

To appear in A. Brenner & J. Gayon (eds.)
The French Philosophy of Science
Springer

What is a mental function?

Joëlle Proust
CNRS
(Institut Jean-Nicod, ENS, EHESS)

It is a remarkable and puzzling fact that, for over a century, psychological and biological research have been exploring the development and functional characterization of brain/mind activity in almost totally separate and non-interactive ways. It cannot be denied, however, that the human brain is the result of evolution in the brains of other mammals. The subcortical structures of mammals present anatomical, neurochemical and functional homologies, and these suggest largely similar mechanisms for emotion, perception and action. One of the reasons for the lack of concern by experimental psychologists with biological issues may derive from a premature, and thus largely sterile, nature-nurture controversy. While it was difficult in the recent past to understand how genes might interact with the environment in expressing themselves, the notion of epigenetic development is now better understood in its precise mechanisms, although much remains to be discovered.¹ The nature-nurture controversy, however, has overshadowed other important points. Even if it is recognized that human behavior largely results from individual and socio-historical interaction with the environment, such interactions can hardly be understood if the general constraints that the species confronts, given its bodily structure, general needs, and physical-social environment, fail to be grasped.

In order to approach the notion of a psychological (or mental) function in a principled manner, we need to understand, in general terms, what a mental function is, and how it relates to brain evolution. To achieve this, we will first need to summarize how teleological discourse has been « naturalized », i.e. how functional explanation has been defined in purely causal terms (section 1). We will also need to characterize how mental functions differ from other organic functions, and consider the causal constraints that are exerted over evolutionary time on this type of function (sections 2-4). In order to discuss this issue, however, we will first have to examine the respective roles of genes and development in regulating adult cognition, and determine the correct methodology to use in addressing the

¹ See Oyama (2000), Jaenisch & Bird, (2003).

question of mental function. Various definitions of mental function correspond to different methodological viewpoints, that we will discuss successively: Evolutionary Psychology² and its modular approach to function, Evo-devo and the idea of a developmental view of function, and neurocognitive theories, with their notion that neural growth determines function. The goal of this paper is to define the concept of a “mental function” that meets the general constraints that apply to the concept of a biological function. Its ultimate aims are to understand how psychology as a theoretical field is articulated with biology, and identify which methodological requirements are entailed by this articulation.

1 – The concept of function

We say that a structure of type X in species S has function F , when the following three conditions are fulfilled:

- (1) Structures of type X in species S typically produce F in inclusive context C .
- (2) Structures of Type X are inheritable or reproducible.
- (3) Structures of type X exist because they have adaptive value (because those organisms that have produced F thanks to X in the corresponding inclusive context have been/are more likely to reproduce than those that have not).

There are three different causal relations involved in our definition of “function”. The first is the idea of a *causal disposition*, that is a mechanism that tends (or used to tend) to produce a given consequence. For example, a muscle tends to contract, a property that has many possible usages, from pumping in or out, to locomotion and prehension. The second is a *reproductive mechanism*, that allows the device in question to be “copied” or emulated either in the same organism (for further use) or in its offspring. The causal mechanism here does not need to be specified: it ranges from genetic reproduction to epigenetically stabilized features, (as with muscles), learning and cultural scaffolding (as with mindreading or planning). The third causal relation is the crux of the dynamic-causal explanation of function, through the notion of heightened fitness: the device in question has been selected, reproduced and/or is presently used *because it gives the organism a better chance for survival*, through the precise effect it produces in the relevant context.

This causal condition is sometimes seen as a “historical” form of causality; but actually, things are more complicated. It can be interpreted either in retrospective, historical terms, as

²The capitalization is meant to distinguish a specific school in evolutionary biology from

the “etiological view” of function recommends, or in dispositional, time-neutral terms, as the propensionist view suggests.³ We will not discuss here the merits of these interpretations, which correspond to the respective needs of evolutionary biologists (interested in the evolutionary history of traits) and of anatomo-physiologists (interested in the causal role of a functional element) as well as to what Mayr called 'functional biology'.⁴ Suffice it to say that this third causal link is a form of causation by consequences immersed in a recurrent selective process. For our present discussion, conditions 1 and 2 need to be spelled out in more detail.

A – Inclusive context

The notion of an inclusive context, introduced in condition 1, is a very important factor that modulates what is called “the categorical basis” of the corresponding disposition. Context is not only the background in which a function operates, it plays a structuring causal role in the functional effect. It is simple to see why. A physical (or biophysical) disposition owes its causal capacity to there being nomic relations between properties engaged by the disposition and the environment in which it is exerted. For a substance to be soluble in water, water is not needed: as a pure possibility, the disposition is relational and context-independent. For this disposition to be exercised however, the substance must actually be plunged into water. If the contexts of a functional device are sufficiently modified, the corresponding disposition fails to be convertible in a causal process.

Moreover, given that the structure, in virtue of condition 2, needs to be reproducible in new organisms to count as a functional item, context needs to be stable at least in its causally crucial dimensions, to allow the structure to reliably produce its effects. Context interacts with function in two different ways, i.e. according to two types of constraints (By “constraints”, are meant the contextual conditions that have to be present for a given functional disposition to be exercised). There are two kinds of such causal constraints that a device must satisfy to produce a functional effect *F*. These constraints have to do respectively with the external or internal context in which the device operates.

External context constraints are the nomic biophysical relations that allow the energy flow between the device and the relevant part of the environment. Let us consider two

the general field (referred to by the same, non-capitalized, term).

³ See Proust (1997) for a defense of the propensionist account.

⁴ See in Mayr (1961/1988), ‘Cause and Effect in Biology’, 24-37.

examples. 1) A muscle contracts in given conditions of gravity. Actually gravity causally contributes to the development and operation of muscles (Thelen & Smith, 1994). 2) Social learning occurs in given conditions of appropriate social, communicational and emotional environment, etc. The kind of feedback that the system receives about the type of social relations, and the value of these relations to itself, is causally crucial for learning to occur.

Internal context constraints are the relations between the functional device producing F and the other functional subsystems of the organism with which the structure producing F interacts in order to produce F . For example, a muscle works in relation with other functional elements: the skeleton dictates the shape and location of the tendons and of the skeletal muscles, which are themselves involved in moving various body segments according to the various demands of motor tasks. Learning how to read minds presupposes a hierarchy of other mental capacities. To read a mind, you need (inter alia) to have conceptual-inferential ability, a linguistic ability including syntax and a semantics for mental states, and an evolved ability to teach and to learn. For any function, there are upstream - or precursor - functional elements that need to be present for the function to be assembled or exercised (downstream functions will also in turn depend on it to develop, but they do not constitute a constraint for their precursor). Bill Wimsatt has theorized this functional asymmetry in terms of a relation of *generative entrenchment* between a functional effect and the preconditions that make its development and normal operation possible.⁵ The solidarity at any given time between the various elements contributing to the F effect is what allows us to speak of a “system”, such as the musculo-skeletal system, or the mindreading system.

B – Reproducibility

The second important aspect of our definition has to do with the concept of reproducibility or inheritability. For evolution by natural selection to occur, the variants that, in a given population and environment, increase their bearers' fitness must be heritable traits. The concept of function, being part of a fitness-based selective reproductive process, involves the intervention of a reproductive device. Quite obviously, one important process that underlies this transmission is the genetic mechanisms of reproduction. Transmitting human hearts (normally) presupposes sexual reproduction. There are however also non-genetic mechanisms that contribute to the recurrence of a functional trait. Some are environmental – such as those ecological parameters that control development, motivation and growth in similar ways in various individuals. Some, and probably most, are cultural – such as the vast

⁵ On this concept, see Wimsatt, 1986 & Griffiths, 1996.

number of learning practices that permanently “reproduce” specific skills and associated tools in new brains - and hands; linguistic communication that creates new tokens of a thought pattern in new individuals; bodily communication that creates new expressive means in the recipients; various prosthetic technologies allowing artifacts “resembling” the dysfunctional structure that is to be replaced or otherwise repaired and/or enhanced in order to maintain the organism’s life. These various kinds of examples are meant to underscore that no identity or exact duplication is required by condition 2.⁶ Every case of transmission has to allow for contingent developmental accidents as well as for interfering stable dynamic patterns that may modify the outcome. We will see later, however, that such variance is a welcome feature that can be exploited and monitored in a dynamic system.

C- The causal-teleological condition

We will not comment in detail on condition 3, which has been discussed at length in heated debates among evolutionary biologists. Stephen Jay Gould and Richard Lewontin have ridiculed the “Panglossian” tendency of adaptationists to identify each single organic feature as a functional trait, much like the Leibnizian Pangloss of Voltaire’s *Candide*. Their objections to an oversimplified application of the concept of function are well taken and are devastating for the naive teleologist that is dormant in us. In order to apply condition 3, as they are right to insist, it must be shown that no other explanation is at hand than the causation-by-consequence explanation (other explanations include developmental or architectural constraints that cannot fail to apply –and thus do not need to be “selected” -, or 'non-selective' genetic explanations, like genetic drift). A methodological recommendation follows about applying condition 3 in a parsimonious manner: no function should be attributed without documentation of a relevant selective history. This kind of consideration motivates the next question we want to raise.

2 – Mental function: the modular view

⁶ Dawkins’ meme theory claims that ideas are identically replicated from brain to brain, and undergo a quasi-darwinian selective process comparable to genes. Sperber’s epidemiology of representation, however, does not postulate that a copying process is involved. Rather, there is repeated production by the recipients’ own informational processes, which allows variants of the same type to be generated by the same epidemiological process. See Sperber (2006).

Having provided a general definition of what a function is, we now need to find the specific difference that will allow us to focus on mental functions. What are the features that make an organic function a mental one? In other terms, what is the disposition (or set of dispositions) that can be copied or reproduced such that having it would allow a system to develop capacities of a mental type (condition 1)? What are the general constraints – internal or external – that apply to them? What are the specific “copying” or “reproductive” mechanisms that implement them (condition 2)? And how do the consequences of the disposition about fitness explain that the mental disposition is adaptive, i.e. has been selected (condition 3)? In sum, are we in a position to identify mental functions?

Although the concept of a function is of common use in psychology and in cognitive science, experimental psychologists have rarely addressed these three questions in any systematic way. It is often observed that experimental psychologists studying a capacity in mature adults rarely attempt to understand the development and full scope of the capacity they are studying. They are aiming to characterize behavioral regularities, not to question the way they were established, which functions they have outside the lab, and which neuronal systems realize them. Although there are, as we shall see below, deep reasons for “functional agnosticism”, there are also more shallow ones. The functional terms used in experimental psychology, such as “perception”, “working memory”, “motivation”, etc. are used to characterize, in broad functional terms, systems of informational processing mechanisms that are logically required, given basic assumptions on what a mind should be. The term *function* is used to refer to a causal role in a set of informational processes relating input and output. Although this usage is *prima facie* pragmatically sufficient to conduct experiments and theorize about the mind, it cannot provide a foundation for psychology as a science; far more is required than a broad causal role “to cut nature at its joints”: the problem with these causal attributions is that both the stimuli and the responses are classified in terms of commonsensical, rather than causally relevant, “natural kinds”; they actually fail to be robustly involved in the functional roles that they are supposed to have (for example, it is debatable that there is such thing as “visual perception” in any strict sense of the term, given the multimodal organization of the perceptual system in mammals).

It may be worth emphasizing that this use of the term “function” did not originate in biology, but rather in rational taxonomy, which from Aristotle on has decomposed the mind into general, wide purpose ‘faculties’: perception has the purpose of extracting

information (perceiving), memory helps store and retrieve it (learning, remembering), motivation allows wanting, acting is the faculty of converting knowledge into goal-directed behaviors, and emoting allows one to create social bonds and to communicate. The various dispositions cited as constituting a mind fail to qualify as biological functions, however, as long as they are not justified by the type of reasoning we have sketched above: no internal or external constraints are investigated concerning how the disposition is supposed to deliver its functional effects, no homologies are invoked across related species to explain how corresponding traits are inherited. Finally, no explanation is given of why the device or mechanism has been selected and reproduced.

It is in reaction to this kind of broad causal-role (non-biological) view of mental function that Evolutionary Psychology has developed. The idea is to systematically identify the teleological condition (condition 3 above) that explains why an information-processing disposition is present. In virtue of condition 3, a given psychological function exists if the specific informational pick-up and the computational transformation between input/output that it effects have been selected because they solve a specific adaptive problem. Where traditional views on the mind identify general-purpose, content-free mechanisms (« learning », « reasoning », « emoting », etc.), Evolutionary Psychologists claim that a specialized content – that which constitutes a specific « essential adaptation » - must organize the very design of an informational mechanism. This in turn suggests that a cognitive architecture has to be composed of many modules, each one having been selected to solve a specific adaptive problem.

As Jerry Fodor defined the term (Fodor, 1983), a module is an informational processing device that automatically, quickly and effortlessly, transforms inputs of a domain into readily usable outputs. Modules however are « informationally encapsulated » in the sense that they use only the information available in their own domain of specialization (for example: visual or linguistic processing); they cannot modulate their outputs by using the various types of information stored in other modules. A common example of this informational encapsulation is offered by such robust perceptual phenomena as the Müller-Lyer illusion: this illusion persists even when the perceiver is aware that the two segments are in fact equal. Whereas Jerry Fodor took modules to be « peripheral » entities, delivering their outputs to a non-modular, central processing unit, Evolutionary Psychologists maintain that functional specialization extends right up into reasoning and other higher-level processes. This fully modular view of cognition, according to them, is the only way to solve the ‘ frame problem ’ that is, to bypass the

computational explosion that would paralyze a general-purpose system confronted with real-world complexity. Indeed a module is the evolutionary solution to combinatorial explosion *as a general selection pressure*.

There are several ways of solving the frame problem: reducing the dimensionality of the problem situation can be achieved by using either domain specific algorithms, or non-standard information-processing models. An alternative way – as we shall see below – is to show that the problem never actually arises for biological systems: it is only generated by an erroneous view of how these systems relate to their « informational » environment. On this alternative view, the brain imposes structure on its environment in a way that reduces its dimensionality. For Evolutionary Psychologists, the problem does arise, and dedicated computational modules are the multiple, but automatic, responses that evolution found to solve it. "Darwinian algorithms" or "cognitive programs"⁷ are automatically activated each time a certain recurrent adaptive problem is encountered. Given that there are many such problems, the mind encompasses many different modules, from cheater detection and mate selection, to food choice, habitat choice and theory of mind.

A notorious difficulty with the notion of an evolutionary module is that of justifying the "adaptive high-resolution maps" of the various mechanisms that collectively constitute the mind. Three types of methods can be used to construct such maps. One is the "reverse-engineering" approach: starting from the problems that our human ancestors had to deal with, find which precise cognitive programs would optimally respond to them. The second consists in testing the hypotheses formulated in this a priori way. The crux of the method consists in creating alternative experimental conditions, in which the distal "adaptive" dimensions of the task are made to compete with more proximal computational explanations of the observed performances. For example, if there is such a thing as a "cheater detection module" whose activity is elicited by a "social contract" situation, experiments will be designed to contrast performances when a detection of a rule violation is presented in a social contract garb, and in an abstract reasoning garb (as in the original Wason task). If one can experimentally show that performance is greatly facilitated in the "adaptive" presentation, and cannot be better explained by some other adaptation or by a general purpose capacity, then the case can be made for a task-specific module being active. A third kind of evidence makes use of neuropsychology and psychopathology: if double dissociations between, say, theory of mind, on the one hand, and cheater-detection

⁷ Cosmides & Tooby, (1994, 73).

on the other, can be observed in brain-lesioned subjects or patients with autism (one kind of performance being maintained while the other is disturbed), then the hypothesis for there being (at least) two different specialized modules for social reasoning is comforted.

Let us pause to consider what Evolutionary Psychology has to tell us about mental functions. First, the idea is that there are as many mental functions as there are specialized modules. Only some of them have been discovered, mostly those that correspond to the Fodorian peripheral modules. Evolutionary Psychology however suggests that all the modules that constitute our reasoning and decisional capacities use computational capacities in a contextual and parsimonious way. Therefore, old-fashioned psychology and neuroscience study only apparent functions: for the responses they describe do not fulfill the three conditions above. 1) They fail to identify the contextual, motivated or adaptive character of information processing. For example, people do not use a « mental logic » to detect rule violation; they use, rather, a faster and more frugal algorithm that bypasses modus tollens. 2) They don't explain how this disposition is acquired and reproduced (it certainly is acquired neither through the teaching of logic, nor through innate logic). 3) They don't explain how the disposition is there.

To capture the level at which it is relevant to speak of a mental function, Evolutionary Psychologists rely on David's Marr (1982) three-level distinction of a research agenda in cognitive science. The « computational theory » has to determine what the goal of the computation is. The level of the « algorithm » has to determine how the input, its transformations, and the output are represented. Finally, the hardware level has to determine how representations are implemented in the brain. By adopting this trichotomy, they choose to look at "mental function" from a functionalist viewpoint (this is not, appearance notwithstanding, a tautology: "functionalism" refers to a view of the mind according to which mental states are definable in terms of their causal-representational relations, independently of their cerebral realization). Mental function is taken to belong to the computational level: function has to do with the goal of a computation: the goal must be clear before we can look for the cognitive processes that subserve it. The "hardware" level, finally, has at most the role of providing additional, optional evidence for the existence of a function. This view of mental function has been very popular among philosophers and psychologists, and more generally among functionalists: if only the causal relations, captured in computational terms, between inputs and outputs are relevant in psychology, then a neuroscientific analysis of the particular way in which these computations are implemented is only of marginal interest.

Many objections have been leveled against Evolutionary Psychology, often inspired by a strong anti-biological view of human psychology. We need only consider here those objections that share the view that Evolution is relevant to understanding mental function. There are three main objections of this sort.⁸

a– Methodology

The first is methodological. Reverse engineering seems to bring back the worst forms of pan-adaptationism. Although some information processing mechanisms must have been selected for their effects, it is difficult to prove that the teleological condition 3 does apply in all the cases where an adaptation seems to be present. Some might be rather exaptations,⁹ or architectural consequences that have no direct teleological explanation. A currently controversial example is the computational apparatus underlying human language, in particular syntax. Hauser et al. (2002) suggested that syntax might have evolved for reasons other than language (like number use, navigation, social cognition). If such were the case, syntax would be an exaptation rather than an adaptation, in spite of the obviously useful effects of a language faculty in our species. Pinker & Jackendoff (2005) on the other hand, argue that the complexity of the interconnected mechanisms that syntax involves have the earmarks of adaptation, which suggests that syntax is an adaptation for communication. Another example is the possible functionality of postural synchronous sway among cooperative speakers¹⁰: although this sway might be adaptive to facilitate communication among participants, it might also be simply the exaptive effect of intrinsic rhythmic patterns in speech production.

It is furthermore not obvious that evolution of mental function would always proceed by finding and using *the* optimal design for solving an adaptive problem. How efficient a cognitive mechanism is, depends on various dimensions of the adaptive problem: centrality of impact (how well does it solve the problem given the mental

⁸ For a general critical approach of Evolutionary Psychology, see Buller (2005) and Panksepp & Panksepp "(2000).

⁹ An exaptation is an adaptation where the effect currently performed by the corresponding trait does not coincide with the effect explaining why the trait was primarily selected. Exaptations, arguably, might still count as functions : although initially selected for effect A, they might now have effect B, which would explain the disposition of the corresponding structure to raise its bearer's fitness and thus be passed on to offspring in the future. But usefulness of an exaptation does not automatically mean that it will actually be passed on : it may also have deleterious effects given the inclusive context in which the organism has to survive.

architecture in its previous design), tolerance for mishaps, temporal constraints, and proportion of cognitive resources that it recruits. Given the necessary trade-offs between these variables, it is to be expected that the hypothetical selected modules should often be sub-optimal in accuracy, while offering acceptable solutions given the time and effort saved. This objective fact however works in favor of overincluding behaviors among adaptations, which is a reason to exert caution in using this line of reasoning.

b - Co-evolution

Some adaptive changes in one species (for example: color pattern in birds) are such that they do not generate a major selective pressure on other species, nor directly affect the physical environment. This however does not seem to be the case for evolutionary changes that are driven by social environments, as is the case for human cognition. According to the Machiavellian Intelligence Hypothesis, any increment in social predictive capacity is bound to have repercussions within and also beyond the species.¹¹ In the primate group, social pressures have led to adaptations for representing and predicting representational and predictive capacities in others (which allowed a « theory of mind » to emerge). The technological and cultural capacities that humans have developed as a social species on the basis of their cognitive capacities have also been constantly transforming the physical environments in which they construct their niches, to such an extent that all the other biota and associated ecosystems have been more or less directly affected. These transformations to the environment constitute new pressures directed at more specific adaptations.

This has led many theorists to conclude, as do Sterelny & Griffiths (1999)¹² and Proust (2006), that there is no invariant environment to which the lineage is adapted. Change in group size, change in population structure, and change in available resources strongly modulate the adaptiveness of altruistic or Machiavellian dispositions in a way that may differ from individual to individual, according to the strategy implemented in the group at large. Technologies of various kinds, as well as human cultural practices, also strongly affect the physical environment in which they have to survive and reproduce. If this is true, cognitive adaptations should be taken to accommodate an evolving rather than a stable environment. Mental function should accordingly not be taken to correspond to one

¹⁰ Shockley et al., (2003).

¹¹ Whiten (1997).

¹² Pp. 328 sq.

recurrent adaptive and « essential » problem (cashed out in terms of stable social and physical configurations). It should rather be characterized as a set of capacities allowing the organism to cope with changing, largely unpredictable environments.

c - Predictability & non-flexibility

The switch from the evolution of mechanisms to the evolution of evolvability of mechanisms constitutes an a priori reason to doubt that modules might be an efficient response to social-cognitive pressures: algorithms specialized in dealing with others in such practical matters as resource sharing or mate choice would be rigid responses to a changing world, not flexible answers to ever changing social constraints. They would also be particularly vulnerable to exploitation by others, given that predictions are made easier when the information relied upon is modular and specialized. The only way to prevent rigidity and predictability would be to have many possible modular responses for any given situation. But in this case, some form of central control of the modular responses should be expected; we would lose automaticity and speed, and we would be confronted with the computational explosion that threatened the general learning account.

In sum: Evolutionary Psychology has interestingly tried to respond to the requirements that an informational device must fulfil to qualify as a mental function. 1) It explicitly aims to identify the relevant context in which a given informational process was selected. 2) It takes genetic transmission to explain how 'Darwinian algorithms' are reproduced. 3) It accounts for the presence of these specialized informational processes by a historical-causal (i.e. 'etiologically') application of teleological condition 3. Central objections however blame reverse engineering methodology; they pinpoint that the appropriate selective context might be characterized in dynamic rather than in factual/discrete terms. Furthermore, they observe that there is presently no clear evidence that modules are genetically transmitted. Finally, the selection of shallow, fast and automatic modular processing seems to be incompatible with Machiavellian constraints, which are part of the inclusive context in which functions are stabilized.

3 – Mental function: the developmental view and "Evo-devo" biology

Several developmental approaches to evolution, in particular evo-devo and Developmental System Theory (DST), have generated important ideas that are crucial to our discussion of mental function(s).¹³ Evo-Devo is the field of evolutionary biology that examines how development has evolved under evolutionary pressures, and how it retroacts on evolution. One of the central concepts of this field is the concept of modularity, which turns out to be of critical importance to understand the basis of mental functions. Developmental system theorists on the other hand question the orthodox view – that genes control the progressive functional specialization of brain areas in interaction with the physical and the social environment –, a position that, according to them, takes mental functions to be predetermined in the genetic code. For DST theorists, in contrast, genes are themselves in part controlled by a variety of epigenetic chemical processes such as the DNA methylation system. In addition, inheritance mechanisms are not exclusively genetic, but extend to a variety of chemical, cultural, behavioral and physical phenomena.

For the proponents of a developmental approach, therefore, what counts as an adaptive problem cannot be read from ancestral environment alone; it can only be known from the structure of what they call the « developmental modules » that structure the growth of the organism under study. A developmental module is a "region of strong interaction in an interaction matrix" (Griffiths, to appear). Developmental modules do have causal effects on other modules (they allow differentiation to occur in neighboring parts); they have however a higher degree of internal interaction, which allows them to be viewed as independent building blocks in the development of an organism. The adaptiveness of such a modular development is similar to the adaptiveness attributed to mental modules: in a modular architecture, the effects of mutations are more local; thus their disruptive effect is less likely to harm the whole developmental process. Although some of these mutations may be quite specific and apparently limited, the outcome however may be extremely important, in particular because of the hierarchical and temporal nature of the "developmental cascade". As Griffiths emphasizes, double dissociation is also a consequence of this modular developmental architecture: a developmental module can be identified on the basis of its being selectively impaired without the other modules being perturbed.

Now why should a developmental module be more relevant to mental function than the mental modules identified by Evolutionary Psychology? The response is straightforward:

¹³ For a clear presentation of these two endeavours, see Robert et al. (2001)

because developmental modules *directly map* the selection pressures. To understand how such a mapping is possible, and how the developmental modules finally connect with mental modules, it is necessary to come back to the circular causal process, in virtue of which niches are causally shaped by populations while also constituting causal constraints to which populations have to adapt. When a co-evolutionary process affects both a specific population and its ecological niche, each co-transforms the other, creating ever changing adaptive problems for the organisms living in that niche. Thus, if you want to identify the selective pressures, look at the developmental modules (e.g. look at how the cells develop, how they differentiate in cascade in interaction with the environment). The mental modules, those that express the stabilized, mature organism, cannot however be directly inferred from the interaction between the species and its environment. Mental modules are much more elusive functional entities, for they result from the conjunction of two factors. First, each organism has a specific developmental pattern resulting from the specific timing of its encounter with relevant events and properties. Second, every mind will be the outcome of an optimization of its informational processes in light of cost-benefit compromises. For example, the degree of granularity that categorization reaches within a domain will depend on past affordances and individual training. There is no « general » environment with normal affordances and normal training procedures. Variation is the rule.

Griffiths and Sterelny thus blame the Evolutionary Psychologists for their lack of sensitivity to what they call the « grain » problem. Let us take an example. What is the level of specialization of a given cognitive program, such as the « cheater detection program » studied by Cosmides and Tooby: Is it designed to detect a cheater? Is it designed to be more emotionally engaged in a task when the risk of a social contract violation is present? Is it to memorize learnt rules when they are more salient? Evolutionary Psychologists claim that a mental function is a unique solution to one independent pressure; reverse engineering is able, starting from the problem, to derive the cognitive mechanisms subserving it. Such a method is indeed successfully applied in the case of morphological traits: the stability of the relevant selective pressures and the obvious relation, for example, between bone length, gait and body mass may allow one to form precise functional claims. In the case of psychological mechanisms, however, there is no a priori indication of the correct grain size.

Only a developmental approach, however, can tell what is dissociable as a separate task; furthermore, the individual's specific interaction with the environment and the ensuing learning process are what determine his resulting psychological organization – i.e. the task- and environment-dependent connections between informational processes that prevail for

that individual. For that reason Paul Griffiths (to appear) takes mental functions to consist neither of ‘virtual modules’, which need not coincide with development, nor, as we will see, with neuronal modules. This notion of « virtuality » is important, in that it points to the fact that mental function is associated with a kind of replication that cannot be described independently of the context of development.

The case for homologies: a tension between two requirements?

DST theorists as well as philosophers of biology¹⁴ have emphasized that homologies should play an essential role in determining biological functions in general, and mental functions in particular. In contrast with analogies, homologies characterize structures, which are similar inside phyla because of a shared ancestry (analogies exist between structures that are similar across phyla, without a shared ancestry). In order to justify the existence of a given function, as many biologists have argued, it is not sufficient to cite a causal link between an adaptive problem and a specialized mechanism; it is also necessary to show that the trait under consideration – the computational mechanism controlling the adaptive behavior – is the result of descent from earlier adaptations. This was, indeed, one of the main messages of Lorenz and Tinbergen’s ethological view of function: a comparative approach is necessary to justify an evolutionary explanation of current behavior.

More recently, authors of different obediences, such as Griffiths (1997), Matthen (2000) or Panksepp & Panksepp (2000), have used, in arguing against Evolutionary Psychology, the role of homologies within cladistic reasoning: “functional classifications can be used to group cladistic units together in a way that allows the theorist to express generalizations about the evolutionary process that apply to many different lineages” (Griffiths, 1997, p. 217). Homologies are indeed helpful for two basic reasons. First, they allow us to trace back how a structure has evolved along a phylum, from precursor to new forms. This allows us to make function attributions that are more strongly rooted in the organism’s anatomy and in the fact that the trait was transmitted because of the additional fitness it conferred on its bearer. Second, they allow comparisons that are not based merely on superficial similarities in behavior; for example, if there is homologous brain circuitry that is activated for fear in macaques and in human beings, there is a prima facie strong reason to say that this circuit globally has the function of helping the system to detect and respond to danger; this even allows us to make precise hypotheses about the kind of danger to which the circuitry most

¹⁴ Griffiths, (in press) ; see also Amundson & Lauder (1994).

efficiently responds (snakes, predators etc.). When no such cerebral homologies are at hand, we are in no position to establish that two analogous behaviors have one and the same function – that is, have been selected because of the particular response they allow, and on the increased bearers’ fitness that ensues.

In the case of human psychological functions, homologies have recently played a major role in functional reasoning. For example, although only human beings have linguistic competence, it has been shown that there is a homology between premotor area F5 in monkeys and Broca’s area (Brodmann’s areas 44 and 45) in humans (Rizzolatti & Arbib, 1998). These areas contain assemblies of neurons that are activated in primates both for executing and simulating manual actions and facial gestures (a “mirror-system” for action), while Broca’s area is involved in phonetic, syntactic and semantic language processing. This homology certainly does not show that monkeys can or could speak, given adequate training; but it suggests that the mirror-system might be a crucial pre-adaptation of language; the “missing link” between primate non-speaking communicators and human speakers might thus consist in an extension of the mirror system, linking it to exclusively human imitative abilities. An action proto-language might have emerged in humans, according to this reasoning, as a capacity for syntactically combining semantically interpreted manual gestures – a capacity implemented in Broca’s area (Roy & Arbib, 2005). Although mirror neurons were not originally “meant” (selected) to be used in communication, they might have later become a crucial piece of proto-language production and understanding. This example shows that homologies can be used to understand the evolutionary lineage of an adaptation within a phylum – rather than simply helping dissociate mental functions by distinguishing their underlying neuronal realizations.

To summarize, the requirement of finding homologies in function attribution, seems to entail that psychological functions should fail to be identifiable when no homological brain structure is. Condition 2 in our definition of function is here becoming more central than condition 3. Griffiths also maintain, however, that psychological functions may include “virtual modules”, that is: dissociable patterns of performance that do not correspond uniquely to separate neuronal systems. If some or most psychological functions are such “competence patterns”, which are shaped by the demands of the current developmental environment rather than by an inherited brain anatomy, it is not clear why we should retain the homology requirement in psychology. If flexibility and plasticity prevail in the mental, it might seem that psychological functions do not have to be identified with inherited

anatomo-physiological structures. The theoretician's burden, in this case, is to give substance to the inheritance condition 2 on function in non-structural terms.

The ambiguity of what is called a function

The preceding discussion brings again to the fore the ambiguity that plagues most uses of the expression “mental function”. In current terminology, “neuronal systems” refer to anatomically specified task-specific activations of neuronal assemblies. The very existence of these neuronal systems seems to most theorists to offer a sufficient guide to mental function. It is common parlance to discuss “the” functions of “the mirror system”, of the “dorsal stream” of perceptual processing, or the role of the amygdala in processing emotional information in perceived faces etc. But the problem here is twofold. First, it is not obvious that what is identified as a causal role (as revealed by a systematic task-specific pattern of activation in the adult brain) actually corresponds to a mental function as defined by condition 3. What is reflected in brain imagery may not be carving out ‘a’ function: it may in fact express either one or several functions (as called for by the particular task), one or several “exaptations”, or simply stabilized interactions between brain, culture and physical environment that do not have a function in the defined sense (without being *inherited* capacities- being there *because* they have this particular effect).

Conversely, what should lead us to expect that bona fide mental functions necessarily correspond to the activity of dissociable, separate neuronal systems? If Griffiths is right to think that virtual modules do not have to be associated with a fixed neuronal substrate, then mental functions “in the strict sense” might be realized by one cerebral substrate or another across subjects, according to the circumstances of their development – where developmental timing pattern, specific early training, injury, or local cultural habits, might play an essential role. Perhaps, in other words, the apparent neuronal fixity of modules is an effect of cultural/environmental homogeneity rather than a solid fact about the brain. If these reflections are on the right track, then the discussion of homology for mental function might have to be upgraded to a higher-order architectural level. We should not expect to find lineages of strictly dedicated, task-specific zones, but rather very general domains, such as emotional areas, versus spatial, instrumental, and episodic knowledge areas and the effects of their action, none of which can function independently of the others. The notion of a virtual psychological module is thus perfectly compatible with the view that the whole brain constitutes the only neuronal module there is.

4 - Mental function: the Neuronal growth approach

We saw above that Evolutionary Psychologists have used Marr's trichotomy in such a way that mental function turns out to be dissociable from brain development, physiology and anatomy. Many biologists and DST theories, however, have objected that homologies have to be present for sound functional attribution: they are the biological earmarks of functional structures. Fortunately, a solution to the homology puzzle is in view. Powerful new ideas on the structural homologies subserving mental functions have emerged in the last few decades from the neurosciences, which come surprisingly close to the theoretical intuitions of the DST theorists – although no clear explicit cross-influence is noticeable in the respective literatures: the mind is built from the developing brain; the dynamics of the brain can only be understood against the background of the dynamics of the organism's environment; neuronal growth is the key to understanding why certain forms of brain activity are selected for their effects.

A major difference in accommodating these ideas, however, concerns the respective roles of learning and of brain dynamics. For “neural constructivism”,¹⁵ *learning* is what *guides* brain growth: learning induces changes in the brain structures involved in learning. For neural selectionism (also called brain Darwinism), the reverse is true: *brain development drives* learning, by the neuronal competition and selection that it generates. Before coming back to this important difference, let us introduce and comment further shared intuitions on mental function among neurocognitive theories.

For both theories, the brain is a “representational device” (*representation* here being taken to mean that the brain states are correlated with other states and properties, about which they carry information). It is widely recognized that representational development in ontogeny is characterized by “U shape” patterns. Children begin by performing well on some task, then they typically undergo a period of failure, by overgeneralizing their earlier knowledge, until they finally come up with a new stable, more robust, and extensive ability.¹⁶ This phenomenon points to the fact that the brain is *nonstationary* - its statistical properties vary with time. Both theories agree that this nonstationary character deeply affects the ways we should think about mental properties, for the structures underlying

¹⁵ Karmiloff-Smith (1992), Thelen & Smith (1994), Quartz & Sejnowski (1997), Christensen & Hooker, (2000).

¹⁶ For precisely documented examples, see Karmiloff-Smith (1992).

acquisition themselves change over time. Later representational stages are not simply refinements of earlier stages, but involve large-scale reorganizations as a consequence of structural changes in the learning mechanisms. Both reject the functionalist interpretation of Marr's trichotomy. Both see the brain as using feedback to regulate its own development. Finally, and crucially, both claim that the cerebral vehicle of mental function is dynamically shaped by the very process that allows mental function to emerge, *and* according to a set of mechanisms that are "meant to" - i.e. shaped by evolution in order to - let that function emerge. In other words, the functional analysis that allows us to understand mental function is referred to the neural vehicle that implements mental activity. This does not constitute a "change of level", as the authors take it that cognition is actually developing at the cell level and across neural populations: dendrite segments and dendrite structure are carrying information; the architecture of cognition can therefore only be understood through the architecture of the developing brain. This claim is a major breakthrough in theorizing about mental function, a breakthrough that needs to be explored in all its consequences.

The traditional genetic explanations of brain function, as we saw above, assume the brain to be "genetically informed" of the general kind of environment it is going to be living in. Further gene-environment interaction in epigenesis is supposed to fine-tune adaptation. In contrast with this view, the neurocognitive theorists are claiming that the brain has the disposition to be dynamically shaped to allow survival in a changing world. The genes work by biasing the brain/world interaction early in development, and not – or not only¹⁷ – by conveying information about which rules or algorithms to apply. The maturational program coded by genes now works only or mainly as a biasing factor: it leads certain areas of the developing brain to be sensitive to particular kinds of inputs.

In both theories, although they may not express their results this way, the intrinsically dynamic, (and, as I will argue later, teleological) form that results from developmental brain/world interaction is that of a hierarchy of adaptive control loops. In other terms, the neurocognitive theories reject the distinction between a cognitive and an implementation level because the very same type of mechanisms (generate and test procedures, for the selectionist, or "constructive", that is, environment-controlled growth, for the neural constructivist) characterize the development of cognitive learning and of the growth or

¹⁷ As we shall see below, some selectionists recognize that genes might make available an initial repertoire of dedicated processes, on which selection will suppress the non-relevant ones.

selection of neuronal cells. This latter point is very important, and needs to be discussed in more depth in each theory.

Selectionism : “ a radically new view of the function of the brain” (Edelman, 1987)

The selectionist theories, introduced by Edelman (1987) and Changeux & Dehaene (1989), adamantly reject the idea that mental function could fail to correspond to neural organization. Changeux & Dehaene (1989) suggest, rather, reinterpreting Marr’s trichotomy so that it refers to different organization levels *within the nervous system*. The most basic architectural level they describe is the single cell level, with a functional differentiation of the axon, dendrite and synapse. At that level, the function of the neuron can already be deemed ‘cognitive’: it is to transform input into output, in virtue of specific patterns of electrical and chemical properties that carry information. A single neuron is already performing a computational task (the program level); it is following an algorithmic process, and does so according to specific physical properties (molecular properties of the synapse and of the membrane). There is therefore no “ontological” autonomy of any one task-level, as functionalists claim, but a relation of “*co-dependence*” among levels. The constraints of the synapse and the membrane determine, in part, which computations can be performed, as well as which kind of goal they can serve. Reciprocally, serving a goal modulates both the computational and the physical levels, and helps stabilize the physical properties of the cell. A second anatomical layer encompasses “circuits”, i.e. neuronal assemblies of thousands of cells organized in well-defined structures, i.e. presenting task-dependent synchronous firings. A third layer is constituted by the “metacircuits”, i.e. relations of neuronal assemblies. Finally the traditional mental faculties are taken to roughly correspond to various of these metacircuits.

Functional agnostics will be quick to ask how such an organization emerges in the first place. The response is that a recurrent two-phase process is responsible for brain organization and learning. An initial exuberant growth of neural structure, leading to an overproduction of synapses, is followed by a selective pruning back of connections. There are successive waves of this sort of growth and selection from birth to puberty, each wave presenting in succession “transient redundancy and selective stabilization”. “One has the impression, writes Changeux, that the system becomes more and more ordered as it receives

‘instructions’ from the environment.”¹⁸ This impression, in the author’s view, is justified; indeed the function of the brain comes down to that: stabilizing those dynamic patterns that have high predictive value, while suppressing those that have low value *given the environment in which development is taking place*.

In summary: learning occurs by selection (as a consequence of brain/world interactions), but only if neurons and their synaptic connections already exist. This succession is objectively justified by the fact that learning presupposes selection. Bouts of learning can accordingly be analyzed, as the authors claim, through some version or other of Herbert Simon’s “generate and test” procedure. Neural proliferation produces variety; neural pruning selects those variants that have been more often activated through feedback from the environment (by suppressing their less successful competitors). Transitions between levels of organization result from a generalized and hierarchical stabilizing effect of “generate and test” procedures with re-entrant feedback loops within larger populations of neurons.

The most striking aspect of this theory, from a philosophical point of view, is that a “causal-teleological” explanation of adaptation, goal or function, is now taken to be common to the phylogenetic evolution of the brain, to developmental (ontogenetic) evolution, to the workings of the mature brain, and implicitly (as we will show below) to the representations that the brain structures carry. “An analogous Darwinian scheme” as Changeux & Dehaene (1989) put it, is at work within the brain as it is within evolution at large: brain structures have evolved neural growth/learning processes that mimic the teleological patterns that populations of organisms are subjected to.

Neural constructivism

This alternative theory takes its inspiration from Piaget’s constructivism, i.e. the view that mental representations are constructed through an action-guided, ongoing internalization of environmental structures. As we saw above, careful observation of human ontogeny shows that learning in each domain is highly discontinuous. Neural constructivists explain the dynamics of learning in development by a progressive growth of dendrites according to the interaction of the brain with perceptual input (in each modality: visual, auditory, proprioceptive, etc.). The fundamental differences with selectionism involve two claims: 1)

¹⁸ Changeux (1985), p. 249.

that dendrite growth (and diversity) is exclusively controlled by the environment, rather than dually by endogenous and exogenous influences;¹⁹ 2) that the immature cortex is taken to be initially equipotent (as brain damage in early development has little or no detrimental effect on mental function). Evidence from brain plasticity suggests that brain function is, as we saw above, a matter of general evolvability rather than of specialized adaptations. For neural constructivism, the actual functional organization of the mature brain depends entirely on the external constraints that the brain needs to learn: “It is the differing pattern of afferent activity, reflective of different sensory modalities, that confers area-specific properties onto the cortex – not predispositions that are somehow embedded in the recipient cortical structure”.²⁰

As a consequence of claims 1 and 2, neural suppression plays only a minor role in brain development. The structuring force consists rather in the creating of neural connections under the influence of incoming data/stimuli. The mechanisms that are hypothesized to generate brain tissue growth and, more specifically, dendritic arborization, seem to involve local releases of neurotrophins, i.e. feedback signals that are delivered post-synaptically and are thus activity-dependent signals.²¹ As a consequence of these constructive, bottom-up mechanisms, the cortex is “enslaved”, that is, fully controlled, by the periphery. Mental function thus consists primarily in “enslavability”: it involves the production of flexible, adapted responses to varying environmental constraints as well as to changing body size. As in the selectionist model, the constructive model associates mental function with a hierarchical brain architecture; hierarchical representations result from cascades of environmental constructivist influences working from cells to assemblies onto circuits, thus building representations of increasing complexity.²²

Constructivists however are more insistent than selectionists in considering that mental function can only be understood as the particular (and somehow contingent) outcome of development. In their view, domain-specific competences of the Darwinian algorithm type

¹⁹ Given that dendrites have non-linear properties, individual dendritic segments could be the brain’s “basic computational units”. Quartz & Sejnowski (1997), p. 549.

²⁰ Quartz & Sejnowski (1997), p. 552.

²¹ For a clear analysis of these mechanisms in the visual cortex, see Katz & Shatz, 1996.

²² Ibid. p. 550. Several interesting principles are used to explain the mature brain’s functional organization; one is the so-called “geometric principle” through which information is collected in a topological way, spatially or conceptually related representations being realized in neighboring physical structures; the other is the “clustering” principle, through which related inputs onto dendritic segments result in a pattern of termination that mirrors the informational structure of the input. (ibid, p. 549)

(cheater detection, snake detection, etc.) can be seen as evolved “mental functions” only if one forgets the whole developmental process that generated them. Actually, they are the result of repeated processing of initially domain-general mechanisms, which have turned out to be more often used for specific inputs: *domain-relevant* mechanisms are thus progressively turned into *domain-specific* mechanisms, as a result of their particular developmental history (Karmiloff-Smith, 1992).

In summary, we see that although the two neurocognitive theories under review are similarly focusing on the dynamics of development and its cascading effects on brain structure and function, they have symmetrical views on the relations of brain and environment. Selectionists see the brain as imposing structure, through its own innate “biasing” agenda, on an unstructured world. Neural constructivists reciprocally see the world as enslaving the brain by imposing on it spatio-temporal patterns of reactivity and sets of representations.

The variety and complexity of the brain processes engaged in learning suggest, however, that the two views might in fact have to coalesce into some encompassing “hybrid” theory: regressive and constructive mechanisms might in fact concurrently be engaged in development -- even though, existing evidence can still be argued to favor one camp over the other.²³

To conclude this section, it may be helpful to summarize the preceding discussion in terms of our analysis of function (see section 1). Concerning condition 1, i.e. an existing disposition (or a set of dispositions) that can be copied or reproduced such that having it would allow a system to develop capacities of a mental type: neurocognitivists answer that it is the disposition of the brain to grow in a way that is sensitive to its developmental environment (more exactly, to the computational demands that it involves). Note that this description of the brain disposition itself includes embedded functions: for example development is itself selected for, and may therefore also evolve as such, which in turn will affect the very disposition of the brain to structure itself. The strength of the neurocognitive proposal for mental function, as compared to modular views, is that the general constraints that exert pressures on brain evolution are made fully explicit in the model. The external constraints are the environmental conditions that differentially affect neural growth; the internal constraints are represented by the set of existing neural assemblies and their

interconnections that allow the brain to grow in ways that are in part predetermined by the existing circuits and metacircuits. Condition 2, which concerns the processes that are used to reproduce the disposition in other organisms, is dually constituted by genetic reproduction and by the mechanisms that allow stabilization of the environment through human intervention. Finally, condition 3 posits that the consequences of the disposition to regulate brain growth is correlated with a capacity to extract information and process it in the way that is the most flexible given the overall external and internal constraints, and has been selected because of this correlation. These theories therefore see mental function as a progressively differentiated, but initially global, capacity to store previous dynamics in existing brain matter in order to predict the environment and to adjust to it. In a currently fashionable style, one could say that the distal function of the brain is to orient its growth so as to “resonate to” the environment - or to be “dynamically coupled” with it in a flexible way. We will elaborate this view in the final section.

²³ Katz & Shatz, 1996, p. 1137, Hurford et al. (1997), p. 567, Dehaene-Lambertz & Dehaene (1997).

5 – Mental function or functions?

The mental representations that are built as an outcome of (creative or regressive) neural growth have a set of functional properties that are necessary ingredients of a working mind. I call these properties “functional” because they are *entailed* by the distal function of the brain that was just spelled out. As a consequence of the selectionist/constructivist model, these representations must be predictive, recombinable, modifiable, robust, and have a descriptive/conative polarity. We will first examine each of these features in order to see which cognitive capacities or developmental constraints refer to them. We will then be in a position to approach a more speculative question: How does recognition of these functional dimensions affect our view concerning how many mental functions there are ?

- a) *Predictability* is an outcome of the control structure of the developing brain. Representations are predictive, in the sense that the feedback used to construct a representation corresponds to a state of the world whose temporal properties are context-relativized. In other words, the brain takes advantage of the contextual cues to predict what comes next in a structured way (keeping track of perceptual cues as well as temporal sequence to reach probabilistically reliable predictions). For example, in an ordinary human environment, meals occur as a succession of routines with a certain dynamic pattern. The brain needs only store a small set of cues to know that it will soon be time for lunch.
- b) Representations can be *recombined* in ways that tend to be less and less specialized with development, in virtue of the very capacity of the mind/brain, as a dynamic system, to generalize knowledge acquired in a specific domain.²⁴
- c) *Modifiability* is also a result of the constant re-evaluation of acquired informational structures through feedback. Flexibility applies both to learning procedures (during development) and to thought contents (throughout life): both are adjusted, monitored and reorganized in a self-organizing way. Representational flexibility, however, should occur in a differential way, constrained as it is by generative entrenchment; this differential flexibility is in keeping with the fact that a representational system, such as a brain, is a nonstationary system with time dependent-properties.

²⁴ Some of the mechanisms allowing such a capacity to emerge from brain structure are described in programmatic terms in Quartz & Sejnowski (1997).

d) *Robustness* is a necessary feature of representational stability in a dynamic world.²⁵ In genetics, mutational robustness refers to an organism's phenotype remaining constant in spite of mutation. By analogy, representational robustness is a property of representations and representation systems in virtue of which they preserve a stable core in spite of being transmitted or generalized to new contexts, or in spite of contextual change. This property of robustness is of major architectural significance given, again, the role of potentially varying, unstable feedback in neural growth. Although as we have seen, learning how to learn is a crucial adaptation to changing environments, the environment in which learning occurs may also be customized to regulate robustness, and lead to a form of environmental selection comparable to niche selection in evolutionary biology.

Two sources of feedback-induced robustness come to mind. One consists in using the body and its own dynamics as a general model for other dynamic phenomena. Bodily motions can be used as a way of representing dynamically social as well as non-social events through overt or covert simulations.²⁶ Bodily gestures, such as pointing in joint attention, can be used to reduce noise in communication; they can also facilitate recall as well as thinking (considerable bodily information goes to structuring “abstract” linguistic symbols).²⁷ The other consists in using the social and physical environment as an external device to shape children’s development. For development to occur, there must be, as Lev Vygostky and later Jerome Brunner insisted, a process of scaffolding through which a child is guided by parents and teachers, allowing him/her to move forward into a zone of proximal development that the child could not reach alone.²⁸ An efficient scaffolding is one that optimizes the “fit” between the informational content being transmitted (a skill or piece of knowledge) and the cognitive properties of the receiving mind. The scaffolding may include, besides the “executive control” of an adult mind, a timely and sufficiently attractive presentation of the task, as well as spatial and sensorimotor cues that allow multiple representation of the problem space. This latter “fit” is regulated in turn by another selection/creation process that applies socially to representations. This process creates what Dan Sperber calls “cultural cognitive causal chains”.²⁹

Bodily postures, ways of moving as culturally shaped, as well as cognitively adapted environments are therefore also selected and maintained in dynamic coupling with

²⁵ On the biological importance of robustness, see Hammerstein et al. (2006).

²⁶ See Proust (2006b).

²⁷ See Barsalou, (1999).

²⁸ See Vygostky, 1978, Ch. 6.

representational systems (each stabilizing the other). They contribute to a considerable degree to representational robustness. This kind of co-evolution might help explain why there are cultural invariants, such as folk-biology, folk-psychology, or religion: the representations that prevail in the socially constructed mind/brain are those that are easier to acquire and transmit, and that fit more snugly the various emotional/motivational demands of the developing brain. Reciprocally, the social environments and bodily practices that allow an easier grasp (perceptual and cognitive) of the associated representations should evolve under the renewed demands of mind/brains that have depended, for their development, on those environments.

In sum, the brain needs a culture to grow into an organized semistable structure, much as its cells need oxygen to survive. *Pace* Evolutionary Psychologists, however, the existence of cultural universals – such as folk biology or folk psychology – does not necessarily point to an innate, genetically predetermined modular organization; these can also be explained in terms of the brain's permanent activity – cognitively resonating to a social/biological/physical environment possessing globally similar constraints.

e) *Conative-descriptive* polarity is an architectural requirement that any cognitive organism has to fulfill : it must deal with information in two complementary ways –extract it, in perception, and use it, in action. In neurocognitive models, this polarity is already implemented at the cell level, each neural cell receiving input and producing a response – (graded) firing or no firing - according to the input. Motor behavior is the organism-level response through which adequate coupling with the environment is performed in a flexible and integrated way (momentary needs are integrated into a single goal-oriented behavior at a time). In human cognition, the higher level at which this polarity controls behavior is the prefrontal cortex level. This structure is a highly adaptable structure that is constantly configuring the system to address current concerns, taking into consideration various time-dependent constraints.³⁰

We are at last in a position to offer an answer to our question: how does this analysis of mental function accommodate traditional notions such as the five faculties (perception, action, memory, affect-desire, reasoning) or the more recent distinction between selective attention, perception, working, semantic, and episodic memories, planning and action, emotion etc. ? If *the* function of the brain is *to ensure a cognitive dynamic coupling with its environment, driven by*

²⁹ See Sperber, (2006).

inputs and biased by innate motivations, is it still biologically justified to distinguish separate mental *functions* according to their causal roles?

A conservative response would defend the view that a simple rational task analysis of what the brain needs to accomplish (i.e. develop into a flexibly learning, sensitive organ able to control behavior) shows how justified the old wisdom was. Information has to be picked up (perception), retained (memory), and it has to be used (action), in a way that is context sensitive (motivation/emotion) and able to combine inferentially with existing knowledge (reasoning). It cannot be disputed that even though these venerable divisions of the mind turn out to be theoretically ill-grounded, they might be practically valuable in allowing research to develop when no principled explanation of mental function is available - or is consensual enough to organize research.

A more speculative and daring view, one that the developmental approach and the neurocognitive models of brain growth have made plausible, is that it is far from obvious that the brain is structured into separate, anatomically distinct faculties of the kind proposed. Multi-reentrant loops dynamically connect perceptual areas with motor areas, memory, and emotion sites. Any task has to cut across all of the "faculties", and will foster further development of their interconnectedness; such interconnectedness *constitutes* what learning that task consists in. To know how to do X, you must do more than "simply remember" - a capacity that would involve a pure form of "procedural memory" - you must also evaluate the benefit (a subcortical achievement), you must have perceptual access to X-related objects, and your brain must have some somatic experience corresponding to how it feels to do X. Performance in action is thus constantly modulated by motivation and emotion as well as by perceptual input and memory, and actually every such contribution is closely associated with others, either by cortical or subcortical connections. Vision psychologists acknowledge that perceiving involves acting with the eyes: muscles regulate vision, and retinas perform saccades that explore the relevant parts of objects of interest. Reciprocally, action psychologists acknowledge that action is constrained by the visual or the auditory spatial properties of the effect of the action (Simon effect), not to mention the essential role of perceptual feedback in the control of action. This functional connectedness suggests that the attempt at treating the traditional faculties as distinct mental functions is not biologically justified.³¹

³⁰ See Duncan (2001) & Koechlin & al., (2003).

³¹ The stronger view of mental function that this article tries to elaborate does not deny that neuro-anatomical similarity across individuals and relative domain specificity in information processing make the modular idiom useful in certain respects. What it denies

An additional argument for a global and dynamic notion of mental function comes from pathology. Contrary to the traditional faculties model, it is not the case that blind subjects are those whose eyes are lost, that mad people are those whose reason is perturbed, that aboulie people are those that cannot act etc. In fact, what cognitive pathology has been showing is that there is no such thing as a “mental dysfunction” that would coincide nicely with the impairment of a brain structure and its associated hypothetical role; impairments rather affect subjects in many different ways, suggesting that the traditional syndromes are only phenotypically similar but in fact causally complex.³² Far from justifying the existence of these separate but collaborative functions, pathology reveals the importance of development timing, and interaction between early acquisitions and motivation in organizing the adult competences (Karmiloff-Smith, 1998). Furthermore, as recent research on Williams Syndrome and autism has shown, different subjects may use completely different strategies to solve the same problem or perform the same cognitive task. For a theory of mind task, for example, some subjects rely more on their semantic memory, some on perceptual cues, some on instrumental reasoning. These various strategies were presumably selected as a consequence of the particular pattern of plasticity that their developing brain has been settling into, given the genetic or environmental constraints it had to face. (Karmiloff-Smith, 2006)

If, as we want to claim, adaptive control is the general “mechanism” or rather, type of mechanism, that characterizes mental function,³³ an evolved causal mechanism that shapes brain growth as well as genetic expression, representational selection and propagation of culture, then we need to look at mental functions as either additional adaptations or exaptations to adaptive control. Kim Sterelny (Sterelny, 2003) for example has suggested that mental skills are specifically meant to cope with what Sterelny calls "informational translucency", a property of

is that these modules are shaped by evolution as the conditions 1-3 above specify. If, as we argued above, the brain is developing in response to a changing environment, and function is determined by developmental constraints and environmental demands, our definition of a mental function cannot mistake a given token or type of functional *effect* (the one that is observed given a social-historical developmental context), with the general function of adaptive control that it exemplifies in that particular dynamic context. This also suggests that interpreting psychopathology is more difficult than commonly acknowledged; the distinction between impairment and compensation, for example, is difficult to draw in the absence of an independent understanding of the mental function(s) (in this broad, dynamic sense of the term), that is supposed to be perturbed. I thank Dick Carter for critical observations associated to this point.

³² For the functional analysis of schizophrenia, as a good illustration of this point, see Proust (2006a).

social or physical environments in which the cues are less reliable or can be manipulated by predators. In such environments, there is a cost in mining information (because of the risks incurred in exploring the presence or value of the cues) and/or in acting on it (when the cues are not reliable, the action becomes ineffective). In such contexts, it becomes important to devise strategies not only for reaching external goals, but also for extracting and using information. One of the most important functions of human culture is to help young organisms acquire the capacity to assess informational quality and to restore transparency whenever it is possible and useful to do so (by changing either the internal or external environments).³⁴ Sterelny explains robust multi-modal cueing and representation decoupling (allowing separate storage of alternative, incompatible representations of the same kind of situation³⁵) as responding to such pressures. Do these skills represent new cognitive functions? In Sterelny's view, these skills have rather to be analyzed as domain-general responses elaborated through culture. The idea of a "cumulatively engineered epistemic environment" refers to the view that the educational or imitative procedures that characterize our human cultures are designed to allow individuals to acquire "entrenched skills". Given that such skills are a product of learning provided with what we earlier called "scaffolding", it is arguable that they do *not* constitute additional cognitive "functions"; they are rather the expression of how the brain preserves representational robustness in uncertain or socially demanding contexts.

In Proust (2006b and in print), I suggested that another important dimension of robustness consists in predicting one's own capacity to predict. Higher level prediction defines metacognition, a control process that is endogeneously applied to the brain's predictive self-evaluative processes. This second order prediction has been studied in metamemory, a field of interest to teachers; more recently, its importance has been discovered for neuroeconomics, where predictive valuation processes are made to apply to the value of predictors of rewards. Should metacognition be taken to represent a distinct mental function? I would want to claim, rather, that the associated skills point to dimensions of adaptive-predictive control systems that are inherent to mental architecture. They are not separate functions, but constitutive aspects of this overarching, uniquely adaptive, predictive, "dynamic coupling" function of animal minds of a given complexity.

³³ For a similar view on cognitive function, see Christensen & Tommasi (2006)

³⁴ These constraints are analyzed in more detail for their consequences on the architecture of the human mind in Proust (2006b)

Acknowledgement

I heartily thank Dick Carter for his linguistic revision, as well as for his critical observations, and Marie-Claude Lorne for her careful reading of a previous version of this article. Research leading to this chapter was conducted in the context of a fellowship on Embodied Communication, at the University of Bielefeld (Germany) during the Summer 2006. I wish to express all my thanks to Günther Knoblich, Ipke Wachsmuth and Scott Jordan for interesting discussions.

References

- Amundson, R. & Lauder, G.V. (1994). Nature's purposes : Analyses of Function and Design in Biology. Cambridge, Mass. : *Biology and Philosophy*, 9, 4, 443-470.
- Barsalou, L.W. 1999. Perceptual symbol systems. *Behavioral and Brain Sciences*, 22, 4, 577-660.
- Boyd, R. & Richerson, P.J. 1985. *Culture and the Evolutionary Process*. Chicago, The University of Chicago Press.
- Buller, D.J. (2005) *Adapting Minds. Evolutionary Psychology and the Persistent Quest for Human Nature*, Cambridge: MIT Press.
- Changeux, J.P. 1985. *Neuronal man, The biology of mind*. New York: Pantheon Books.
- Changeux, J.P. & Dehaene, S. 1989. Neuronal models of cognitive function. *Cognition*, 33, 63-109.
- Christensen, W.D. & Tommasi, L. 2006. Neuroscience in context: The new flagship of the cognitive sciences. *Biological Theory*, 1,1, 78-83.
- Christensen, W.D. & Hooker, C.A. 2000. AN interactivist-constructivism approach to intelligence ; Self-directed anticipative learning, *Philosophical Psychology*, 13, 1, 5-45.
- Cosmides, L. & Tooby, J. 1994. Beyond intuition and instinct blindness ; toward an evolutionarily rigorous cognitive science, *Cognition*, 50, 41-77.
- Fodor, J. 1983. *The Modularity of Mind: An Essay on Faculty Psychology*, Cambridge, MIT Press.
- Dehaene-Lambertz G. & Dehaene, S. 1997. In defense of learning by selection : Neurobiological and behavioral evidence revisited. *Behavioral and Brain Sciences*, 20,4, 560-1.
- Duncan, J. 2001. An adaptive coding model of neural function in prefrontal cortex. *Nature Neuroscience Reviews*, 2, 820-829.
- Edelman, G. M. 1987. *Neural Darwinism : the theory of neuronal group selection*. New York: Basic Books.
- Fodor, J. 1986. *The modularity of Mind*. Cambridge, Mass: MIT Press.
- Hall, B.K. 1992. *Evolutionary Developmental Biology*. New York : Chapman & Hall.
- Jaenisch R. & Bird, A., 2003. Epigenetic regulation of gene expression: how the genome integrates intrinsic and environmental signals. *Nature Genetics* 33, 245 - 254
- Griffiths, P.E. 1996. Darwinism, Process Structuralism and Natural Kinds. *Philosophy of Science*, Vol. 63, 1-9.
- Griffiths, P.E., 1997. *What emotions really are*. Chicago, The University of Chicago Press.
- Griffiths, P.E., (to appear). Evo-Devo meets the mind ; towards a developmental evolutionary psychology. In R. Brandon & Roger Sansom (eds.), *Integrating Evolution and Development*, Cambridge, Cambridge University Press.

³⁵ Decoupling is needed for representing an event at different times, representing fiction as not true, and understanding false beliefs. See Sterelny (2003) & Proust (2003).

- Hammerstein, P. Hager, E.H., Herz, A.V.M. & Herzog. 2006. H. Robustness: a key to evolutionary design, *Biological Theory*, 1, 1, 90-93.
- Hauser, M., Chomsky, N. & Fitch, W.T. 2002. The language faculty : What is it, who has it, and how did it evolve ? *Science*, 298, 1569-1579.
- Hurford, J., Joseph, S., Kirby, S. & Reid, A. 1997. Evolution might select constructivism. *Behavioral and Brain Sciences*, 20, 4, 567-8.
- Karmiloff-Smith, A. 1992. *Beyond modularity*. Cambridge, MA : MIT Press.
- Karmiloff-Smith, A. 1998. Development itself is the key to understanding developmental disorders. *Trends in Cognitive Science*. 2, 10, 389-398.
- Karmiloff-Smith, A. 2006. Ontogeny, Genetics and Evolution: A perspective from Developmental Cognitive Neuroscience. *Biological Theory*, 1, 1, 44-51.
- Katz, L.C. & Shatz, C.J. 1996. Synaptic Activity and the Construction of Cortical circuits. *Science*, vol. 274. 1133-1138.
- Koechlin, E., Ody, C. & Kouneiher, F. 2003. The Architecture of Cognitive Control in the Human Prefrontal Cortex. *Science* 14 November 2003: Vol. 302. no. 5648, pp. 1181 - 1185
- Maynard-Smith, J., .1983. *Evolution and the theory of games*, Cambridge, Cambridge University Press.
- Mayr, E. (1961/1988) *Toward a new philosophy of biology*, Cambridge: Harvard University Press.
- Millikan, R. 1984. *Language, Thought and other biological categories, New Foundations for Realism*, Cambridge, MIT Press.
- Oyama, S. 1985/2001. *The ontogeny of information* (revised edition). Cambridge : Cambridge University Press.
- Panksepp, J. & Panksepp, J.B. 2000. The seven sins of evolutionary psychology. *Evolution and Cognition*, 6, 2, 108-131.
- Pinker, S. & Jackendoff, R. 2005. The faculty of language : what is special about it ? *Cognition*, 97, 1-36.
- Proust, J. 2003. *Comment l'esprit vient aux bêtes, Essai sur la représentation*, Paris, Gallimard..
- Proust, J. 2003. Can radical theories of simulation explain mental concept acquisition ? in J. Dokic & J. Proust (eds), *Simulation and knowledge of action*, Amsterdam : John Benjamins, 201-228.
- Proust, J. 2006a Agency in schizophrenics from a control theory viewpoint, in W. Prinz & N. Sebanz (eds.), *Disorders of volition*, Cambridge, MIT Press, 87-118
- Proust, J. 2006b. Rationality and metacognition in non-human animals, in S. Hurley & M. Nudds (eds.), *Rational Animals ?* Oxford, Oxford University Press.
- Proust, J. in print. Metacognition and metarepresentation: Is a self-directed theory of mind a precondition for metacognition ? *Synthese*.
- Quartz, S.R. & Sejnowski, T.J. 1997. The neuronal basis of cognitive development : a constructivist manifesto. *Behavioral and Brain Sciences*, 20, 537-596.
- Rizzolatti, G. & Arbib, M.A. 1998. Language within our grasp. *Trends in Neurosciences*, 21, 5, 188-194.
- Robert, J.S., Hall, B.K. & Olson, W.M. 2001. Bridging the gap between developmental systems and evolutionary developmental biology, *BioEssays*, 23: 954-962.
- Roy, A.C. & Arbib, M.A. 2005. The syntactic motor system. In K. Liebal, C. Müller & S. Pika (eds.), *Gestural Communication in Nonhuman and Human Primates*, Amsterdam, Benjamins, 7-37.
- Shockley, K., Santana, M-V., Fowler, C., 2003. Mutual interpersonal postural constraints are involved in cooperative conversation. *Journal of Experimental Psychology*, 29, 2, 326-332.

- Sperber, D. 2006. Why a deep understanding of cultural evolution is incompatible with shallow psychology. In N. Enfield and S. Levinson (eds.), *Roots of Human Sociality*, Oxford, Berg.
- Sterelny, K. 2000. Development, Evolution and Adaptation, *Philosophy of Science*, 67 ; 369-387.
- Sterelny, K. 2003. *Thought in a Hostile World, The evolution of Human Cognition*, Oxford: Blackwell.
- Sterelny, K. & Griffiths, P.E., 1999. *Sex and Death, an Introduction to the Philosophy of Biology*, Chicago, The University of Chicago Press.
- Thelen, E. & Smith, L.B. 1994. A dynamic systems approach to the development of cognition and action, Cambridge, MIT Press.
- Vygotsky, L.S. 1978. *Mind in Society. The development of Higher Psychological Processes*. Cambridge, Harvard University Press.
- Whiten, A. 1997. The Machiavellian mindreader, in A. Whiten & R. Byrne, *Machiavellian Intelligence II, Extensions and Evaluations*, Cambridge, Cambridge University Press, 144-173.
- Wimsatt, W.C. 1986. Developmental constraints, generative entrenchment, and the innate-acquired distinction in W. Bechtel, ed., *Integrating Scientific Disciplines*, Dordrecht: Martinus Nijhoff, 1986, pp. 185-208.
