

## **Towards an Evolutionary Framework for Human Cognitive Neuroscience**

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In a recent review of her research on early language acquisition, Max-Planck Society neurolinguist Angela Friederici (2005) demonstrated a correspondence between the major changes in the linguistic competencies of children in the first months and years of life and the markers of event related potentials to acoustic stimuli on the interval from 50 to approximately 600 ms following presentation. Thus, extended periods of individual development find their expression in microgenesis – the rapid progression of processing operations in the adult brain. Though elucidation of these operations is a prominent objective for psychology and neuroscience, the developmental evidence, so obvious in data presented by Friederici, played little if any role in mainstream studies for the most part of the cognitive era. The reason for this was the computer-metaphor framework, which stressed the similarity of symbolic information processing in conventional computers and humans. The presumed unitary constraints, which could be attributed to the central processing unit of mental machinery, have never been found. This failure of the mind/computer metaphor was predestined by its inherent incompatibility with evolutionary and developmental concepts.

In replacing computer science as the integrative platform for studies of the mind, theoretical biology created a number of new approaches from socio-ecological studies to neuroeconomics and even neuroaesthetics (Zeki 1999). However the second major framework for present day cognitive science, that of Fodorian modularity (widely known also as evolutionary psychology – see e.g. Cosmidis and Tooby 1994), seems to be equally unable to handle the basic facts of correspondence between onto- and microgenesis. One such fact is, for instance, the asymmetric relationship between supposedly independent modules. This asymmetry is manifest in the relative speed of processing and in the contingencies of information transfer. A related feature is that the brain mechanisms behind cognitive modules do not build random mosaics, but rather demonstrate gradient-like proximity relations (Goldberg 1990; Velichkovsky 2005). It is this gradient organization that, in our opinion, testifies to the existence of a vertical dimension of mental functioning. The functional architecture of mind/brain is not a mosaic of category-specific modules but instead is a continuous representation that has a highly consistent and orderly topological arrangement.

In view of this architecture, concentration on the solely local mechanisms may leave us in ignorance of the evolutionary context, obstructing access to evidence of cross-domain similarities. Encapsulated in their respective sub-domains, researchers implement a paradoxical practice of, on one hand, splitting the traditional mental functions into more and more fragmented modules while, on the other hand, using outdated phenomenological terminology as if the functions still were singular entities.

## **The vertical dimension of perception**

In the case of sensory-perceptive systems, the classical division, which goes back at least as far as the work of neurologists such as Holmes and Pötzl, is the distinction between spatial and object perception. Colwyn Trevarthen (1968), amongst others, coined this idea as the differentiation of two visual systems, one for identification of objects (What?) and one for their localization in space (Where?). In subsequent decades, the cortical basis for these types of processing in primates was described as dorsal and ventral pathways, and the interpretation was of two parallel, i.e. strictly modular mechanisms (Ungerleider and Mishkin 1982). In this particular aspect, recent reinterpretations of the ventral pathway as the substratum of perception-for-consciousness and the dorsal pathway of perception-for-action (Milner and Goodale 1995) changed nothing.

We would prefer to consider these pathways as different levels in the evolution of behavioral control (cf. Bernstein's, 1947, distinction between levels of spatial field and object action). Firstly, it is increasingly clear that a similar architecture can be found across several modalities. The division of dorsal and ventral streams is also found in acoustic (Scott 2005) and in somatosensory (Dijkerman and de Haan in press) systems. There is more similarity across modalities at each of these levels than between the levels within one and the same modality. The same principles govern egocentric localization in visual, acoustic, olfactory and somatosensory domains (Shipley and Rowlings 1971). The inter-modal integration of spatial perception is characteristic to processing in the midbrain, basal ganglia, limbic paleocortex and in parietal lobes. At first sight, there seems to be more modular organization within the ventral pathway. On closer inspection, each object category also evokes significant responses in regions maximally sensitive to other stimuli. Moreover, each category is associated with its own particular pattern of response, indicating that the representation of an object is not restricted to a region that responds maximally, but rather is distributed across a broader expanse of the cortex (Ishai et al 1999).

Our second argument against a modular interpretation of this major division of human perception is that both systems seem to be asymmetrically related. An undifferentiated spatial localization can be realized by many old subcortical structures including midbrain mechanisms. In contrast, object recognition and category processing is localized cortically. It usually needs more time, and is contingent on information resulting from the stage of egocentric spatial localization (Vecera and Palmer 2006; Velichkovsky 1982).

## **How many attentional systems?**

One possible reason for the asymmetry in relationships of dorsal and ventral streams could be the involvement of focused (or focal) attention in the object-centered types of processing. Although some identification tasks, such as that of familiar faces, can be performed when attentional resources are depleted, binding an object's features into a unique combination normally demands focal attention, in contrast to processing separate features and spatial localization (Treisman 2006).

The problem with attention is however that it seems not to be a single entity or process. In contemporary neurocognitive research, there are a number of relevant classifications, which can be interpreted in a modular but also in a multilevel manner. Michael Posner and his colleagues (see e.g. Posner and Dehaene 1994) find three species of attention, which they call Alerting, Orienting and Executive. While this distinction is supported by functional, neuropsychological, biochemical and, in the recent times, clinical and genetic studies, other authors elaborate on

different classifications. For instance, Carr's multilevel approach (2004) describes the lowest level as attention for monitoring environmental space. The next level is selective attention, in charge of choosing specific objects for deeper processing. At the third level, there is attention used in retrieving information from semantic memory. Of course, attention (and awareness, which has also been divided into a variety of forms) cannot be considered today as a kind of Cartesian *rex cogitans*: the term is simply an expression for a particular effectiveness of underlying neurophysiological mechanisms. The question is how many different groups of mechanisms could be behind such classifications. Are they reconcilable with each other and with the stratification of perceptual processing in two basic streams?

The functions of Orienting and monitoring space can be most simply attributed to the mechanisms of the dorsal pathway. There is no natural analogue to ventral stream processes in Posner's classification, while in Carr's theory (2004) this is undoubtedly the second level, i.e. the selection of an object for deeper processing. The three remaining groups of mechanisms do not naturally fall into a dichotomy of dorsal vs. ventral mechanisms of perception. First of all, Alerting is a kind of unspecific arousal mediated mainly by subcortical structures. As such, it has to be considered a prerequisite to any form of goal-directed activity, motor or mental. On the other hand, attentive retrieval from semantic memory and, in particular, metacognitive ('executive') control are clearly 'above' the perceptual processing represented by mechanisms of dorsal and ventral streams. Thus, the analysis of only two contemporary theories of attention leads to a differentiation of up to 5 groups of mechanisms loosely ordered along the vertical dimension of mind/brain functioning.

### **How many memory systems?**

Similar splitting of traditional concepts is currently seen in other domains of cognitive and neurocognitive science. With two higher-order forms of attention (for semantic retrieval and for executive control), we are in the realm of the cognitive 'central processes' once claimed to be devoid of any structure (Fodor 1983). Instead of being isotropic, they demonstrate a marvelous collection of functional subdivisions. Though it is by no means understood in detail, the overall picture seems to imply the evolutionary stratification of the mechanisms in question, especially apparent in the case of memory. This is perhaps the best example of how the logic of research leads us toward reinterpretation of data and theoretical models.

In the time of the computer metaphor, all forms of processing were "in memory", in one of several sequential blocks: very-short-term, short-term and lastly long-term. This "boxes-in-the-head" approach changed little in the modularity era, but many new, usually dichotomic divisions have been introduced, among them verbal/ nonverbal, procedural/ declarative, implicit/ explicit, semantic/ episodic. Memory system theories around the year 2000 often resembled descriptions of '2000 memory systems'. Once again, the emerging understanding is that firstly, some of these distinctions are more related than others and secondly, there is no single brain structure, which could be claimed to be one of the memory modules. In a sense, brain mechanisms, including that of the hippocampus, are multitasking genies rather than narrow-minded 'idiots'.

As an alternative, memory could be considered as imbedded in countless activities, which seldom and probably only in humans have a direct mnemonic character. Memory effects are then by-products of these non-mnemonic processes of developmental changes and episodes of task solutions. Whether the effects of memory testing are finally strong or weak depends on two things; firstly, the correspondence of structures activated at encoding and at retrieval, and secondly, the approximate location of these structures along the neuro-evolutionary axis. For example, self-referential encoding of verbal material leads, in a sudden memory test, to a better performance than an intentional memorization (Challis et al 1996). The reason for this is that the

personal encoding involves, in contrast to rehearsal, phylogenetically new prefrontal and orbitofrontal regions of the cortex with their massive projections to both hippocampi (Velichkovsky 2002).

### **Cognitive-affective neuroscience**

Close to the end of this essay, we do not intend to continue with considerations of human thinking and decision making where, at least, two different forms of processing have been described in the recent time: one very much resembling perception and another of more contemplating mode (Kahneman 2002). A modular interpretation of this distinction is possible but an evolutionary one is clearly preferable. Of interest in the present context is only that both forms of thinking are asymmetrically related to the whole *terra incognita* of affective and emotional processes, which has, of course, often been interpreted in an isolationist way, e.g. as the domain of ‘affective neuroscience’.

The idea that there may be distinct evolutions, one for a cognitive and another for an affective ‘part’ of mind/brain is, in our opinion, untenable. Therefore, the task for the future will be to reconcile these two areas of research on the basis of a common evolutionary framework (Davidson 2003; Panksepp 2000). It is an open question whether existing evolutionary psychology may be of great help in this endeavor, as it is interested solely in modular adaptations and in a relatively recent period of anthropogenesis. In the first place, there is insufficient empirical data. One of the most spectacular recent discoveries was the description of mirror neurons mediating imitation, and the understanding of actions and states of others (Rizzolatti 2004). Mirror neuron systems, which are often treated as modular pathways, are also involved in mediation of emotion. However, effects of emotional contagion seem not to be evoked in a straightforward modular fashion. We have recently found that these effects are strongly contingent on additional information about gaze direction (eye-to-eye contact), i.e. on a possible communicative interpretation of the situation (Schrammel et al in press). This finding may be particularly related to the key role of communication in development of human emotions (see Holodyski and Friedlmeier 2006).

The evolutionary aspects of our mental life – cognition as well as emotion – are as obvious and important for neurocognitive studies as they have been chronically neglected in the past. In these highly integrated matters, consideration of possible modular organization is of undoubted but preliminary value. Any advanced explanation will eventually be of one of the developmental kinds: phylogenetic, ontogenetic or microgenetic. It could be expected that with the further progress of human cognitive neuroscience, these explanations will often match each other, as nicely demonstrated in the neurolinguistic studies of Angela Friederici and her colleagues at the Max-Planck Society.

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