Adaptive cognition without massive modularity

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Abstract

Massive modularity theory has replaced classic, Fodorian modularity as a major focus of research within cognitive science. The massive modularity thesis posits that there are a large number of knowledge and action stories, designed in a piecemeal fashion over evolutionary time to solve specific, adaptive problems. We criticize massive modularity as a general theory of human cognition, with particular attention to the issue of context-sensitive perception, thought, and language. First, the experimental methods used to uncover individual modules are notoriously inadequate and fail to meet reasonable standards by which modules may be dissociated from one another. Second, input criteria, by which modules are presumably defined, may be impossible to discover given the context-embedded nature of human performance. Third, catalogues of experimental effects that are assumed to demonstrate the presence of modules do not constitute a comprehensive theory of the acknowledged interaction of brain, body, and world in ordinary cognition. An alternative conception of cognitive performance, based on principles of self-organization, better explains the embedded, context-sensitive mechanisms of adaptive cognition.

Keywords
adaptive cognition, massive modularity, relevance theory, evolutionary psychology, psycholinguistics

1. Introduction

The discovery of predictable behaviors in real-world and laboratory situations has led some scientists to posit functionally specialized modules of mind.

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Specific predictable behaviors originate in specific modules, which evolved for specific adaptive purposes. We critique this modularity thesis as a general theoretical framework for understanding human cognition, with specific attention to claims about massive modularity and context-sensitive perception, thought, and language. Our aim here is not to refute the importance of evolutionary considerations in theories of thought and language, nor to dismiss the important contributions of relevance theory, often cited in support of massive modularity, to our understanding of cognition and communication. However, we will argue that there are significant problems with the general idea of massive modularity, and therefore offer an alternative conception of cognitive performance based on principles of self-organization. Self-organization better explains the embedded, context-sensitive mechanisms of adaptive cognition and language use.

2. Fodor's modularity thesis

Consider for example the following brief conversational exchange between John and Mary as they walk along a California beach:

John: "Mary, look over there at those two men lying under the yellow umbrella."
Mary: "Oh my God, they are dinosaurs from the 1920s!"

John's task at this point is to create an interpretation of Mary's utterance that is sufficient for their personal and joint adaptive needs in context (e.g. John must recognize that Mary believes that the men on the beach are wearing very outdated swimwear). One aim of any interpretation of ostensive speech is to determine what the speaker's communicative intention was, in saying what he or she said. How listeners create interpretations of speakers' communicative intentions is a topic of great debate in the cognitive sciences. An important modular proposal assumes that people possess a dedicated language "module" that immediately completes a purely linguistic analysis of any speech input (i.e. the men are prehistoric creatures living in the 1920s), before other cognitive and contextual information is brought in to infer context-sensitive meaning (i.e. the men's attire is similar to the beachwear from the 1920s) (Fodor 1983). This modular perspective on language processing posits as well that linguistic knowledge is separate from general cognition, and that more specific modular separations exist between the lexicon and the grammar, syntax from semantics, and semantics from pragmatics. Under Fodor's view a module is a perceptual input system that has a number of characteristics, including being informationally encapsulated, unconscious, fast acting, mandatory in its operation, providing shallow output, localized in specific brain areas, innate,

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domain-specific, and exhibiting both ontogenetic and pathological universals. Modules were originally thought to be peripheral processes of language, perception, and motor activation, while central cognitive processes were assumed to be strictly non-modular.

Since the publication of Fodor's 1983 book, experimental psycholinguists and cognitive neuroscientists have considered the implications of this modularity thesis, particularly in regard to whether the language module is really informationally encapsulated and localized in specific brain sites. Most generally, the results of many psycholinguistics studies, focusing on topics such as lexical ambiguity resolution, sentence parsing, and pragmatic language interpretation have suggested that more interactive constraint-satisfaction models better account for the extant data than do strict modular theories (i.e. theories that typically predict serial processing during online linguistic interpretation). Interactive models specifically allow early access of top-down, including contextual, information during immediate linguistic processing. Within cognitive neuroscience, many studies have shown that damage to particular brain sites do not provide selective functional deficits, contrary to the predictions of a classic modularity theory (Elsabbagh and Karmiloff-Smith 2006). Many scholars have now claimed that language and cognition is better characterized in terms of dynamical interactions of brain, body and world than as a set of independent modules in mind (Gibbs 2006; Hollis et al. 2009; Spivey 2007; Van Orden et al. 2009).

Debates continue over different aspects of Fodor's (1983) original claims about modularity, in language processing particularly. But the move toward more interactive models of language parallels important new assertions in modularity theory that the mind is massively modular. Evolutionary psychology claims that evolution could only work if our cognitive and biological organization is modular, precisely because there would otherwise be no distinct targets for adaptive pressures. The massively modular mind comprises a large number of knowledge-and-action stories, designed in a piecemeal fashion (over evolutionary time) to serve specific, adaptively important ends. As the term *massive* implies, modules have been proposed specific to wide ranging domains, including face recognition, perception of emotion, friendship, rigid objects' mechanics, spatial orientation, tool-use, folk biology, semantic inference, specific food aversions, music, number and mathematical concepts, to name just a few. In a clear departure from Fodorian modularity, massive modularity allows that central and nested modules, such as a comprehension module working within a theory of mind module (Sperber 2002). And some scholars argue that virtually every human concept constitutes its own distinct module (Sperber 2002). Thus, modularity is spun out to become "a fundamental property of living things at every level of organization" (Barrett and Kurzban 2006: 628).

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Cognitive scientists who embrace massive modularity theory have different conceptions of what defines a module, and how modules are functionally and biologically organized to create human minds. Some proponents of massive modularity, typically within developmental and cognitive psychology, focus on the content or distinctive subject matter of individual modules (e.g. face recognition, number concepts, language, music), while others, mostly evolutionary psychologists, argue that modules are best defined in terms of their specialized adaptive functions (e.g. the ability to detect cheaters defends against loss of one's resources). Many massive modularity advocates retain some of the older Fodorian characteristics in which information encapsulation, domain specificity, brain location, and innateness are keys to empirically identifying individual modules, while other advocates offer looser characterizations of what constitutes modules and how these are functionally organized within the mind. We now consider several of these more radical views of massive modularity to explore implications for theories of human thought and language.

3. New ideas on massive modularity

Many advocates of the massive modularity thesis ground their thinking in an "argument from design," such as (Carruthers 2006: 25):

1. Biological systems are designed systems, constructed incrementally.
2. Such systems, when complicated, need to have entirely modular organization.
3. The human mind is a biological system, and is complicated.
4. So the human mind will be massively modular in its organization.

Cosmides and Tooby (1992) offered another version of this rational argument, which goes:

1. The human mind is a product of natural selection.
2. In order to survive and reproduce, our human ancestors had to solve a range of adaptive problems (finding food, shelter, mates, etc.).
3. Since adaptive problems are solved more quickly, efficiently, and reliably by modular systems than by non-modular ones, natural selection would have favored the evolution of a massively modular architecture.
4. So the human mind is massively modular.

Both these deductions assume either complex biological systems need have a massively modular organization or that adaptive problems are necessarily solved in modular outcomes. It is no surprise, then, that both arguments conclude the human mind is massively modular, given their starting presuppositions. Some empirical studies interpreted within the massive modularity frame-

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work do consider alternative, usually domain-general, hypotheses. But most studies within the framework entertain no other theoretical perspective on human performance, particularly, in our view, ideas about self-organized origins of language and thought, which need not stipulate massively modular organization. As we will later describe, self-organization offers a fundamentally different account of context-sensitive behavior.

Nevertheless, there are many empirical findings interpreted to support massive modularity theory, with the best overview of this work given in Barrett and Kurzban (2006). Barrett and Kurzban also defend massive modularity against various criticisms, most of which they argue apply exclusively to Fodorian modularity. They specifically argue that narrow information access is not a critical property of massive modularity, that modules need not be informationally encapsulated, that experimental demonstrations of information integration do not undermine modularity, that cognitive flexibility does not provide evidence against domain-specificity in human cognition, and that automaticity is not a defining property of modularity. They also defend massive modularity against several developmental arguments, including claims against innateness, strong nativism, novelty in development, and the assumption that modules necessarily require their own genes. Moreover, massive modularity theory, according to Barrett and Kurzban, is not contradicted by the rarity of perfect dissociations in cognitive neuroscience studies and does not require that modules be spatially discrete or located in specific parts of the brain.

Barrett and Kurzban (2006) clearly give up a lot when they reject all the traditional empirical characteristics associated with Fodorian modularity theory. Each of the above-mentioned corollaries was at various times in the previous quarter century seen as being supported by significant empirical evidence. But each body of positive evidence in favor of Fodorian modularity was eventually demonstrated to be unreliable or, as Barrett and Kurzban argue, irrelevant to a broader notion of modularity based on functional specialization. Thus, Barrett and Kurzban boldly acknowledge the failures of research associated with classic modularity theory and return to square one, in a manner of speaking.

But what kinds of empirical evidence provide support for the massive modularity thesis? For the most part, Barrett and Kurzban point to isolated empirical studies whose results are consistent with the idea that functionally specific modules, governed by some input criteria, are the primary causal bases of different human behaviors. They specifically propose a radically stripped down definition of modules in which input criteria are the sole reliable informational basis on which to define modules, To take one example, Barrett and Kurzban describe a study on economic game behavior in which participants allocate more money to an anonymous other when stylized eyespots are present on top of the computer screen, compared to a condition where the eyespots are not present (Haley and Fessler 2005). They interpret this finding to be

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"comprehensible from the perspective of modules designed to be sensitive to cues of social presence but not other theoretical perspectives" (Barrett and Kurzban 2006: 643). When a module causally directs an individual's economic behavior, it operates "on only certain kinds of inputs or to privileged inputs related to that function" (Barrett and Kurzban 2006: 643).

Right away, this interpretation of the empirical evidence raises several important questions. First, the incredible diversity of effects from both social psychology and cognitive psychology due to the presence of others—even the mere imagining of possible social others—makes it difficult to spell out in detail the actual input criteria for social presence. How does mere imagining the presence of others, for instance, without any explicit cues, such as eyespots, unlock the social presence module and provoke its operation? One answer to this question posits a kind of lock and key mechanism that equates input criteria with features of locks that entail the features of the input keys (Barrett 2005). As long as a specific representation (the key) is tagged as relevant to some design feature (the lock) of a module (e.g. information relevant to "social presence"), then that module will operate, regardless of whether its input is perceptual or abstract. Barrett (2005: 282) notes in this regard that "modules need not accept only perceptual cues as data; they can leverage the prior operations of other devices, and combine perceptual with contextual information."

Widening of the types of inputs that may trigger modules, however, works directly against the goal of spelling out objective criteria, to tie phenomena of social presence together and to their specialized module. As the number of input types grows, the chances of broadly realized input criteria shrink. Criteria appear more likely to be indeterminate. Worse yet, the data concerning possible input types, already considered, are no more likely to suit objectively specifiable input criteria than to be products of context-sensitive perceptual experience or cognitive imagination (for example, the mere imaginings in the case of the eyespot experiment and the social presence module). Perhaps this is why massive modularity scholars tend to identify input criteria with independent variables, intuited by scientists, which result in dependent effects in experiments.

Consider, for example, the systematic work of Cosmides and colleagues on content-specific intricacies in human reasoning, to specifically show how cheater detection modules and hazard management (i.e. precaution) modules possibly explain people's performance on a modified Wason selection task (e.g. Cosmides 1989; Fiddick et al. 2000). The content-specific effects observed in these studies refute several domain-general accounts of reasoning, such as relevance and deontic reasoning. But, yet again, the experimental findings do not reveal adequate input criteria to explicitly define the highly specialized cheater detection or hazard management modules. The "functional contents"

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of these modules only refer to experimenter intuitions about what experimental conditions and findings mean. Even if these intuitions are guided by important considerations from evolutionary biology and history on the possible ancestral problems of adaptation, the fact that people perform differently with different contents in the Wason task does not speak directly to whether different modules are responsible for participants' behaviors in these studies. That is just the forgone conclusion.

Identifying an experimental manipulation with input criteria only produces an explanation when the specifics generalize beyond the manipulation. This concern in no way detracts from claims about the relevance of detecting cheaters in certain reasoning tasks, or whether these data truly reflect adaptive problems faced by our ancestors. Rather, our point is that advocates of massive modularity invariably assign each experimental effect to its own very specific module—what some have described as the "effects = structure" fallacy (Gibbs 1994; Lakoff 1987), or the "module mistake" (Van Orden and Kloos 2003). The general consequence of this strategy has been a veritable explosion of modules being proposed within the broad cognitive science and evolutionary psychology literatures. On the surface, all this fits nicely with the idea of "massive" modularity but can equally well be criticized as a collection of "just so" stories drawn on tenuous links between experimental effects and hypothetical evolutionary principles. "Functional content" in such accounts does marginal work, and only in the just so story, not in actual input criteria or the workings that define the module. As others have aptly commented, "Many adaptationist arguments for higher-order cognition are mere consistency arguments. They lack even the power of retrodiction because they so easily accommodate conflicting and contrary adaptationist accounts" (Atran 2005: 57).

4. The crucial importance of specifying input criteria

Much of the empirical literature on massive modularity simply catalogues different experimental findings, as we have explained, which must rely crucially on specifying input criteria. However, there is new discussion among a few theorists, about the exact organization of modules in the massively modular mind that may require further, secondary, tertiary, or even higher-order specification of input conditions. For example, Carruthers (2006) describes an architecture of the mind in which, "modules are function-specific processing systems, which exist and operate independently of each other, and which have complex, but limited input and output connections with others. Each of these systems will have a distinct neural realization, and will be forged in its use of information, while having internal operations that are inaccessible to others. Moreover, the set of systems will be organized hierarchically so that all but the bottom layer of modules will be constituted out of other modules as parts. And

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then to claim that the mind is massively modular in organization means that it is composed out of many, many such systems" (Carruthers 2008: 294).

Under this view, similar to Barrett and Kurzban (2006; also see Barrett 2005), environmental information triggers the activation of specific modules, given the appropriate input triggering conditions. A module performs its proprietary computations, such as when seeing a human face triggers activation of a face recognition module, and then outputs its results to other modules both at similar and higher levels of the hierarchically arranged cognitive system. Thus, the outputs of some modules serve as inputs to other modules, requiring rich and busy junction points to support many indirect lines of connection. Eventually more central modules are triggered to produce domain-specific beliefs and desires, or products of more generalized reasoning. Ultimately, these more central modules produce appropriate cognitive and motor plans (e.g. consciously realizing that the human face you have seen is your brother and that you wish to say hello to him).

This kind of modular system has many complications, as Carruthers and others explicitly acknowledge. For instance, although one module cannot change the operation of other modules, it can search through and use the archives of other modules (the implied distinction is between input to a module versus the processing data base of a module). In addition, any individual module may be composed of sub-modules, and different modules may have sub-modules in common. Most importantly, the language module and some other central modules may integrate the outputs of different and otherwise distinct modules. The language module must deal with outputs from a wide variety of visual, auditory, and spatial modules, for example, regardless of their formats. Finally, even if modules no longer must satisfy classical Fodorian criteria, some or most modules will be domain-specific in their input conditions, innate, and encapsulated, nevertheless (also see Cowie 2008).

Many critics have raised questions about this new and massive modularity. First, this view does not explain how concepts emerging from different modules can be combined, which should be an important property of a combinatorial cognitive system. Thus, if a cheater detection module and a brother module do not feed into one another, how can we form a complex concept for a cheating brother? (Machery 2008; Weiskopf in press). Second, as we have already noted, although many modules have perceptual triggers, many in addition are part of the more central system of modules, which apparently lack identifiable proprietary triggers. The practical reasoning module can be triggered by almost anything, for example, from seeing a bottle of expensive wine about to roll off a high shelf, to the possibility of giving a talk at an upcoming conference (Cowie 2008). A computational process of mind that has neither proprietary subject matter nor proprietary triggers appears to lack any criteria for being distinguished as a separate module.

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How, then, might individual modules be empirically identified? Although Barrett and Kurzban (2006) rejected most of the classic criteria for identifying modules, they clearly accept that the appearance of double dissociations provides most reliable indicators of distinctions between modules. A double dissociation is observed when one module's empirical effects appear in circumstances in which another's are absent, and vice versa. For example, some scientists have postulated a dissociated (and missing) syntax module in Broca's aphasia that is not missing in Wernicke's aphasia, and a module associated with semantics that is dissociated (missing) in Wernicke's but not Broca's (two different circumstances of brain damage). These two dissociations together constitute a double dissociation. Effects in intact performance may also appear to doubly dissociate, and are equated with modules as well. Notably, a failure to find a double-dissociation need not be evidence against massive modularity, but "when double dissociations are found, this is strong evidence for modularity, and moreover, it can be used to make inferences about the design features of the modular system that dissociates" (p. 642).

Yet there are serious demonstrated flaws in the method of double-dissociation. Non-modular architectures, such as distributed neural networks, can produce selective dissociations when neural material is "lesioned" (Patterson and Plaut 2009). And other options are possible and plausible. For instance it is plausible that all living beings comprise strongly nonlinear complex systems (e.g. Solé and Goodwin 2000). A defining feature of complex systems is that qualitative changes in system behavior are induced at tipping points by minimal quantitative changes in system parameters, which can result in double dissociations (Van Orden et al. 1997). A tiny change in a control parameter of a 'toy' neural-network, at a tipping point, will likewise change the qualitative outcome of its macro-level behavior—no components need be lost or gained in this qualitative change; extant components simply reconfigure their dynamical interaction. When access is lost to abstract regions of the model's behavioral state-space, its dynamical repertoire is reduced. Thus dissociations are readily produced in systems that do not have functionally specified components (Farrar and Van Orden 2001; Kello 2003). It should come as no surprise then that generations of false positive dissociations and double dissociations have been outed in the literature of cognitive psychology and neuropsychology (Van Orden et al. 2001).

Behavioral dissociations are not sufficiently constraining, as evidence, to decide among theoretical frameworks. Thus to view double dissociations as unequivocal evidence for modules begs the question of modularity (Shallice 1998). The attributive logic that equates dissociations with modules simply and strictly requires that modularity is true before the fact. A related concern is that perhaps any distinction can be dissociated in human behavior or in the behavior of brains. Cognition and behavior may be indefinitely dissociable, in

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which case dissociative and subtractive methods cannot fail to confirm any modular intuitions (Van Orden and Paap 1997).

Barrett and Kurzban's (2006) advocacy of double-dissociation is neither convincing nor reassuring on these points, and our concerns are also widely acknowledged in functional neuroimaging, which relies heavily on dissociative and subtractive methods (e.g. Noe 2009; Roskies in press; Uttal 2007). Reliable exclusionary criteria could perhaps weed out misleading dissociations. However, without well-defined criteria, each scientist's intuition (about evolution, computation, language, the brain, or whatever) will decide whether brain or behavioral data count as evidence for one module or the other, and there lies the problem—different scientists entertain contrary and idiosyncratic intuitions. Thus we are left with no means to distinguish modules except details of input criteria, which are not yet forthcoming. This means simply that the goal of describing reliable input conditions is crucial.

5. The problem of embedded modules

Even more problematic for the goal of specifying input criteria, however, is the proposal that many modules are embedded within one another. A cheater detection module, for example, exists within a social exchange module, which is itself embedded within a social presence module, and that module is likely further embedded in other modules associated with the perception of conspecifics. Yet there is no empirical test described in this literature, as far as we know, to corroborate a causal effect of one embedded module (e.g. detecting cheaters and only detecting cheaters) independently of effects of other modules (e.g. noting the presence of others, imagining the presence of others) within which the module of primary interest (e.g. cheater detection) is presumably embedded. Instead, individual studies show the effects of different, though closely related, experimental manipulations in human performance, and from this theorists have postulated that different, yet closely related modules must also exist. From this starting point, massive modularity theorists, such as Carruthers (2008), have claimed that modules are deeply embedded.

We find again, as we have throughout this literature, the stark silhouette of missing evidence. We lack altogether empirical justification to motivate modular distinctions, other than effect = module. But one may too easily find an indefinite "massive" number of empirical effects and dissociations, with respect to aspects of mind, task, and context, which all influence people's cognitive and linguistic performance. Such demonstrations by themselves supply insufficient motivation to posit distinct modules, to explain often task-specific behaviors. Lacking evidence, massive modularity has been justified exclusively in modularity assumptions before the fact, plus just-so stories after the fact.

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Consider another different example of the embedding of modules in massive modularity theory. One proposal suggests that language understanding is accomplished, partly, through the activation of several modules, most notably *default semantics*, *relevance comprehension*, and *theory of mind* modules, with each of these having close connections to the more central language module (Capone 2009). The default semantics module derives purely semantic representations of words and utterances, and stores these representations in an archive. Evidence presumably favoring the existence of the default semantics module is the fact that people easily understand a conventional figurative statement like "John kicked the bucket," meaning John died. People may simply access this meaning from the default archive, without necessarily needing to first reject the literal meaning via the relevance comprehension module.

Relevance comprehension modules emerged, according to Sperber and Wilson (1995), from the evolutionary transformation of human cognition to maximize the relevance of the information processed. Sperber and Wilson specifically describe a presumption of "optimal relevance" (Sperber and Wilson 1995: 270): "(a) the ostensive stimulus is relevant enough for it to be worth the addressee's effort to process it;" and "(b) the ostensive stimulus is the most relevant one compatible with the communicator's abilities and preferences." One implication of optimal relevance is a trade-off between cognitive effort and cognitive effects. Cognitive effects are achieved when a speaker's utterance strengthens, contradicts, or denies an existing assumption, or when a speaker's utterance is combined with an existing assumption to yield some new cognitive effect. In the tradeoff, listeners will attempt to maximize cognitive effects while minimizing cognitive effort.

The relevance comprehension module specifically operates on its input in the following manner:

a. Follow a path of least effort in computing cognitive effects: Test interpretive hypotheses about disambiguations, reference resolutions, implicatures, etc. in order of accessibility.
b. Stop when expectations of relevance are satisfied.

Various findings from both linguistics and psycholinguistics are quite consistent with the idea that speakers and listeners strive to achieve some degree of optimal relevance in discourse (Gibbs and Bryant 2008; Gibbs and Tendahl 2006). Listeners, in particular, appear to follow a path of least effort when inferring speakers' communicative intentions. But these data speak more clearly to the issue of relevance than to modularity. They do not necessarily support the claim that a "comprehension module" operates in some independent manner, with its own priority input criteria, during ostensive inferential communication.

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Finally, the theory of mind module supplies listeners with beliefs about specific mental states of speakers on the basis of speaker's linguistic and nonlinguistic behaviors. For example, in our opening example, Mary's metaphorical comment about the men on the beach, "Oh my God, they are dinosaurs from the 1920s," aims to alert John that she believes that the men's beach attire was quite outdated, and similar to that worn during the 1920s. Fodor and others had argued previously that *general* mind-reading abilities can be applied to each particular domain, in this case linguistic understanding. In contrast, Sperber and Wilson (2002) posit that a specialized comprehension module is dedicated to the complications of linguistic interpretation. Therefore, the relevance comprehension module constitutes its own unique module.

One reason offered for the possible existence of separate default semantics and relevance comprehension modules is that if there is ever damage to the default semantics module, then the relevance comprehension modules can take over some of its functions. These two modules are triggered by inputs from a common bulletin board, including information from the language module, and send their outputs back to the same central module for further elaboration and action (e.g. to determine what a listener should say in response to something that he or she just understood). The default semantics module is considered to be a specialization of the relevance theory model, which was ontogenetically related to it but was then partitioned and became autonomous to some extent (if not for the fact that both modules have connections to the central bulletin board module).

Unlike older, serial models of linguistic processing, the above modular characterization does not assume that semantic information from the default semantics module is first computed and then output for use by the relevance comprehension module to infer context-sensitive, pragmatic meaning. The relevance comprehension module may, in fact, possibly output information that is then used by the default semantics module. But once more, we have a theoretical account that demands the existence of various independent modules of mind, yet does not provide a concrete explanation of how these modules work together. Even if various sources of linguistic and nonlinguistic information are computed and output to a central module, it is unclear what the central module does to create interpretations that are deemed sufficient to satisfy expectations of relevance.

But more critically, the above account of language processing, on the surface, remains unable to describe the sufficient input conditions necessary to trigger each modular system, enough to define one module as being uniquely different from another. Moreover, we still do not know how context, within a massively modular theory, operates to direct linguistic processing (e.g. does it shape the activation and operation of individual modules or simply decide after the fact what outputs are most relevant?). Sperber (2005) has considered these

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problems and offered several speculative ways to deal with context sensitivity. He acknowledges that modules are not mandatorily triggered by specific input conditions unless they are first made available to be triggered by context. For example, each of us may have a face recognition module or even a sub-module for each person we are quite familiar with. But this does not guarantee that we can immediately recognize the face of each person we know. If you come across your dentist in a rather unexpected context, sitting in the front row of a public lecture you are giving, it may take some time to make the connection. Not all modules are mandatorily triggered given appropriate and available inputs, which nonetheless satisfy input criteria.

Modules only perform their functions and output their products depending on "whatever else the mind/brain is doing" (Sperber 2005: 134). Accordingly, there must be some flexible energy allocation process to ration the sufficient resources necessary to perform module's functions (i.e. attention). Efficient allocation is essential to invest energy sparingly and still process the right inputs. Most generally, modules whose inputs have high cognitive import in the history of the species should receive resources, as well as those that pertain to an area of stable interest developed by an individual, and finally those modules whose inputs are relevant to ongoing cognitive processes have a greater claim on energetic resources. From this point of view, competition for resources among modules is more likely to produce positive results than a central specialized device. As Sperber (2005: 135) argues, "The system as whole exhibits context sensitivity through the allocation of energy among modules." Finally, Sperber speculates that the regulation of effort in cognitive processes is achieved by non-cognitive brain processes that are largely genetically specified.

We applaud Sperber's suggestion that understanding the context-sensitive dimensions of language and thought demand a serious consideration of what the mind/brain is doing as a whole. Massive modularity theory has, otherwise, consistently failed to consider "whatever else the mind/brain is doing." In our view, it is this failure which has led this theory to posit so many modules or modular systems, simply because human performance is different in different empirical tasks. Indeed, there may be no need for modules of language and thought because the human capacity for self-organizing can create context-sensitive behaviors, obviating the mass of entrenched overspecialized mental representations.

At least one massive modularity advocate briefly entertained this idea and suggested that language comprehension, as it unfolds in communication might create local comprehension modules "on-the-fly" where encapsulated conditions are continually modified as the conversation continues (Carruthers 2008). But the possibility is immediately rejected for the following reasons, which reveals important insights into why massive modularity has evolved to its current state:

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"Cognitive science, like any other science, is in the business, inter alia, of discovering and studying the properties of the set of natural kinds within its domains. And a natural kind, in order to be a worthwhile object of study, must have a certain sort of stability, or regular occurrence. In contrast, the state of a competition system that has undergone a specific conversational history, and hence that has a particular distribution of degrees of accessibility among its representations, is something that might exist just once in the history of the universe, that particular combination of processing principles and accessibility (yielding the 'processing data' because of the on-the-fly module) might never recur again . . . If cognitive science is to attain the sort of generality that one expects of a science, it needs to carve its kinds at recurring joints" (Carruthers 2008: 16).

Yet the search for the "recurring joints" in nature typically does not take into account what a system is doing as a whole and ignores the possibility that regularities in human cognition may arise from self-organization, as a whole, rather than independent modules in mind. Carruthers's dismissal of emergent regularities in human cognition offers a completely circular argument, all in an effort to bolster the scientific credibility of massive modularity theory.

6. The situated, self-organized nature of adaptive cognition

Our alternative to massive modularity theory seeks to explain both the regularities and context-sensitive variations in human performance, across different experimental tasks and real-world situations. We claim that adaptive behaviors are self-organizing and so require no functionally pre-specified modular mechanisms. Complexity theory, as developed in the physical and biological sciences, recognizes that nature is composed of many interacting subsystems demonstrating strong tendencies to self-assemble or self-organize the behaviors of individual organisms as well as groups of living organisms (e.g. Bak 1996; Bassingthwaighte et al. 1994; Camazine et al. 2003; Depew and Weber 1995; Hooker 2009; Kauffman 1993; Prigogine 1997; West 2006; Zewail 2008).

Any system can be said to self-organize whose structure is not imposed from outside forces or from internal blueprints alone (e.g. internal mental representations). Self-organizing systems are capable of creating new structures because their components' linked dynamics are dominated by these interactions instead of by activity of isolated components. Emergent mechanisms are temporary, or "soft-assembled," because they go away when a dynamic linkage changes sufficiently; they have no separate off-line or dormant status in the components of a system as hard-assembled modules. Soft-assembly operates in a highly context-sensitive fashion, within particular environmental niches, to create the very specific physical patterns and behaviors of living systems.

Consider the example of traffic patterns on freeways. These patterns are not imposed by some external agent or force (they are autonomously given), ex-

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hibit moments where traffic flows easily and then bottles up into traffic jams (exhibit nonlinear stabilities and instabilities over time), are influenced by roundabouts, traffic signs, and weather patterns (basins of many "attractor" stable patterns within the system), comprise fast-occurring local interactions among several cars at the same time that slower developing large-scale patterns of traffic flow over an entire city (comprise several hierarchical levels each operating on its own time-scale), as larger scale freeway paralysis emerges from very few smaller interactions among just a few individual cars (as global patterns emerge from local interactions among components), and the emergent structure of a traffic jam decides when individual cars must stop and go (demonstrating top-down constraints on the behaviors of component processes).

Similar to explaining the patterns of traffic jams, a self organizational approach to human behavior maintains that different regularities and instabilities unfold over time according to particular types of constraints on dynamics. Complexity theorists aim to study such behaviors or perceptions by looking at the points of sudden transition between them—the moments at which one coherent behavior or percept gives way to another. They use mathematical tools to describe such strongly nonlinear changes. More specifically, the behavior of a system over time (e.g. repeated measurements of a brain or body or world, within a brain, body, and world interaction) is represented as a continuous tracing of a line trajectory in a multi-dimensional space with the controlling parameters represented on the different axes. As a system changes states over time, it traces a trajectory in its phase space landscape—a path of the successive phases it occupies. Much of the emphasis in the study of human perception, cognition, and language adopting a dynamical view has focused on the structure of phases of possible behavioral trajectories and the internal and external constraints (i.e. couplings among brain, body and world) that shape how these trajectories unfold. When a system's behavior is observed over an extended period, it sometimes happens that certain regions of the phase space are frequently occupied, some others occasionally so, and many others never. The areas of phase space the system occupies or approaches more frequently than others contain attractors. An attractor exerts a kind of pull on the system, bringing the system's behavior close toward it.

Living systems have "massively" multiple attractors shaping behavior at any one time. Once again, the flow of traffic along a freeway may be constrained by multiple attractors, of varying strength, including habitual idiosyncratic behaviors of individual drivers like tailgating the cars in front of them, as well as physical and social structures that limit the rate of traffic flow such as weather conditions, roundabouts, traffic lights, and signs indicating speed limits. The massive ensemble of available attractors represents transient areas of stable repeated behaviors, of varying degrees, which emerge through self-organizing interactions among the system's component processes. The shift

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from one attractor to another, on the other hand, is called a "phase transition," "phase change," or "bifurcation." Although a system's trajectory typically approaches different attractors periodically, as in a commuter's typical day, the system is never fully captured by any of them—a state of affairs called metastability. Plotting the behavior of such a system over time shows a tendency to move abruptly, and often unpredictably, toward one and then another region of attraction. In fact, the majority of the trajectory's time is spent in such regions of attraction. From a dynamical point of view, metastable phase transitions are the heart of cognitive flexibility. They are essential to explain how living beings, alone or together, can both engage and disengage adaptive, flexible, context-sensitive behaviors. Cognitive and behavioral scientists have variously applied these ideas (e.g. Adamatsky 2005; Goldfield 1995; Guastello et al. 2009; Kelso and Engstrøm 2006; Larsen-Freeman and Cameron 2008; Spivey 2007; Tschacher and Dauwalder 2003; Ward 2002).

Some work has gone so far as to describe differential equations and how different potential functions capture the long-term dynamics of a participant's performance (e.g. Kelso 1995). Potential functions describe an attractor landscape, which at different times for a participant, can reflect trade-offs of relatively stable versus unstable states of behavior. An early, classic set of experiments demonstrated self-organization in human action by asking participants to move the index finger on each hand in one of two ways (Kelso 1984). First, participants moved both fingers in the same direction, back and forth, similar to the way most windshield wipers move together, first to the right, then to the left ("180° phase" movement). When participants were required to speed up the oscillation, to the point where they were moving fingers back and forth as fast as possible, they spontaneously changed to move their fingers in phase (like windshield wipers that meet in the middle of the windscreen). The spontaneous shift from one (180° phase) pattern of finger wagging to its opposite (0° phase) of finger wagging, demonstrably constitutes a phase transition, satisfying the same list of complicated criteria as phase transitions in non-living physical systems.

Self-organization does not only occur within individual minds and bodies, but also shapes the behaviors of groups of individuals. For example, one study looked closely at this, using two people sitting next to one another in rocking chairs. Intrinsic rocking frequencies of the chairs were manipulated by positioning weights at the base of the chairs (Richardson et al. 2007). Participants observed each other's chairs or looked away from one another. Most interestingly, when participants looked at each other, they soon settled into a dynamic of rock synchronously, even when the natural frequencies of their chairs differed. Thus, people unknowingly rocked against natural frequencies in order to reach synchrony, an example of temporal self-organization, producing an emergent temporal structure, instead of some internal executive representation.

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The kind of dynamic coordination seen in the finger wagging and rocking chair studies stem from the biomechanical and physical constraints that naturally, and nonlinearly, couple together different limbs of the body, or of two bodies in close proximation. In each case, the stability in behavior that emerges cannot be reduced to properties of the components, which counts out internal motor programs. Instead, self-organization in behavior, which includes the transition from one stability to another, as well as new forms of stability, arises from the interplay of brain, body, and environment as a single "context-sensitive" system. For instance, other work has examined cognitive performance in laboratory environments, as a whole context-sensitive measurement system. This work looks at trial after trial temporal coupling within cognitive experiments, tracking temporal patterns that emerge across an individual participant's sequence of response times or accuracy, spanning all the trials of the experiment (e.g. Gilden 2001). Close examination of changes, trial by trial, across the repeated measurements, reveals characteristic dynamical signatures that actually gauge the coupling between task and person (e.g. Kello et al. 2007; Wijnants et al. 2009).

Just as for the dynamics of individuals in rocking chairs, spatiotemporal and cognitive constraints emerge in the pacing and structured sampling of cognitive activities in commonly used laboratory tasks. Constraints in this case refer to the relations between persons and the tasks that they do. Among other things, for instance, the visibility of a stimulus and where it is presented, the trial pace at which the person must respond, the specific difficulty of the decision or judgment in a task trial, and the cognitive state at the moment of the trial, can be considered, all with respect to the specific participant at that moment in time, in the experiment. Naturally, each person's immediate cognitive state, unique knowledge base, and embodied skills will determine her capacity to meet each trial's challenge, and produce successful and effective performance, trial after trial. Consequently, a patterned oscillating graph of the repeated measurements, ordered across all the trials, can reveal the specific quality of the coupling between person and task. Remarkably, the kinds of coupling already discovered reveal changes due to development, skill acquisition, comfort zone, well being, aging, disease, and motivation. And they do so because "effects" of these factors change interdependently across time, obviating "modular" independence (Hollis et al. 2009; Van Orden et al. 2009, are reviews).

7. Context-sensitivity in ordinary language use

It may come as no surprise, in this essay, that conversation also provides a range of phenomena that may be best understood in terms of dynamic

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coordination. Consider, again, our opening example of John and Mary walking along the beach when Mary states, "Oh my God, they are dinosaurs from the 1920s!" What may have shaped Mary's "decision" to metaphorically describe the men on the beach as "dinosaurs"? Of course, there are many possible theoretical answers to this question, including the idea that communication, of any sort, can be characterized as the alignment of conceptual representations (Garrod and Pickering 2004), or from adhering to cognitive and communicative principles of optimal relevance (Wilson and Sperber 2004). Under both these views, people's apparent coordination in speaking and understanding is partly a matter of their accessing the right conceptual information about the upcoming gestures, words, syntax, intonation, gaze, or posture to use in context.

Yet there is much research from psycholinguistics that demonstrates the emergent, implicit coordination between people in terms of their speech, prosody, gaze, posture, gestures, and body positioning during conversation, and which recommends a primary role for shared constraints and soft-assembled interpersonal coordinative structures (Shockley et al. 2009). The primary difficulty of traditional representational views, however, is that they remain unclear about how different levels of linguistic and physiological activity become coordinated to produce coherent, meaningful behavior. How might lower-level aspects of speech rhythm and body sway, for instance, shape higher-level aspects of word choice, syntax, and thoughts, and vice-versa? A self-organization perspective claims that interpersonal coordination, including that taking place in conversation, is all about emergent coordinative structure in which all aspects of dynamics of each body and brain may come together to more closely mimic the other, as the two systems come to change and behave as one (Fowler et al. 2008).

Most importantly, soft assembled processes need not commit immediately to a single conceptual organization, so long as multiple organizations are equally supported. Ambiguity in this sense is equivalent to instability and uncertainty. Thus, in John and Mary's conversation, John's previous statement "those two men lying under the yellow umbrella" places the conceptual focus on what 'makes them worth looking at.' In addition, the men were wearing very outdated swimwear, which greatly limits the range of expressions that Mary, being Mary, might offer in reply. Yet a range of options remains. Mary could have said "extinct lizards" or "fashion catastrophes" or "museum pieces" or many other things to make the same point about the 1920's bathing attire. Mary's subsequent choice of the metaphorically used word "dinosaurs" reflects the exact brain, body, and world contingencies of the moment. Although we as scientists, and maybe as friends of Mary, have some access, possibly reliable access, to the constraints that exist before she says "dinosaurs," we have no access to the precise contingencies that enact the word "dinosaurs" in

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the very moment when it is spoken. We can, nonetheless, offer a statistical model of how those possible contingencies arise, and interact, according to the principles of self-organization to explain Mary's speech behavior, without postulating the existence of modular mechanisms.

A variety of other experimental research in psycholinguistics has explored the continuous but context-sensitive dynamics of self-organization in ordinary language use. For example, speech perception is an adaptive behavior that is often advanced as an ideal case for modularity. But speech perception studies also provide excellent evidence on the shift from one stable percept or behavior to another, and back again, and the instability that makes this possible and is endemic in human performance. For example, one can build a continuum along an acoustic dimension with different stimulus words as the stable end points, such as "say" and "stay," and explore the unstable category boundary along this continuum.

The continuum is constructed on the duration of a brief gap of silence that distinguishes "say" from "stay." Minimize the gap (0–20 ms) and every instance sounds like "say;" greatly expand the gap (60–80 ms) and every instance sounds like "stay." For any constructed continuum and any listener that is tested, there will be critical values of the gap between 30–50 ms at which perception of "say" switches abruptly in quality to perception of "stay." The details of this demonstration of categorical perception are more readily explained as a "sudden jump" within the framework of dynamical systems in which the nonlinear interplay of context and stimulus dimensions create, or soft-assemble, the behavior we see as a dynamical category boundary (Tuller 2005). For example, hysteresis is observed when the critical transition from "say" to "stay" is delayed and pushed to longer gap durations, because previous experimental trials presented minutely different gap durations that change incrementally from direction of "say" and toward the direction of "stay."

Hysteresis is not a statistical kind of uncertainty but a kind of dynamical instability that can amplify available context and constraints. Thus, if the incremental changes are reversed to progress from "stay" to "say" then the critical transition is pushed to shorter gap durations. But changing the available constraints can also turn hysteresis into its opposite dynamical signature, a contrastive effect, in which the sudden jump from "say" to "stay" (or vice versa) is not delayed but comes extra early. For example, incrementally changing stimuli in sequence will now pull the category boundary toward the "say" end of the continuum so that the "say" perception loses stability earlier and transitions sooner to people perceiving "stay" (or vice versa if the order of presentation is reversed).

Viewed as a problem of self-organization, stimulus dimensions in speech perception have a Necker cube quality with ranges of ambiguity or instability

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that can be closely studied for nonlinear interactions among mind, body and world. Moreover, the sudden jump in Necker-like perception in "say/stay" has been corroborated as a simultaneous qualitative change in different recordings of the central nervous system. These findings illustrate how context-sensitive qualitative change in the dynamical patterns of the nervous system coincides exactly with the context-sensitive qualitative change in speech perception (Kelso 1995).

Consider another instance of context-sensitive self-organization in speech perception. If speech perception is modular, then it should be possible to specify input criteria for the atomic units of speech perception in the transduced speech signals that become meaningful speech. But the salient units of speech perception may emerge from the specific contexts in which speech is used, and not as invariant input units to a fixed speech perception module. For example, one set of experiments had participants, naïve to the real intent of the study, enact scripted performances about producing speech or examining speech (Goldinger and Azuma 2003). When participants enacted speech as in a play, they produced speech that changed the relative salience of phonemes versus syllables, simply because the script dictated them to do so. But when participants had to act as scientists and analyze recordings of the previous speech as stimulus inputs, they confirmed that syllables were the primary unit of speech.

Speech perception appears to fluidly accommodate task demands even at the causal interface of speech input, which allows context to be constitutive of perceived speech. The critical ratios of constraints that define boundaries in speech perception "adjust flexibly with factors such as phonetic context, the acoustic information available, speaking rate, speaker, and linguistic experience" (Tuller 2005: 355). These demonstrations of self-organized speech perception are not rarified experimental phenomena, but laboratory analogs of the flexible perception required to recognize the same word produced by males, females, speakers of different ages, and with different dialects and accents and by the same speaker in markedly different linguistic and intentional contexts. It makes little sense, then, to try and delineate input criteria for a speech perception module because different units of speech emerge in different contexts according to self-organizing principles. This conclusion would explain why massive modularity has yet to specify any input criteria, despite their central role both empirically and in massive modularity theory.

Several studies have explored self-organization processes in online sentence processing. One program of research has examined people's interpretation (i.e. grammaticality judgments and reading time) for syntactically garden-path sentences (e.g. "As the author wrote the book describing Babylon grew") and demonstrated "digging in effects" in which early commitments to the wrong syntactic analysis make it harder to reanalyze what these sentences mean (Tabor and Hutchins 2004). These "digging in effects" arise from self-

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organizing processes in which each word encountered gives rise to a set of attachment sites that interact with the attachment sites generated in perceiving other words. The interaction between the varied attachment sites allows the system to relax into a state where all the various syntactic and semantic constraints are optimally satisfied. Most generally, a self-organized view of syntactic processing both accounts for the continuous dynamics of sentence comprehension, and does so in a way that requires no overseeing mechanisms to decide which is the right analysis to give to any sentence.

A different application of dynamical systems to language processing examined people's understanding of category exemplars in sentence contexts (Rącaszek-Leonardi et al. 2008). Consider the sentence "The mouse was eaten by the bird even though it tried to hide". How do people infer that the "bird" in this sentence refers to an atypical member of the category such as "eagle" and not a common, typical member like "sparrow" or "robin"? People heard sentences that were either neutral (e.g. "The food was ate by the bird even though it was not xxx"), or biased (e.g. "The mouse was eaten by the bird even though it tried to hide") in their prompting of a category word (e.g. "bird"). As they heard the sentences, participants were visually presented a probe word at 0, 450, or 750 after the offset of the category word. These probes were either typical exemplars of the category (e.g. "robin") or atypical members of the category that were, nonetheless, appropriate to the sentence context (e.g. "eagle"). People made speeded lexical decisions to the probes words. Analysis of the response times to contextually relevant but atypical probe-exemplars did not decrease until 450 msecs after hearing the category word. Somewhere between 300 and 450 msecs, after hearing a word like "bird," the instability arising from multiple available patterns leads to a rapid reorganization, creating a contextually relevant interpretation for "bird." This cognitive reorganization occurs in a fashion reminiscent of a phase transition (i.e. in a change of stability), and it is not accomplished through a linear search among category exemplars within a modular lexicon.

8. Language and cognition

Self-organizing principles appear to scale-up and account for many higher-order cognitive performances. For example, one study investigated whether people's verbal reports about imagined action can be explained without appeal to representational structures (Van Rooji et al. 2002). While standing in one spot, participants were handed rods of different lengths that they then held at an upward 45-degree angle. The participants' task was simply to say whether they could use that rod to touch a distant object. Across a series of trials, the rods presented to participants increased in length and then decreased, or

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decreased in length and then increased, or were presented in randomly ordered lengths.

Determining whether a rod can reach an object involves assessing information on the rod's length and one's bodily abilities (i.e. one's posture, ability to lean forward with feet planted on one spot, arm length and so on), which combine nonlinearly in a dynamical account. In fact, the results of Van Rooji et al. (2002) showed the hysteresis pattern of nonlinear dynamics in the ordered, but not the random conditions. First, participants tended to give the same categorical responses in the random sequence condition. This assimilative effect coincides with the expectation that a dynamical system tends to cling to the state it resides in. Second, there was an inverse relationship between rod length and probability of "yes" responses. This contrastive effect was enhanced when the coupled sequence ran from shorter to longer rods rather than the opposite, exactly what is expected if the unstable ambiguous ("multistable") region is relatively large here. Finally, the three nonlinear dynamic patterns—hysteresis, critical boundary, and enhanced contrast—were all observed, though to different extents, in each participant's behavior across the trials of the experiment.

These data are consistent with a dynamical account in which the participants' imagined actions arise from the interplay within a "control parameter" (a parameter that leads the system through various attractor landscapes) and a "collective variable" summarizing dynamics of the entire system. These parameters are not represented internally; they are soft-assembled, but determine an "imagining landscape" that is an emergent property of the entire embodied system. Van Rooji et al. argue that it is difficult to imagine how a traditional representational theory, such as a modular account, could explain the dynamical patterns observed in participants' task-behaviors, given the complexity of having to integrate different internal mechanisms that are usually postulated for each finding (i.e. the problem of integrating hysteresis, enhanced contrast, and critical boundary within a single mechanism). Nonetheless, these complex patterns are predicted before the fact by the more general dynamical model of self-organizing behavior.

Imagine now a different "quintessentially cognitive phenomenon" where a person is asked to solve the following problem (Stephen et al. 2009). Participants were presented with a static display of a complex gear system and asked to predict the movement of a target gear given the clockwise or counterclockwise turning direction of the driving gear. As participants tried to solve this task, their eye movements and finger motions (as they traced their fingers along the computer display of the gears) were monitored. Early on, participants solved the problem by manually simulating the forces of the gears (i.e. tracing their finger along the gears' edges on the computer). But later, most of the participants spontaneously discovered a mathematical parity solution to the problem by tracing alternative gears on the display. This adoption of a new strategy

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was preceded by critical fluctuations in participants' finger and eye movements (and other nonlinear criteria), indicative of a phase transition.

Solving gear problems according to dynamical principles differs considerably from other approaches in which the informational or semantic content of the system has the sole causal power to affect behavior. At the very least, though, the dynamical account is straightforwardly consistent with cognitive processes that unfold over time. The dynamical account also explains the creation of new structure (i.e. it resolves a well known conundrum of representational accounts), and predicts the details of the transition from one cognitive state to another. Of course, it does all this without internal blueprints, or modules, previously presumed to be the driving, causal basis for behavior.

Lastly, decision making can also be explained as a self-organizing process. When making real life decisions, of large and small consequence, people often experience the sense of being pulled in different directions at once. McKinstry et al. (2008) have demonstrated that this impression has some literal truth to it. Participants in one experiment were asked questions like "Is murder sometimes justified?" and moved a mouse to click on their chosen response box as quickly and accurately as possible. Even though people always gave a specific response, an analysis of their mouse trajectories and their deviations, while moving toward the different response boxes, revealed a degree of cognitive uncertainty when making the decisions. The simultaneous "pull" from different response alternatives, in thinking about whether murder is sometimes justified, for example, influences the executed trajectory of their mouse response. The finding suggests that decision making need not necessarily be complete, in some specialized cognitive subsystem or module, before the output is shared with other subsystems, including the periphery of the body's actual motor response. Instead, like all the cognitive activities we have discussed, decision-making may self-organize according to dynamical principles, constrained within the on-going interactions among brain, body, and world.

We have reviewed only a small part of the large experimental literature on situated, self-organizing processes in human perception, language, and cognition. Our aim, once again, has been to demonstrate how principles of self-organization may account for the continuous dynamics of human performance, giving rise to both stability and instability in a wide variety of laboratory and real-world behaviors. The conceptual tools of dynamic systems theory offer new ways of conceiving of how people come to engage in adaptive behaviors, ranging from perception and action up to language and higher-order cognition, without postulating systems of independent, internally represented modules. Self-organization may occur within an individuals' mind, and also among a group or population of individuals, as when clusters of shared beliefs and other cultural norms emerge among individuals to influence the selfsame individuals (Gibbs and Cameron 2007).

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9. Conclusion

Our analysis of massive modularity raised several significant problems for this perspective as an empirically informed, comprehensive theory of human cognition. First, the experimental methods used to uncover individual modules are notoriously inadequate and fail to meet reasonable standards of evidence by which modules may be dissociated from one another. Second, input criteria, by which modules are presumably defined, may be impossible to discover given the context-embedded nature of human performance. Third, catalogues of experimental effects that are assumed to demonstrate the presence of modules do not constitute a comprehensive theory of the acknowledged interaction of brain, body and world in ordinary cognition. Part of the difficulty here is that standard experimental studies of modularity employ methods that seek only changes in average performances on different trials or tasks (a very simple dynamic), and typically randomize stimuli, eliminating sequential effects that are revealing of more complex dynamics.

These problems for massive modularity theory at the very least present challenges, yet to be overcome, for this theory of both the regular and context-sensitive aspects of human behavior. Both evolutionary psychology and relevance theory, two foci of our discussion, have important contributions to make to cognitive science. But adaptive cognitive performance seems to us to be a phenomenon of self-organization involving the continuous nuanced interaction of mind, body and world. This alternative position is not simply a retreat from positing domain-specific to domain-general properties of mind, because self-organization is not about causal, internal representations, or functionally dedicated processes. Instead, the locus for control of cognitive activity only emerges and thus resides within the interaction itself, which coordinates mind, body and world. Control does not reduce to elements of this triad, plus interactions.

A proponent of massive modularity may respond to our argument, and empirical demonstrations that favor situated soft-assembled cognition, in the following manner. Individual modules may admittedly be dynamical, even self-organizing systems, yet this alone does not refute the possibility that they are functionally specialized, adaptive mechanisms. To take one example, for instance, even if speech perception is a self-organizing process, it remains distinct in its input conditions, informational contents, and adaptive operation from other modalities such as vision. Thus dynamic systems theory may offer interesting insights on how to model human performance, in different experimental tasks and contextual circumstances, but it does not sufficiently describe the contents of mind and language.

But it is in no sense obvious that speech is inherently different, except superficially, because the same principles are at work in visual perception (Galan-

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tucci et al. 2006; Oudeyer 2006). One difficulty with both classic Fodorian modularity and massive modularity theories is their refusal to seek commonalities between different so-called modular systems, such as, for example, the extreme overlap between language comprehension and motor performance as seen in research on embodied language processing (Gibbs 2006). Simply acknowledging that individual modules operate in a dynamical manner misses the crucial idea that the system as a whole self-organizes. Our assertions, coupled with the failure to supply reasonable persuasive evidence of modularity, could mean that functional perception and functional content are among those things that are emergent, on-line, and are nowhere contained in the brain/body as dormant intact representations, impatient to be activated. Massively variegated emerging properties of the system, as a whole, shape the soft-assembled local movements of the body, as it conforms in task- and context-specific ways, to meet the general and idiosyncratic needs of being and staying alive.

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