-Smith (2010), in his review of *What Darwin Got Wrong*, points out how Fodor and Piattelli-Palmarini (2010) describe how the internal structure of the organism plays a role in determining which adaptations emerge – these may be construed as endogenous pressures. Be that as it may, the way I apply the terms exogenous and endogenous selective in the adaptationist explanation of cognitive architecture that follows is not widely represented in the philosophy of cognitive science literature, nor in

to give rise to domain-specific sub-systems. At the end of the section, I argue that endogenous selection pressures gave rise to neural network structures called a rich club/ hub core that maintains a balance between functional integration of domain-specific sub-systems and metabolic efficiency.

First, I will begin with the distinction between *exogenous* and *endogenous* selective pressures. *Exogenous* pressures refer to problems impinging from the external Environment of Evolutionary Adaptedness in which ancestral organisms of a species were embedded, the same context that EP theorists, such as Cosmides and Tooby, employ in their explanatory framework. Examples of such adaptive problems may be found in any environmental feature external to the organism, but also impinge on the organism's survival and reproductive viability. As was discussed in sections 2 and 2.1, exogenous selection pressures encompass the familiar problems posed by, *inter alia*, cooperative and rivalrous interaction with conspecifics, acquisition of resources, and avoiding predation. These selection pressures shaped many of the traits and features that eventually achieved fixation, meaning that these traits were retained throughout phylogenetic history, and are still expressed in the phenotypes of modern humans (Tooby & Cosmides 2005: 22). For example, the exogenous selection pressure posed by detecting moving objects may have selected for cognitive mechanisms (some of which being domain-specific) that aided in the detection of dangerous predators, or for facilitating the acquisition of potential sources of nourishment. Such a mechanism may very well correspond to some sort of domain-specific mechanism, aptly called an animacy-detection system (Caramazza, A., & Shelton, J. 1998).

mainstream evolutionary psychology. The distinction's novel status notwithstanding, I will attempt to argue for the explanatory benefits of distinguishing endogenous and exogenous pressures.

Conceive of the domain-specific mechanisms in cognitive architecture as relatively localized neural networks – call these “hubs” or “sub-systems” (van den Heuvel et al. 2012). Sub-systems are defined in terms of domain-specificity, and should be understood as specialized networks that respond to narrowly constrained inputs. It bears repeating that some sub-systems may satisfy the conditions for being modular: such sub-systems would instantiate cognitive functions that are (1) domain-specific in the sense of having narrowly constrained activation conditions and produce a restricted range of representations; (2) encapsulated by having access to only their own proprietary databases; and (3) operate mandatorily by responding automatically to received inputs. The network hubs corresponding to modules enable cost-efficient, in terms of being metabolically cheap, solutions to adaptive problems recurrent in the external environment.

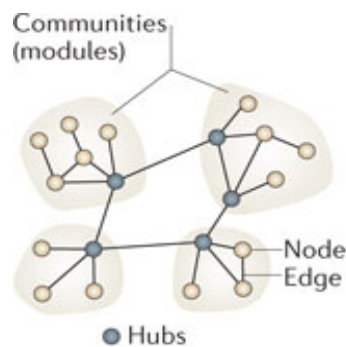


Fig. 3: Exogenous Pressures Select for Domain-Specific Sub-Systems

Sub-system, or hub, organization enables the formation of specialized neural communities. Density of connections is generally greater within a community than between communities. Computational studies suggest additional advantages of specialized organization: modular networks deal more effectively with the increased processing demands imposed by variable environments modularity confers a degree of resilience against dynamic perturbations and small variations in structural connectivity (taken from Box 3, “Communities, cores, and rich clubs,” from Bullmore and Sporns 2012: 342).

It is of little concern to my overall thesis whether some of these domain-specific networks turn out to be modules. My specific target is the MM cognitive architecture, which leaves room for there being some, perhaps even many, mechanisms that satisfy conditions for modularity. My target is the stronger MM thesis that modules constitute the entire cognitive

architecture, and especially central cognition. To successfully undermine MM, it will suffice to point out the aspects of cognitive architecture primarily concerned with central cognition are governed by non-modular mechanisms.

My approach to developing a non-MM cognitive architecture stems from *endogenous selection pressures*. Endogenous selection pressures refer to adaptive problems imposed by the organism's own intrinsic physiology. Some internal structural arrangement of various mechanisms and sub-systems within the organism may present a host of potential impediments to survival and reproduction (Sterelny & Griffiths 1999: 352). On the dimension of metabolic efficiency, it was proposed by Rosch (1978: 3) that a viable cognitive architecture is constrained by the general principle of cognitive economy, the challenge of maximizing information about the environment while conserving finite resources. For instance, internal systems that are unsuitably structured or maladaptively arranged can impede metabolic efficiency or disrupt the inter-dependent coordinated activity of cognitive sub-systems (Sporns 2011: 127-8). Moreover, sub-optimal structural arrangements and maladaptive integration of different mechanisms could impede fitness-enhancing functions from otherwise emerging, perhaps due to restrictions imposed by metabolic inefficiency, which leads to diminished survival and reproductive viability in the long run (Godfrey-Smith 2013: 53). Without integrative mechanisms in place, the computational demands imposed by specialized cognitive sub-systems during evolution of the brain would impose deleterious metabolic inefficiencies, translated into wiring costs in network terms (Sporns 2011; Chklovskii & Koulakov 2004; Kaiser & Hilgetag 2006), and the second problem of over-segregation of processing systems would impede functional performance in central cognition (Bullmore & Sporns 2012). De Reus and van den Heuvel (2014: 2) further clarify the second problem when they point out that, without the structural interconnectivity of

anatomically distinct processing systems, the global exchange of information essential to higher-order cognitive processes would be compromised.

The modern brain is a suitable model for illustrating how adaptations responsive to endogenous pressures emerged and persisted during its evolutionary development. The explanation for how network hubs get interconnected in certain predictable patterns and why some hubs became highly interconnected is not to be found in the Environment of Evolutionary Adaptiveness of hunter-gatherer ancestors. To find the appropriate explanatory context, one must look the properties of the internal organization of the evolving brain.¹⁰ To secure fully the distinction between endogenous and exogenous pressures, the evolving hominid brain in the Pleistocene acquired additional specialized sub-systems (viz. the exogenous selection process), with the addition of those sub-systems imposing stricter metabolic demands further selecting for the metabolically efficient variations of interconnected brain structure (viz. the endogenous selection process).

Incorporating the notion of endogenous pressures into models of cognitive architecture helps to illuminate findings from Bullmore and Sporns' (2012) account of cognitive economy in brain network topology. With the aim of identifying the selection pressures that shaped the precise organization of neural structures, their analysis uncovered the network structures that relay outputs between networks and efficiently process information to facilitate central cognition (2012: 338). Throughout the evolutionary history of the human connectome, referring to the total number of network connections in the brain, there were two competing mandates of minimizing metabolic and wiring cost while retaining efficient information flow constitutes an endogenous

¹⁰ Locating the etiology of cognitive mechanisms solely in features of the environment of evolutionary adaptiveness reflects an externalist perspective, whereas an explanation in terms of the intrinsic properties of cognition stems from an internalist orientation. See Godfrey-Smith (1996: 30-65) for a discussion of the distinction between externalist and internalist orientations to explaining properties of cognition.

selection pressure that favored mechanisms whose role is to strike a balance between the two demands (Sporns 2013; Sporns 2012: 347; Sporns 2011: 134-9).

The human brain is replete with sub-systems and sub-routines that carry out functions that accomplish specific ends (think of memory sub-systems, vision and audition processors, language faculties, etc.). If during the course of evolutionary development, the brain gradually accreted domain-specific sub-systems, a commensurate wiring cost would follow each new addition, simultaneously leading to the expansion of cortical volume along with increasing metabolic costs. Concurrent with wiring and metabolic costs, the accretion of different sub-systems concurrently brought along adaptive problems of functional coordination and integration (Bullmore & Sporns 2012: 336). Indeed, to function properly each sub-system, corresponding to additional network hubs, had to be integrated by dedicated structures whose proprietary functions would include, at a minimum, performance of the requisite computational tasks to efficiently relay outputs among the vast multitudes of sub-systems (Sporns & Bullmore 2010; 2012: 336). In other words, these endogenous pressures – metabolic cost and functional integration of additional network hubs – would have selected for mechanisms whose basic functional repertoire was geared toward coordinating and integrating activity among the sub-systems.

This line of reasoning satisfies the parameters set by the selection pressures argument from Cosmides and Tooby (1997). Recall that the objection stems from the observation that there must be stable, recurrent adaptive problems inherent in the environment for adaptive mechanisms to emerge. The endogenous pressures adduced above do constitute stable, recurrent adaptive problems in the environment; only in this case the relevant environmental context is the topological and integrative arrangement of specialized hubs in the connectome. De Reus and van

den Heuvel (2014: 1) define the connectome as “the complex network of all neural elements and neural connections of an organism that provides the anatomical foundations for emerging dynamic functions.” Another way to put it is either the Environment of Evolutionary Adaptiveness needs to take into account the intrinsic physiological organization of the organism, or if partisans of EP like Cosmides and Tooby insist on the strictly externalist construal, then the Environment of Evolutionary Adaptiveness remains an inadequate explanatory device for some structures in cognitive architecture.

The two stable, recurrent pressures in the internal organismal system are metabolic cost and functional integration of sub-systems. By reverse engineering the connective properties of brain networks, one may infer the emergence of structures whose functional role is to mitigate metabolic cost and facilitate functional efficiency (Sporns & Bullmore 2010; 2012: 343). In the space of possible permutations of network hub organization, there are differences in fitness-value along the two dimensions of functional capacity and metabolic efficiency (van den Heuvel et al. 2012; Sporns 2013). Studies of the particular topological arrangement of neural networks within the human brain have uncovered exemplars of fitness-enhancing permutations. Liang et al. (2017) recently conducted network analyses and discovered that some permutations of network connectivity minimize metabolic cost – measured in terms of cerebral blood flow – while maintaining functional efficiency in cognition.

The balance between these two pressures can be viewed as a sort of functional and metabolic homeostasis. Both endogenous pressures selected for network structures that could effectively maintain the homeostatic balance between functional integration and metabolic efficiency (Sporns 2013). The following are two such adaptive mechanisms in brain networks that facilitate the homeostatic role: the “rich club” and “hub core” (Bullmore and Sporns 2012: 342). The

topologically centrally located “rich club” is a place of intersection among hub sub-systems where the highest levels of interconnectivity among hubs have been measured (van de Heuvel et al. 2012). In particular, sub-system connections traversing the greatest distance within the connectome tend to link up with the rich club (Bullmore & Sporns 2012: 343).

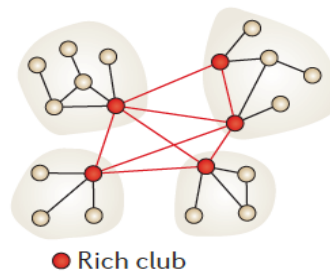


Fig. 4: Endogenous Pressures Select for Rich Club

Densely interconnected regions within sub-system hubs correspond to rich clubs that assist in efficient information flow. Distal connections in the rich club are metabolically expensive, suggesting an important functional and integrative role to offset the metabolic investment costs by the organism (from Box 3, “Communities, cores, and rich clubs,” from Bullmore and Sporns 2012: 342)

Nested within the rich club is a sub-component called the “hub core” which creates more centralized linkages across distant sub-system hubs (Sporns & Bullmore 2010; 2012: 342). The hub core’s function is to implement information flow across the topologically distal sub-systems.

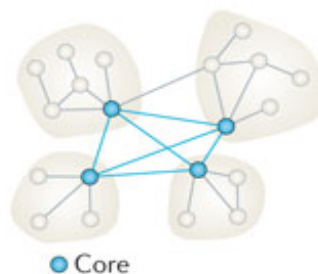


Fig. 5: Endogenous Pressures Select for Hub Core

Inter-modular connector hubs occupy a topologically more central or potential ‘bottleneck’ role between networks. An integrated core of densely inter-connected hubs has a central role in generating globally efficient information flow and integration (from Box 3, “Communities, cores, and rich clubs,” from Bullmore and Sporns 2012: 342).

With suitable adaptive solutions to endogenous selection pressures in hand, how do these rich club and hub core structures enable homeostatic functions, and how could their intrinsic functionality map onto cognitive architecture?

4 MODULAR SOLUTIONS TO ENDOGENOUS PRESSURES

Inferring features of cognitive architecture from neural network models raises the question of whether rich clubs and hub cores should be regarded as modular systems, comporting with the MM thesis. Even if partisans of MM grant that there are endogenous pressures, and that Bullmore and Sporns (2012) have accurately identified the functional role of the rich clubs and hub cores, the circumscribed functional properties of these network structures may nonetheless satisfy the three conditions for modularity. A modular solution to endogenous pressures (i.e., the homeostatic goal of mitigating metabolic cost while functionally integrating sub-systems within the brain [Sporns 2011: 142]) would be (1) domain-specific, (2) encapsulated, (3) operationally mandatory cognitive mechanisms, reinforcing the claim that MM architectures supply a satisfactory solution to endogenous pressures.

Proponents of MM might argue that the functionality of rich club/hub core need not extend beyond that of a control system/switchyard. A mechanism acting as a control system/switchyard would be an information-exchange channel that feeds information to different interconnected sub-systems without necessarily *processing* those inputs. The actual processing of representations in central cognition would take place in the different sub-systems, rather than in the rich club per se. If the rich club/hub core is really just a switchyard, then proponents of MM could claim that these topologically central structures satisfy the three conditions of modularity.

In that case, the rich club and hub core could be regarded as a specialized module that subserves mundane metabolic and information trafficking tasks.¹¹

The (1) proper domain would correspond to the retrieving and delivering of outputs between the hub sub-systems via the rich club/hub core. By parity of reasoning with respect to exogenous selection pressures, homeostatic regulation would count as a recurrent endogenous selection pressure calling for a specialized modular solution. A modular system would take the outputs from multitudes of specialized hubs competing with one another for metabolic resources, and would allocate resources to relevant sub-systems by monitoring the cognitive task at hand (Sperber 2004: 61-2). To illustrate this procedure, suppose sub-system A is capable of delivering outputs that satisfy the activation conditions of sub-system B (i.e., the representational outputs delivered from A fall within the proper domain and database of B). The rich club/hub core Z is the switchyard from A to B. We should regard the proper domain of Z to be the retrieval of outputs from A in order to send those outputs to B. This scenario illustrates how the rich club/hub core would satisfy modularity condition (1).

If rich clubs and hub cores are (2) encapsulated, they would still fulfill their homeostatic role by having a strictly circumscribed database to which it has access, and the other cognitive systems would lack access to the rich club/hub core database. Returning to the above scenario, rich club/hub core Z would be encapsulated in the sense of having access only to the databases of hubs A and B, but not to the other sub-systems, and other sub-systems would not have access to rich club/hub core Z's database. And this seems plausible if Z really is just a switchyard that relays outputs between A and B. It would not need to have access to a wider range of cognitive

¹¹ Carruthers (2006), for instance, proposes that the *language content-integrator*, and on Sperber's account (1994, 2000) the *metarepresentational* module, correspond to higher-order modules that traffic information across subordinate module databases.

databases to function accordingly. This scenario demonstrates how the rich club/hub core satisfies modularity condition (2).

The rich clubs and hub cores would also need to be (3) mandatory in operation to count as a modular system. Returning to Sperber's description, "a procedure is mandatory if, given the appropriate input, it will follow its course and produce its output whatever the rest of the cognitive mind is doing" (2004: 6). Returning to the scenario once again, the "cognitive reflex" description (Sperber 2002; 2004) would accurately describe the procedures followed by rich club/hub core Z after it receives information from sub-system A. It does not need to perform complex operations on the representations it receives from A in order to act as a switchyard. To carry out its operations efficiently, Z operates automatically upon receiving outputs from A and promptly sends the information to sub-system B. The processing of those outputs take place in modular systems further downstream in central cognition. Thus, the rich club/hub core satisfies modularity condition (3).

As illustrated in the above scenario, if the rich club/hub core is no more than a switchyard, then its functional properties would satisfy the three modularity conditions. *A fortiori*, there is no need to posit a domain-general mechanism (pace non-MM architectures) to overcome endogenous selection pressures. Domain-general mechanisms would be rendered superfluous if there is a viable modular solution to endogenous selection pressures. Therefore, EP should favor the MM thesis even with respect to endogenous pressures.

5 ENDOGENOUS PRESSURES SELECT FOR DOMAIN-GENERALITY

In response to the defense of MM from section 4, I will argue that the functional properties of rich clubs and hub cores go beyond that of a switchyard, and cannot satisfy the three modularity

conditions. In addition to the homeostatic function introduced in section 3, I will argue that the rich club/ hub core also integrates representations in order to facilitate central cognition. On this account, then, the central cognition functions of rich clubs and hub cores are conceptualized as an exaptation, an adaptive mechanism that was coopted to serve additional functions beyond its original homeostatic function. I will show how a topologically central placement ideally positions the rich club/hub core to serve as the underpinning of belief fixation, analogical reasoning, and other features of higher-order thought in central cognition. The upshot is: in virtue of its structural interconnectivity to different sub-systems, the rich club/hub core is best suited to facilitating the computational tasks involved in central cognition.

There is ample evidence of adaptive functional characteristics facilitated by these network structures that modules are unlikely to manifest. This would especially be the case if the two functions of *homeostatic regulation* and *processor in central cognition* are complementary and instantiated by the same mechanism. Furthermore, if the rich club/hub core facilitates a manifold of central cognitive processes, the mechanism looks less like a module than a central system that is (a) domain-general, (b) unencapsulated, (c) operationally flexible. To argue for this conclusion will require examination of different strands of evidence from brain imaging studies focusing on the functional properties of the rich club/hub core in central cognition.

With the homeostatic adaptive role of the rich club/hub core already in hand, we will explore how rich clubs and hub cores facilitate central cognition. To argue for these structures being a processor in central cognition, rather than a mere switchyard, the topologically centralized location of rich clubs and hub cores is suggestive of a viable background trait for central cognition. Higher-order cognitive functions, like belief fixation and abstract reasoning, were late emerging compared to perception and attention (Fodor 1983: 43). And, according to Anderson

and Penner-Wilger, “the later something emerges, the more potentially useful existing circuitry there will be” (2013: 44). The processes of central cognition were among the latest to evolve, and the existing circuitry of the rich club/hub core could have gradually added on central cognitive capacities. The most plausible analogues in neural network models to central cognition systems would be those mechanisms that are optimally positioned to retrieve outputs from interconnected, specialized sub-systems. If it could be established that complex processing of information takes place *within* the rich club/hub core, then it would be highly suggestive of an integral role in central cognition. Fodor anticipated such a proposal in his seminal work, *The Modularity of Mind*:

Input analyzers [and modules], with their [...] relatively rigid domain specificity and automaticity of functioning, are the aboriginal prototypes of inference-making psychological systems. Cognitive evolution would thus have been in the direction of gradually freeing certain sorts of problem-solving systems from the *constraints* under which input analyzers [modules] labor – hence of producing, as a relatively late achievement, the comparatively domain-free inferential capacities which apparently mediate the higher flights of cognition. (1983: 43, my emphasis)

One presumes Fodor would disavow a Darwinian, or adaptationist, reading of the passage above (see Fodor. & Piattelli-Palmarini [2010]), but it nonetheless anticipates the idea that exaptational properties of central cognition could have been built by opening up pathways of interconnectivity among specialized sub-systems that were originally anatomically (and functionally) segregated. Recall from section 3 that the original homeostatic role of the rich club/hub core was made feasible by anatomically interlinking disparate sub-systems. We can read Fodor’s reference to unlocked “constraints” under which domain-specific sub-system labor

as just the sort of exaptational re-purposing of the rich club/hub core requisite for central cognition. Following a similar line of thought, Mithen (1996) described the evolutionary event leading to central cognition as a semi-breakdown in strict segregation between specialized cognitive sub-systems. Whereas mere structural integration would be sufficient for maintaining metabolic efficiency (by shortening communication distances between nodes, with each node corresponding to cortical sub-systems [van den Heuvel et al. 2012: 11372]), but global, *functional* integration of different sub-systems is prerequisite for central cognition (Cocchi et al. 2014). The capacity for functional integration amounts to the capacity for combining contents from different databases into more complex representations, an important precondition for compositional thought (Fodor 1994; Fodor & Lepore 1996). The additional (i.e., exaptational) functional integration would have followed later in evolutionary history at the locus of structural interconnectivity among sub-systems. Indeed, for central cognition to get off the ground, “there must be relatively nondenominational (i.e., domain-*inspecific*) psychological systems which operate, inter alia, to exploit the information that input systems provide” (Fodor 1983: 103). Following Fodor’s reasoning, the rich club/hub core broke down the functional constraints under which specialized sub-systems operated, creating the potential for pulling contents from the different sub-systems to execute computations that form beliefs, make inferences, and perform other central cognitive tasks.

The contentious claim most in need of defense is that homeostatic regulation and central cognition are complementary traits instantiated by the same mechanism. Here is the defense. The genetic variants that exhibited the rich club/hub core enjoyed the fitness advantage imparted by metabolic efficiency. However, the adaptive value of the trait would have compounded considerably if it imparted functional properties as well. Recall that the functional properties of

central cognition include the composition of complex thoughts involved in analogical reasoning and belief fixation. To draw a variety of inferences and create analogical relations, these central cognition tasks must draw on multitudes of informational realms and databases contained in the sub-systems (Weiskopf 2014:17). The rich club/hub core would be the mechanism that is suitably interconnected to draw on these different databases. Due to being densely interconnected to other sub-systems (Baggio et al. 2015), the rich club/hub core would be best positioned to pull from different databases and facilitate central cognition.

If the foregoing inference from structural integration to centrality to functional integration holds, then the functional properties of the rich club/hub core would be twofold: (A) homeostatic regulation of metabolic resources (Sporns & Bullmore 2010; 2012: 337), but (B) facilitating central cognition. The latter role would include, *inter alia*, drawing on different database and applying computational rules that integrate concepts, compose beliefs, form inferences, and carry out complex sequences of goal-directed action. Fig. 6 below illustrates the compounding fitness benefits offered by a complementary relation between properties (A) and (B):

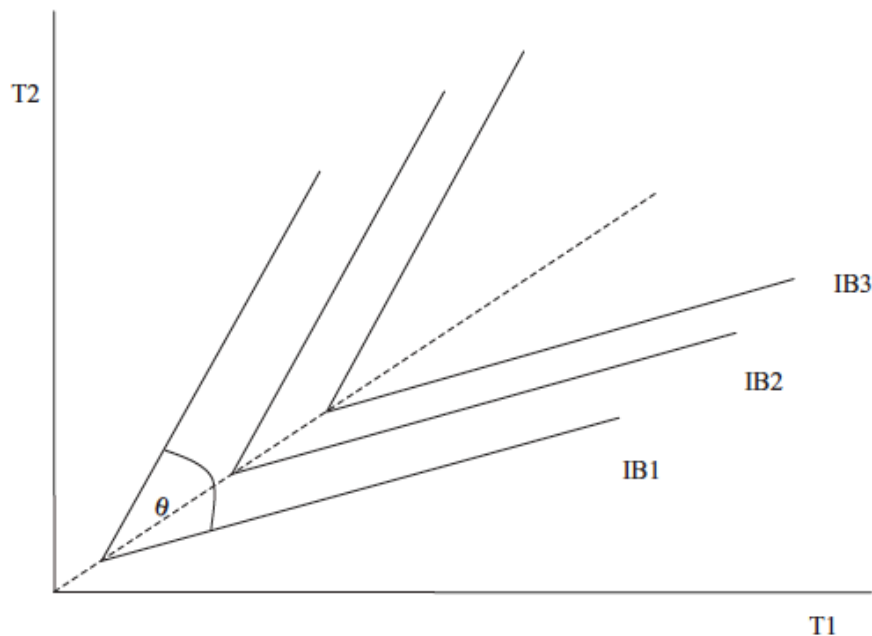


Fig. 6: Adaptive Value of Complimentary Homeostatic and Central Cognition Roles

Assign the two properties of functional integration/metabolic homeostasis and central cognition to T1 and T2 respectively. The three ratios represented as IB1, IB2, and IB3 represent phenotypic permutations wherein T1 and T2 vary independently, translated into fitness benefits tied to the presence of one at the cost of fitness detriments by the comparative absence of the other trait. Complimentary homeostasis such that changes in T1 induce changes in T2 (and vice versa) endows the greatest adaptive value, represented in the dashed linear slope (taken from Schulz [2008: 737]).

As illustrated in Fig. 6 above, some adaptive traits compound their fitness value if they occur together interdependently (Schulz 2008: 737), rather than being "bolted on" separately as distinct traits to different mechanisms (to use Carruthers' wording [2008:300]). Take for instance the widely observed phenomenon of neural reuse: the cortical region of pre-existing neural circuitry becomes re-purposed in order to facilitate a wider variety of functions (Anderson & Penner-Wilger 2013). Here is a useful analogy from biology: feathers originally evolved for thermal regulation, which were reassigned to flight capacities or to signaling among conspecifics (Persons & Currie 2015). Feathers confer compounded adaptive benefit by overlaying a

multitude of distinct functions. It is not uncommon to observe mechanisms take on functions that diverge from older, etiological functions (Sterelny & Griffiths 1999: 320). Likewise, mechanisms in the mind could have followed an analogous pattern of "jury-rigging" additional functions of central cognition on pre-existing structures to impart additional adaptive benefits. Revisiting the concept of exaptation, some functions occur via reconfiguration of existing brain circuitry or assignment to pre-existing structures of additional functions. The appearance of additional functions need not co-occur with the addition of new, specialized sub-systems (Anderson & Penner-Wilger 2012). Functions (A) and (B) – respectively, homeostatic regulation and central cognition processing – would impart additional fitness benefits if they are complimentary traits (i.e., if they are instantiated by the same mechanism). In fact, if traits (A) and (B) were bolted onto different mechanisms, these traits may have actually imposed more fitness costs than benefits. Consider the metabolic costs carried by (B). If (B) appeared before (A), then the metabolic costs imposed by such brain organization would result in net-negative fitness. If too metabolically costly, there would have been selection against the emergence of (B). By parity of reasoning, a mechanism that instantiates (A) by breaking down constraints of processing and desegregates specialized sub-systems without active participation in the processing of those representational outputs would confer far less adaptive value than an alternative mechanism that could integrate information.

But why think (A) and (B) are complementary traits inhering in a single mechanism rather than their corresponding to separate modular systems? Defenders of MM would not be convinced. The MM architecture would regard (A) and (B) as distinct rather than complementary traits. However, the MM model would need to posit not only a module for (A), but also an *additional* module for (B). And it doesn't stop there, for MM regards central cognition as

composed of multitudes of separate modules. Recall that the MM thesis posits a multiplicity of modules specialized for each informational domain in the cognitive database: separate modules for mate selection, cheater detection, face recognition, and so on, with each new module evolving independently of one another. So exogenous pressures selected for each central cognition module. But then each central cognition module had to be structurally and functionally integrated with the prior modules, given the wiring and metabolic costs imposed by its addition to the connectome. So there would have been a separate endogenous selection process in favor of the integration of each additional module into the existing architecture. But how does each cognitive module emerge without imposing too great a metabolic cost, and how does the homeostatic regulator module emerge before the additional cognitive modules appear? The presence of cognitive modules imposed the very endogenous pressure that selected for the homeostatic regulator in the first place. A more pressing question is which selection process – between the endogenous and exogenous – drives the other, and how would the MM framework begin to resolve these question?

I propose a defense of the more parsimonious explanation on offer from the non-MM thesis. A central system would facilitate both (A) and (B). The functional properties of central cognition scaled up incrementally as the structural interconnectivity of sub-systems via the rich club/ hub core increased over of the course of evolutionary development of the brain. The structural interconnectivity of specialized sub-systems was a precondition for the commensurate scaling up central cognition capacities.¹² Cortical volume, and computational capacity, would have also increased allometrically as the density and volume of neural network inter-connectivity increased throughout the phylogenetic history of the human brain (Herculano-Houzel 2016). The product

¹² What needs to be determined is whether this commensurate scaling up of integration and cognitive complexity is a linear or non-linear relationship. While I do not address such concerns here, these details could be uncovered through further investigation and development of this non-MM cognitive architecture.

turned out to be a hierarchically structured cognitive architecture that strikes a balance between (A) homeostatic regulation of metabolic resources and (B) computational power in central cognition (Barrett 2012). Both of these properties, (A) and (B), inhere in the rich club/hub core. The evolutionarily prior property of structural integration comes from interlinking disparate sub-systems, shortening communication pathway length and securing (A) metabolic homeostasis. But through the reuse of neural mechanisms (Anderson & Penner-Wilger 2013), the structures facilitating the foregoing functions could take on additional, exaptational functions relevant to (B) central cognition. Note that I am not arguing that a non-MM cognitive architecture evolved *because* it is the most efficient and the most parsimonious. Many evolved mechanisms are not the most effective conceivable solutions to selection pressures (cf. Barrett 2015: 78). Rather, the argument is that complementary relation between (A) homeostatic regulator and (B) central cognition processor constitutes a parsimonious solution to endogenous pressures that also comports with recent evidence from the cognitive sciences, particularly from brain mapping and imaging methodologies. These strands of evidence converge on the non-MM thesis, or so I will argue.

There is a growing body of evidence suggesting that rich clubs and hub cores actively participate in the actual *processing* and *integration* of information from different hub sub-systems (see Zamora-López et al. 2009; Bullmore and Sporns 2012; van den Heuvel et al. 2012). These strands of evidence support the conclusion that the rich club facilitates function (B) – that of central cognition – in accordance with a central system that is (a) domain general, (b) unencapsulated, and (c) operationally flexible (viz. the central cognition features of non-MM architectures).

First, we must establish that the rich club/hub core is (a) domain-general. A study by Anderson & Pessoa (2011) revealed the task diversity of interconnected cortical regions across a broad range of cognitive tasks relating to language semantics, reasoning, semantic memory, and working memory. While measuring the functional diversity of 78 different cortical regions from 0 to 1 (i.e., the closer to 1, the more diverse the functional role of that cortical region), Anderson & Pessoa (2011) determined that the average diversity of these regions was .70 in 1,138 experimental tasks across 11 different cognitive BrainMap task domains, including explicit (semantic) memory, reasoning, language semantics and working memory (see Fox et al. [2005] for more on BrainMap task domains). Another study by Kitzbichler et al. (2011) uncovered a negative correlation between clustered, modular processing and cognitive effort – especially in working memory tasks associated with central cognition – and positive correlation with “more globally efficient” configuration of processing. This analysis reveals functionally integrated, rather than a segregated, processing of cortical regions in central cognition tasks.

These functionally integrated cortical regions correspond to the rich club/hub core, as evidenced by a study done by Shine et al. (2016: 6) which found that this mechanism integrates representational outputs from different sub-systems across central cognition tasks, including abstract reasoning and belief formation. One may refer to this characteristic as a *high participation index*, meaning that the rich club/hub core participates across a wide range of cognitive tasks associated with global processing of information in central cognition (Bullmore & Sporns 2012: 342). The rich club/hub core structure is no mere switchyard, as an information trafficking hub would not apply computational rules that *integrate* the representational outputs delivered from various informational domains.¹³ Uttal (2001) points to neuroimaging findings

¹³ Another way to formulate the adaptive value of functional intergration in central cognition concerns the generality constraint, a principle originally formulated by Evans (1982). Take analogical reasoning for instance. The

that demonstrate vast integrated neural networks facilitate complex reasoning tasks, rather than heterogeneous, specialized sub-systems. Further analysis of dynamic network changes during cognitive control and complex reasoning tasks reveals that no one sub-system alone possesses the computational capacity to produce complex representational outputs of central cognition, except via its integration with other specialized sub-systems (Cocchi et al. 2013: 9).

Taking the foregoing studies of the communication dynamics of functional integration into account, we evidence of domain-general cognition being facilitated by functional interconnectivity between sub-systems, rather than taking place in any one specialized sub-

idea that analogical reasoning must be a component of domain-general cognition is partially based on the claim that the units of analogical thought, concepts, must conform to isotropy (Fodor 1983, 2000). The idea of isotropy is that any one of our propositional attitudes can be used to evaluate any other propositional attitude (Carruthers 2013a: 144). Isotropy implies a certain sort of holism about conceptual belief systems, in the sense that propositions imbedded in any one belief could in fact be related to any other proposition. An example: my ASTRONOMY thoughts could be related to my BOTANY thoughts when I form a deductive inference like the following: “were the sun to suddenly become a red giant, the flowers in my garden would wither.” The upshot is that any given thought could potentially be related to any other thought. The generality constraint follows from isotropy. If I possess concepts F and a needed to entertain the thought Fa, and if I possess G and b required to entertain Gb, then I should be able to formulate the thoughts Fb and Ga.

Suppose that central cognition really does exhibit isotropy and conforms to the generality constraint. To satisfy the generality constraint, the massive modularity framework faces the following dilemma: either (a) higher-order modules do not satisfy the generality constraint, or (b) higher-order modules do satisfy the generality constraint. Taking the first horn of the dilemma, if (a) higher-order modules do not satisfy the generality constraint, modules alone cannot impart the cognitive flexibility required to compose novel conceptual structures. Massive modularity would therefore fail to account for all features of central cognition (Weiskopf 2010: 19). To the second horn, if (b) higher-order modules satisfy the generality constraint, then it follows that the proper domains of these higher-order modules encompass the domains of all subordinate modules, so these modules would in fact be domain-general. Furthermore, the higher-order modules would have access to the databases of all sub-ordinate modules, so the higher-order modules would be unencapsulated. Therefore, on (b) massive modularity collapses into central systems theory, thereby relegating the distinction between ‘higher-order module’ and ‘central system’ to a trivial linguistic dispute (Weiskopf 2010: 15). If modular mechanisms do not adequately account for key features of central cognition, then the analogy between modules and the neural network rich clubs and hub cores fail to obtain.

The sort of analogical reasoning on central systems theory that conforms to the generality constraint is predicated on mechanisms that are domain-general and unencapsulated. In order to combine content across conceptual domains, there must be a system that can receive multiple inputs and perform multiple functions simultaneously (hence, it must be domain-general), and be capable of ‘looking’ into different databases to compose unbounded, novel conceptual structures (hence, it must be unencapsulated). Therefore, since only the central system could satisfy the generality constraint. The benefits that follow from analogical reasoning would include tool construction (Mithen 1996) and category learning (Holyoak 2012), so it is not difficult to imagine the adaptive value enjoyed by a cognitive architecture that facilitates domain-general analogical reasoning capable of satisfying the generality constraint.

system (Cocchi et al. 2013: 9; Cole et al. 2013; Bola & Sabel 2015). These bodies of evidence therefore speak against the claim that processing of representations takes place within the “isolable, function-specific processing systems,” in reference to Carruthers’ sense of domain specificity (2006: 7). Perhaps these findings should not be surprising, given the processing constraints implied by the three conditions of modular conditions (i.e., (1) domain-specificity, (2) informational encapsulation, and (3) mandatory processing).

To illustrate the functional advantages of the rich club/hub core cast as domain-general processor, return to the scenario involving rich club/hub core *Z* and output hubs *A* and *B*. Suppose hub *A* delivers outputs that are the proprietary inputs of hub *B*. If *Z* functionally integrates contents, then *Z* could apply computational procedures on the outputs of both *A* and *B* to generate complex, compositional thought characteristic of central cognition. If *Z* applies recursive rules of inference – like modus ponens – to its representational inputs across different content domains, then the rich club/ hub core would serve as an effective domain-general processor in central cognition. Switchyards do not possess the discriminative capacity to tease out combinatorial properties of the different representational outputs, for the property to process representations from multitudes of sub-system databases implies the capacity to *read* those representational inputs. Thus, if the rich club/hub core functionally integrates the representational inputs of interconnected sub-systems, this mechanism would be (a) domain general.

In order for the rich club/ hub core to act as a domain general processor, it would also need to be (b) *unencapsulated* with respect to informational databases contained in sub-systems in order to facilitate central cognition. Assuming that the rich club/ hub cores unrestrictedly accesses the entire cognitive database, then this structure would be better able to apply domain-general rules

irrespective of the content domain. After measuring communication paths of sub-systems in the connectome, van den Heuvel et al. (2012: 11374) determined that 69% of communication paths pass through the rich club/hub core, indicating wide access to informational domains. A landmark study from Scannell et al. (1995) revealed that the rich club/hub core structure connects in cortical regions across a vast array of functional domains, including hub sub-systems undergirding fronto-limbic, visual, auditory, and somatosensory and motor regions. Evidence of the rich club/hub core access to different cognitive domains also comes from cross-species comparisons. Analogous structural and functional characteristics of rich club/ hub cores have been identified in comparisons between the cat cortex (Zamora-López et al. 2009, 2011), macaque cortex (Harriger et al. 2012), and the human cortex (van den Heuvel & Sporns 2011). What suggests that the rich club/ hub core is unencapsulated is the wide range of sub-systems from which information may be retrieved. Across all three species, these sub-systems include “occipital and parietal visual and sensory regions, temporal auditory regions, frontal (pre)motor regions, as well as insular, medioparietal, and mediofrontal regions overlapping the limbic system” (de Reus & van den Heuvel 2013). Tying these findings into the rich club/ hub core’s role in central cognition, counted among the requisite preconditions for higher-order cognitive processes in central cognition is unrestricted access to databases in order to furnish the mind with complex thoughts in reasoning and inference.

Finally, the rich club/hub core is also a (c) flexible processor. The cortical regions specified above have been described as a collection of “multi-demand systems” (Fedorenko 2014: 4). The multi-demand system has been shown to play a processing role in “attention (Posner & Petersen 1990; Desimone & Duncan 1995; Peterson & Posner 2012), working memory (Goldman-Rakic 1995), cognitive control (Miller & Cohen 2001; Koechlin et al. 2003; Badre and D’Esposito

2009), structure building/unification (Hagoort 2005), timing and/or sequencing (Luria 1966; Janata and Grafton 2003; Fuster 2008), attentional episodes in goal-directed behavior (Duncan 2010), and conscious awareness (Dehaene and Changeux 2011)” (cf. Fedorenko 2014: 4).¹⁴ Yue et al. (2017) and Cohen and D’Esposito (2016) found that modular processing and flexibility in higher-order cognitive performance are negatively coordinated, with inter-modular activity (i.e., rich club/ hub core) increasing scaling up commensurately with the complexity imposed by the cognitive task. Grayson et al (2014) determined that the rich club/hub core undergirds the fronto-parietal network, which plays a role in deployment of attentional resources. One component of the fronto-parietal network, called the anterior insular cortex, imparts flexible processing by selecting relevant information across different modalities for entry into central cognition (Michel 2017). These findings suggest that the rich club/hub core structure mediates task switching in central cognition, befitting an (c) operationally flexible, rather than mandatory, processor. With all three features of non-MM cognitive architecture in hand, we may conclude that the rich club/hub core corresponds to a (a) domain general, (b) unencapsulated, (c) operationally flexible processor in central cognition.

In summary, the proposed intrinsic functionality of the rich club/hub core (i.e., the adaptive responses to endogenous pressures) engenders two complementary functions: (A) homeostatic regulation, and, (B) central cognition processor comporting with the three features of non-MM architectures: (a) domain-general, (b) unencapsulated, (c) flexible processor.

Note that the structure of my response to the selection pressures objection is an inference of functional properties from structural properties. It is important to flag a lingering worry

¹⁴ Connecting the present analysis of central cognition with theories of consciousness, it might be worth exploring further whether the cortical regions undergirded by rich club/ hub cores also instantiate a global neuronal workspace (see Baars 1988; 1997; 2002). Such a connection is beyond the purview of the present discussion, but further investigation may nonetheless prove worthwhile.

concerning this sort of inference. The evidence adduced by cognitive neuroscience and brain network theory lends support for my thesis, but perhaps fall short of being decisive. Admittedly, any attempt to integrate a theory of cognitive mechanisms with neural models is a task that is highly speculative in nature and presents a host of explanatory limitations (Weiskopf 2016). However, the evidential support is sufficient to cast doubt on the selection pressures objection, which argued against the plausibility of domain-general computational systems evolving to govern central cognition. I demonstrated why there is no need to posit a *general* exogenous selection pressure to account for the evolution of a domain-general, non-modular processor. However, I do not mean to imply that modules have no explanatory merit. Proponents of MM may be on the right track in positing some domain-specific modules in cognitive architecture, especially perceptual input systems. But given the inadequacy of modules in accounting for the functional capacities of the rich club/hub core, we may conclude (based on the available evidence) that endogenous pressure selected for a non-modular system. Thus, proponents of EP should regard the non-MM architecture as not only compatible with their paradigm, but as the cognitive architecture that best explains which brain variants of structural organization that endogenous pressures selected for.

6 CONCLUSION

What I have argued is that the term *selection pressure* is open to various interpretations. A given interpretation determines the sort of cognitive architecture that conforms most closely to the principles of evolutionary psychology (Woodward & Cowie 2004: 3). I introduced a distinction between selection pressures that are either endogenous or exogenous. Granting this distinction forms the basis for predicting that a domain-general, non-massively modular

architecture emerged during the evolution of cognitive architecture, rather than a massively modular one. Evolutionary models lacking the distinction between endogenous and exogenous pressures cannot account for the factors that selected for different neural network structures like the rich club/hub core. Evolutionary theorists of the cognitive mind should extend their explanatory scope, and not just look at external environmental structures to formulate hypotheses about the cognitive mind. Recognizing that the Environment of Evolutionary Adaptedness corresponds to brain organization itself, to factors inside the skull, leads to a plausible hypothesis about the evolutionary origins of central cognition.

This paper is not a defense of the explanatory merit of evolutionary psychology *per se*. Indeed, philosophers should be wary of relying too heavily on evolutionary psychology in promoting any particular architectural framework. One flaw that bedevils EP lies at the heart of its methodology. Reverse engineering systems in the cognitive mind reveal what that system does, but not necessarily why that system was selected for serving that function; hence, the importance of seeking out independent strands of evidence that converge on any given adaptationist explanation. Objections to EP *per se* aside, my objective is more modest in scope, in that the foregoing is meant to show how reframing the notion of a selection pressure in EP uncovers the fitness benefits conferred by a non-MM cognitive architecture. I maintain that the arguments in this paper should compel those partial to MM architectures to explore lines of argumentative support aside from the selection pressures objection. Further empirical investigation in the cognitive sciences and brain network theory may yet vindicate the MM thesis, but the current evidence from these research domains point in favor of the non-MM cognitive architecture. As things stand, we have in hand a plausible evolutionary story of how domain-general central cognition emerged through the process of natural selection.

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