Theoretical behaviorism meets embodied cognition

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Theoretical behaviorism meets embodied cognition
Two theoretical analyses of behavior

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Abstract
This paper aims to do three things: First, to provide a review of John Staddon's book *Adaptive dynamics: The theoretical analysis of behavior*. Second, to compare Staddon's behaviorist view with current ideas on embodied cognition. Third, to use this comparison to explicate some outlines for a theoretical analysis of behavior that could be useful as a behavioral foundation for cognitive phenomena. Staddon earlier defended a *theoretical behaviorism*, which allows internal states in its models but keeps these to a minimum while remaining critical of any cognitive interpretation. In his latest book, *Adaptive dynamics*, he provides an overview and analysis of an extensive number of these current, behaviorist models. Theoretical behaviorism comes close to the view of embodied cognition, which also stresses the importance of behavior in contrast to high-level cognition. A detailed picture of the overlaps and differences between the two approaches will be sketched by comparing the two on four separate issues: the conceptualization of behavior, loopy structures, parsimonious explanations, and cognitive behavior. The paper will stress the need for a structural analysis of behavior to gain a better understanding of both behavior and cognition. However, for this purpose, we will need behavioral science rather than behaviorism.

Does behaviorism have a new lease on life? Behaviorism has been declared dead many times over. Behaviorists, to this day, responded defiantly that they are still alive and kicking (Baum, 2000), and that "the disinterested observer might well conclude that the vigorous attacks on an already moribund movement are a sure sign that behaviorism is ready to resurrect." (Staddon, 2000, p.4). Still, within the larger psychology and cognitive science community behaviorism has become viewed as an outmoded approach that is rightly ousted by cognitively oriented studies, and that can be safely ignored without any ill effects. Behaviorist claims to the contrary sound shrill, a within group affair meant to close up the ranks against a hostile intellectual environment.

Thus, for many years now, those attracted to the austerity of behaviorism could only dream about the grand old times, when behaviorist ideas ruled psychology. Their many critiques of cognitive models and pleas for a return to behaviorist rigor (e.g. Rachlin, 1994; Staddon, 2000; Uttal, 2001) remained unheeded. However, there are signs that could indicate that some form of behaviorism might be on the rise again. The reasons for this have less to do with the behaviorist movement itself, as with developments within the cognitive sciences. Here the initial, almost exclusive focus on strictly internal and computationally interpreted cognitive functioning has caused a critical backlash. This comes in many forms. There is, of course, the increasing importance of the neurosciences and, after a long neglect, consciousness is again a central topic, as well as the emotions. However, the development that is particularly relevant for behaviorism is the one toward a more dynamic, embodied and situated interpretation of cognition, or embodied cognition for short.

The general ideas ought to be familiar nowadays.[1] Cognitive functioning was initially conceived as a process that occurred essentially within the head, and could in principle be replicated by a computer without recurrence to body and environment. Nowadays, it is increasingly acknowledged that many cognitive processes are also dependent on external processes and the dynamical interplay between internal, cognitive processes and bodily and situational characteristics. An example, used by Clark, is that solving a jigsaw puzzle becomes much easier when it is possible to rearrange and sort the pieces on a flat surface that can be viewed. Cognition to a large extend depends on, or, some would hold, even consists of, *perception-action loops* that bind organism and environment together in a continuous reciprocal interaction. In embodied cognition, action and perceptual feedback become a necessary part of human problem solving and intelligence, while the complexity of any internal cognitive apparatus can often be greatly reduced.

In this paper, I will focus on a particular interpretation of embodied cognition that I have called elsewhere Behavioral Systems Theory (Keijzer, 2001), and will here, more loosely, refer to as a behavioral systems approach. The notion of a behavioral system stands for a whole neural, bodily and environmental interaction system as envisioned in Beer (1995) and Smithers (1994). Consider building a robot. Robots function only given a specific control structure, a specific embodiment and a specific environment (Brooks, 1999). In addition to an internal control architecture, both body and environment are also essential ingredients of the processes that generate the intelligent action of any robot. As the robot can only function within a specific environment, a behavioral system approach considers these aspects of the environment as part of the total behavioral system. An additional feature of a behavioral system approach is a general suspicion concerning the use of representation as an explanatory concept in such explanation (Brooks, 1991a; Keijzer, 2001; Van Gelder, 1995). I will take it that this suffices for a rough indication of a behavioral systems approach. In later sections, this picture will be filled in with more detail.

At this point, the question how a behavioral systems view relates to the behaviorist tradition arises. There seem to be some evident overlaps in both approaches. Behaviorism always downplayed the cognitivist tendency to work with complex, mindlike internal mechanisms, and so does a dynamic, embodied approach. Behaviorism always focused on externally visible behavior and its explanation. A dynamic, embodied approach similarly focuses again on

[1] There is a standard list of authors who are generally seen as the important initiators of this development: Beer (1995), Brooks (1991a, 1991b), Clark (1997), Kelso (1995), Thelen & Smith, 1994, and Van Gelder (1995, 1998) are probably most often mentioned. Of these authors, Clark remains somewhat less radical than the others.

systematic organism-environment relations, behavior one might say, and this also comes close to behaviorism. From this perspective, one might expect that the rise of a dynamic and embodied approach should go hand in hand with a return of behaviorist ideas.

However, so far nothing of the sort has happened. Current behaviorists hardly refer to the dynamical and embodied literature, while proponents of the latter do not name behaviorists as their intellectual precursors. Why? Why have these two approaches so far not made a happy alliance? Trying to answer this question will be interesting for getting both current behaviorism and the dynamic and embodied approach in sharper perspective.

In the following, I will review John Staddon's 2001 book *Adaptive dynamics: the theoretical analysis of behavior* with this question in mind: What is the relation between current behaviorism and a dynamic and embodied approach? Staddon is one of today's major defenders of a behaviorism that he calls *theoretical behaviorism,* which allows all kinds of internal states (Staddon, 1993, 2000). Staddon's theoretical behaviorism probably comes closest to a dynamic and embodied approach and so provides the best test case for investigating whether and possibly how both approaches do make contact. In the book reviewed here, *Adaptive dynamics*, he explicitly focuses on many specific behavioral models that exemplify this theoretical behaviorism. This makes it possible to trace divergences and similarities between the two approaches in detail.

The paper has the following structure. The following section will provide a brief sketch of Staddon's theoretical behaviorism and the way in which it differs from the more generally known Skinnerian version. Subsequently, I will discuss what Staddon has more specifically to offer on the study of behavior in his *Adaptive Dynamics*. The main dish consists of a comparison and elaboration of theoretical behaviorism and a behavioral systems approach focused on four topics: (a) what is behavior?, (b) loopy structures, (c) parsimonious explanations, and (d) cognitive behavior.

Staddon's theoretical behaviorism

Staddon provides a nice introduction and overview of the behaviorist tradition in his *The new behaviorism: mind mechanism and society* (Staddon, 2000), which is a slightly revised and extended version of an earlier book (Staddon, 1993). Here, he sketches the line from Watson to Skinner's radical behaviorism, which has nowadays become the familiar bugbear version of behaviorism. Staddon acknowledges Skinner's experimental achievements but also holds him partly responsible for the demise of the behaviorist tradition. Skinner's highly prominent radical behaviorism explicitly prohibited the expansion of a stimulus-response analysis to include internal properties at a time when the computer made it possible to develop this notion in a scientifically respectable way. Skinner explicitly rejected the notion of internal mechanisms when it came to the study and explanation of behavior. According to Staddon, this blocked theoretical advances within behaviorism so that a natural next step for a behaviorist approach, such as connectionism, could not be accommodated but was forced into, what he names, an uneasy home in cognitive psychology (2000, p.146).

Radical behaviorism also precluded the possibility of a behaviorist antidote against the all out mental explanations that became prominent with the cognitive revolution. Radical behaviorism rejected the very notion of internal explanatory mechanisms. But when it became clear that one could use respectable explanatory internal mechanisms, it did not provide any constraint on the specific kinds of internal models used within the cognitive approach. Criticisms concerning how much and what kind of internal mechanisms are appropriate had to come from within cognitive quarters, with the dynamic, embodied and situated approaches as a prime example.

Staddon's theoretical behaviorism is formulated in opposition to Skinner's radical behaviorism, but it also keeps a distance from neurophysiological explanation and cognitivism. In contrast to Skinner, theoretical behaviorism explicitly embraces the use of unobservable, hypothetical internal mechanisms to account for the experimental findings of behavior. This commitment to postulating and evaluating the explanatory capabilities of internal mechanisms makes Staddon's behaviorism *theoretical*. Theoretical behaviorism is in this sense similar to the pre-Skinnerian behaviorism of Clark Hull, as "it shares with Hullian behaviorism the idea that the ultimate aim of behavioral study is the derivation of *mechanisms*" (1993, p.97). However, while Hull envisioned his "intervening variables" in physiological terms, Staddon focuses on more abstract 'black box' mechanisms. Staddon sees "internal states as purely theoretical constructions based on information from historical experiments" (ibid.). In *Adaptive dynamics* in particular, Staddon maintains a distance from neuroscience. He does, of course, not deny the biological machinery for behavior, but he insists that "an essential step in understanding how all this machinery works is dynamic *black box modeling*," and that such models "will always provide the most compact summary of behavior. And such an account is likely to be *much simpler* than a neurophysiological account, if indeed one can be found." (2001, p.2). In his eyes, the nervous system is way too complex to allow understanding its relation to behavior and it is better to be "physiologically agnostic", while his professed aim is "to explain *behavior*, not brain-behavior relations." (2001, p.xi).

Postulating abstract internal models brings theoretical behaviorism very close to standard cognitive approaches. Staddon sees two important differences. First, theoretical behaviorism is explicitly historical and dynamic. Staddon focuses on abstract "dynamic theories that define how moment-by-moment experience changes the state of the organism" (1993, p.97-98). Internal states are formulated on the basis of a history of reinforcement and with an eye to the changes wrought by experience, rather than as a cognitive representation. However, this criterion hardly applies to the models discussed in *Adaptive dynamics*, and I will not discuss it here. Second, while cognitivism is committed to models that in some way reflect our intuitive notion of cognitive processing, the models of theoretical behaviorism are under no such constraint. Theoretical behaviorism "is the study of the mechanisms of behavior, where mechanism is whatever works to account for behavior" (1993, p.98). Staddon's mechanisms are cut loose from any assumed similarity to mental concepts and constructed only to get the explanatory job done as parsimoniously as possible. I want to stress here that this formulation brings him very close to the theoretical underpinnings of a dynamic, embodied and situated approach to the study of intelligent behavior (Keijzer, 2001).

In sum, theoretical behaviorism is Staddon's own and influential brand of contemporary behaviorism that cannot be dismissed out of hand, only because it is called behavioristic. Theoretical behaviorism deserves attention as a modern account of behavioral phenomena. *Adaptive dynamics* develops this approach in detail.

An overview of 'Adaptive Dynamics'

Here, Staddon moves beyond a general theoretical discussion of the relative merits of various forms of behaviorism and cognitivism. He interprets behavior as a joint venture of two ingredients: adaptation and dynamics. Behavior is adaptive because it tends to change over time in order to maximize a specific function, such as food intake. Behavior is dynamic because it is a process, which consists of a series of events that occur over time. Adaptation and dynamics address different questions: What does the behavior maximize? and: How is the behavior produced? (p. xi). These two notions also link his theoretical behaviorism to two important formal approaches: optimality analysis and dynamical systems theory. These two forms of modeling provide the main structure of Staddon's approach.

Staddon spends two chapters on optimality analysis, one centered on psychology, the other discusses the slightly different but ultimately equivalent techniques of behavioral economics. Viewing behavior as an efficient way of dealing with environmental problems provides a successful unified account of operant (instrumental) behavior in animals. Operant behavior is behavior initially freely emitted by an animal, such as key pecking by pigeons, that can subsequently be modified by feedback regulated by a particular reinforcement schedule. Operant behavior can be viewed as a process maximizing some utility, where its specific implementation becomes no more than a constraint on a process of optimization. Staddon discusses the allocation of behavior problem where an animal has to choose between different behavioral options in order to maximize the amount of some preferred behavior, such as feeding. Staddon is positive about optimality analysis as a unifying framework, but also stresses its shortcomings. To quote: "optimality models provide a tolerably good picture of what animals manage to achieve, but a poor picture of how they actually do it. Animals often behave optimally; they almost never optimize in any literal sense." (p.77) Optimal behavior depends on causal mechanisms that allow this behavior to take place, but the same mechanisms are operative when the behavior is not optimal. Therefore, these mechanisms are fundamental whereas optimization is not (p.78).

In the remaining, and much larger part, of his book, Staddon presents dynamic modeling as a formal approach that does allow one to get a grip on fundamental behavioral mechanisms. Here his old adherence to black box modeling comes into its own. In this discussion, two threads are closely intertwined. On the one hand, Staddon discusses different behavioral phenomena of varying complexity: trial and error learning, reflexes, habituation as a simple form of memory, feeding as an example of motivation, credit assignment in operant and Pavlovian learning, spatial navigation, and the timing of behavior. As such, this may seem an odd assortment of behavioral topics, rather than a representative overview of behavioral phenomena. What binds them together is the other thread in the discussion; dynamic models targeted to account for all these phenomena. Here one finds a natural coherence that reaches from the fairly simple to the relatively complex.

The dynamic models presented are all variations on, and combinations of the simple analog memory elements provided by leaky integrators. Given a stimulus value X and a response value V, any change in X will be followed by a change in V so that the difference between V and X will become zero. This will happen with a delay designated by *a*. A difference will diminish rapidly at first, then increasingly slower until it is reduced to zero. The delay makes the leaky integrator act as a simple memory for the previous stimulus situation. Staddon further adds a summer—subtracting V from X and turning the integrator into a differentiator—and a threshold to make a unit that is the elementary ingredient of many adaptive processes (p.98). These units are subsequently combined in various ways. Several integrators can be set in parallel, in a winner-take-all configuration, or in a cascade in order to model behavior on different time-scales. These minimal, non-cognitive elements are capable of modeling a wide variety of behaviors.

The descriptions and analyses of the various behavioral phenomena, mentioned above provide the targets for these integrator models. I will discuss trial and error behavior and feeding behavior as examples of Staddon's theoretical behaviorism in action. Staddon gives a nice description of the trial and error behavior that allows, for example, Salmonella bacteria to move towards a food source, in this case a pipette dispersing nutrients that diffuse slowly into the watery medium where the bacteria move about. How do they do it? These bacteria are capable of two behaviors relevant for this form of chemotaxis. They can tumble, changing direction in a random way, and they can swim forward. If a bacterium moves in the right direction, it keeps moving forward. If it moves into an area that is worse than that from which it came, it starts tumbling and then moves out in a different direction (most of the time). But, how can the bacterium detect that it moves in a wrong direction? These bacteria are too small to detect a chemical gradient across their body surface. In the 1970s, McNab and Koshland showed that a *successive comparison* provides the key to this behavior. Different absolute food concentrations had no effect on tumbling behavior. However, after a sudden change in concentration, tumbling greatly decreased or increased, depending on whether the change was for the better or for the worse. So, by simply increasing the chances of moving forward when the food situation is better than it was just before, these bacteria end up at the point where the concentration is highest. This mechanism requires some form of memory in order to compare the current situation with the previous one and Staddon subsequently shows how one of his integrator models deals very nicely with this and a number of other behaviors of bacteria.

Another example of Staddon's theoretical behaviorism is provided by three chapters on motivation and feeding behavior. Staddon interprets motivation as a set of reversible processes that are simpler than learning, which induce irreversible changes in an organism. Motivational factors govern "the processes that allow organisms to vary the amount of time and effort they devote to a particular motivated activity" (p. 160), in this case the regulation of the amount of feeding on a given food, and also preference for one food type over others. (Ibid.) He treats feeding regulation as a separate process that "can be understood in isolation, leaving until later the question of how feeding and drinking interact." (p.161) Most studies are done with food-deprived laboratory rats as a representative organism for the experimental study of this issue (p.161). The experimental data show that rats are capable of regulating their nutritive intake across all kinds of experimental manipulations. They also show that this regulation takes place on several time scales, ranging from fast and peripheral sensory feedback on the basis of taste alone, to increasingly long-term and central factors, such as stomach extension, blood sugar level and body weight. Rats adjust the size of meals and inter meal intervals to maintain a preferred nutritive intake.

Staddon accounts for these data with a model that consists of a cascade of integrators, the output of each providing the input for the next one and each with an increasingly slower time constant (a) as the cascade mimics the progression from fast peripheral to slow central regulatory factors. The tendency to eat—called *reflex strength*—is the difference between a reference value and the weighted sum of the states of the integrators, the last having the largest weight and impact on regulation. This model shows the main experimental characteristics of feeding regulation, such as eating in meals (rather than continuous feeding), meal-size, eating an extra-large first meal after deprivation, and short- and long-term regulation of food intake. Finally, Staddon addresses the question whether feeding patterns are dependent on associative learning. Experiments done by George Collier who uses a slightly different experimental paradigm seem to indicate that this is the case. After discussing these experiments Staddon concludes that his regulatory model still stands while learning mechanisms come in only later as a secondary effect.

The book treats much more than just these two example cases, but this is sufficient to get an impression of what Staddon is up to with his theoretical behaviorism and how he aims to achieve this. It is also sufficient to start of a critical behavioral systems analysis of Staddon's "theoretical analysis of behavior."

A behavioral systems-based critique

How does Staddon's theoretical behaviorism look from the perspective of a behavioral systems approach? In the following, I will discus four issues that are important for drawing similarities and contrasts between the two. First, there is the issue of behavior itself. Do the two approaches target the same topic? The second issue concerns different interpretations of the environmental feedback loop that links action back to perception. The third is whether parsimony provides an adequate guide for developing models of behavior. The last concerns classical cognition. Where and how does intelligent thought, traditionally set apart from behavior, come into the picture? The discussion will provide a sketch of some major differences between the two approaches as well as ways in which they may relate to one another.

What is behavior?

How do behaviorism and a behavioral systems approach interpret behavior? First, it is important to stress Skinner's influence on the behaviorist conception of behavior. Early behaviorism tended to interpret behavior as responses: objectively observable doings of an organism that result from a stimulus. These responses somehow had to be cast in terms of movements. The difficulty, of course, is that a similar response, say a lever press, can be brought about by a multitude of different movements by different body parts. Skinner changed the behaviorist conception of behavior in two ways. Behavior was not to be measured in terms of movements but in terms of effects, and the prediction of behavior did not require predicting the moment of any individual response occurring, but rather the frequency of its occurrence (Baum, 2000, p.263-264). The Skinnerian conception of behavior allowed his radical behaviorism to abstract away from the complex details of the movements involved in any particular behavior. Behavior became a process that optimizes reinforcement.

Staddon distances himself from Skinner's approach. Behavior as envisioned within optimality analysis, for example, fits in nicely with an abstract Skinnerian view on behavior, but he claims that this kind of analysis does not provide a good picture of *how* organisms optimize their behavior (see above). In turn, Staddon focuses on accounts of the mechanisms that are operative within organisms. In doing this, he returns to the task of giving a full blown natural science account of behavior that attempts to explain how behavioral phenomena are generated, whether optimized or not. Such an account plausibly ought to focus on behavior as a process that is constituted by physical movements. These movements are the place where the how question seems to bottom out. However, Staddon's move away from radical behaviorism to focus on internal mechanisms is not accompanied by a similar move away from an abstract Skinnerian interpretation of behavior. At this point, theoretical behaviorism and a behavioral systems approach differ in an important way.

It is standard practice within biology to differentiate between structural and functional aspects of living systems. Usually structural and functional aspects go hand in hand in biology, but when it comes to behavior the picture seems to be all function and hardly any structure. Take animal body form as a comparison case. Here morphological and taxonomical descriptions are closely connected with function ascriptions. There is an enormous amount of knowledge about the morphology of animal bodies. People have for centuries been dissecting every animal found under the sun, setting out their components in detail, categorizing them and attempting to discover the function of all these structures. Leafing through Brusca and Brusca's (1990) textbook on the invertebrates gives a good impression of the sheer amount of work that has been done. For behavior, the situation is different. There is no comparably detailed account of the structure of behavior that attempts to trace the movements involved when animals and humans behave.

What has been done within biology and psychology with behavior is much more limited. In psychology, the behaviorist solution of behavioral description can be described as function without structure. Structure has been sifted out as irrelevant for operant behavior. For example, changes in the feeding behavior in insects and rats can be functionally equivalent while the structural properties of the behaviors are hugely different. Within ethology, the behavioral details of different animal species have been an important topic of study from the start (Tinbergen, 1951). Nevertheless, in practice, there has been a tendency to focus on functional aspects of behavior—e.g. feeding behavior, sexual behavior, and social signaling (Alcock, 1989). Such functional aspects remain the dominant way of characterizing behavior. Movements tend to be treated as 'motor behavior', another functional form of behavior. In contrast, there is little elaboration of the idea that movements—or rather sensorimotor couplings in the embodied view—ought to be taken as the general and basic structural components of behavior's functional regularities.

Of course, there have been good reasons for this neglect. First, it has been extremely difficult and time consuming to provide detailed accounts of the structure of behavior. It requires skilled observers and a suitable notation system, both difficult to come by and often of a disputed validity (Jacobs et al, 1988). However, below, I will argue that the situation has changed. Second, there has never been a strong incentive to go to all this trouble for psychologists and cognitive scientists. The intelligence of behavior comes out in the results, not in its execution. The minute ethological study of, say, grooming movements in mice then does not seem strikingly relevant for non-biologists.

However, from a behavioral system perspective, a good structural characterization of behavior is a necessary prerequisite for uncovering the mechanisms of behavior (Keijzer, 2001). Instead of starting out with existing functional patterns, attention is turned to basic sensorimotor couplings that, given the particulars of a behavioral system, produce a functional pattern. The paradigmatic example remains Brooks' behavior-based approach to robotics (1999). He challenged the idea that, fundamentally, robots are mechanisms that translate a planned task into an executed task. Instead, he built robots around a set of very basic but concrete sensorimotor capabilities. These capabilities were subsequently extended by adding new control structures on top of the old one. Functional regularities arise from such robots as a side effect. In the words of Steels, functionality emerges from the system (Steels, 1991), and is not a basic feature. A structural characterization stresses (neural, bodily and environmental) subsystems and the generation of behavior. In contrast, a functional characterization presupposes the presence of behavior. The latter focuses on the choices between different behavioral options, and is most easily ascribed to a whole behaving agent.

At this point, it is important to be clear on the notion of a structural characterization of behavior. Filling large databases with recordings of arbitrary collections of movements does not sound like a good idea. A suitable analogy here is by casting behavior as an extension of organismal form, only dynamic and fleeting. The analogy with body form suggests the need and the option to develop something like the *anatomy of behavior*: a systematic laying out of behavioral structures that subserve specific functions for the organism. Such a behavioral anatomy also suggests a comparative approach that tracks differences within and between the different animal phyla. Animals can be classified according to the presence of a circulatory system, number of basic body tissues, presence of a coelom, internal skeleton, and so on. The same could be done for behavioral structure, making a systematic inventory of the behavioral capabilities of various animals, figuring out how these fit together, and how such capabilities can be, and have become, extended in certain groups or species. All of this is, of course, to be done in close conjunction with the comparative study of nervous systems. The important point here is that nervous systems are not interpreted as supporting more or less 'intelligence', but that the aim is to uncover the specific behavioral capabilities made available by a particular nervous system, of course in conjunction with a particular body and environment.

Viewing behavior as an anatomical structure suggests a number of characteristics. First, any specific behavior is not arbitrary present but is part of a systematic array of behavioral capabilities that forms a structurally integrated and hierarchically built-up whole, just like animal bodies with their characteristic body architectures. Second, an anatomical characterization of behavior centers behavior on particular organisms instead of generalized task descriptions to be performed by an arbitrary 'agent'. Third, these arrays come in many different forms, just like and, of course, in close conjunction with the huge variety in organismal nervous systems and body forms. Good 'anatomical' descriptions of behavior will provide a differentiated picture of the different means by which functionally equivalent outward results are achieved. Fourth, these arrays can differ hugely in complexity. Following Brooks' idea of continuously extending existing robotic capabilities, as well as the general evolutionary picture emerging from comparative neural and behavioral studies, the suggestion is of a wide range of behavioral anatomies in the animal kingdom, of which the human case forms the current upper end.

A behavioral systems approach makes it natural to differentiate between functional and structural characterizations of behavior, giving due credit to both. Still, given the dominance of the functional ones, a behavioral systems approach will emphasize the importance of structural characterizations. Staddon's theoretical behaviorism does not explicitly use such a distinction. His important differentiation between adaptive optimalization and the dynamic mechanistic aspects of behavior comes close in some respects (see above). However, he does not apply this differentiation between adaptive and mechanistic aspects to the phenomenon of behavior itself. As a result his characterization of behavior fluctuates between structural and functional ones, even when the aim is to provide an account of the enabling, structural mechanisms that generate behavior.

The two examples discussed above—bacterial trial and error behavior, and rat feeding behavior—provide an illustration. Staddon treats them in a similar way: Both provide forms of whole-organism behavior that can be modeled by some version of his integrator models. However, while the bacterial whole-organism data remain fairly close to bacterial sensorimotor capacities, this is not the case for rat lever pressing to get food. These data are disconnected from the basic behavioral capacities that generate the option of recognizing and pressing a lever in the first place. These data are also disconnected from other behavioral options available to the rat. Given the astounding difference in behavioral capacities of bacteria and rats, it can only seem feasible to present highly similar models for both as long as behavior is interpreted in terms of achieved tasks irrespective how it is done. Staddon clearly uses a functional characterization of behavior while he aims for mechanisms of behavior.

Staddon could hide behind his data by claiming that he targets behavior and that his models deal with genuine behavioral data, which suffices for scientific respectability. However, this is exactly the position that he opposes within psychology as "much behavioral research has degenerated into what Richard Feynman once called 'cargo-cult' science. It follows the procedures of science—careful experimentation, quantitative data, the latest statistical tests. But it lacks the soul of science, which is simply *curiosity*, the desire not just to 'get results' but to *understand* how the world works." (2001, p.371) Staddon clearly sees his own project as curiosity driven and providing a hypothetical account of a behavioral mechanism. Using the data as a shield will not be satisfactory for him.

However, Staddon can criticize a behavioral systems approach in ways that are more substantial. First, for Staddon behavioral science is not subordinate to neuroscience (2001, p.2). Behavioral science studies behavior, not brain-behavior relations. Behavioral science has its own top down approach and goals—building abstract input-output models—that can be had irrespective of advances in neuroscience. Staddon could argue that a behavioral systems approach focuses on detailed brain-behavior relations and gives up the status of behavior as a separate domain. Second, Staddon states that the brain is simply too complex to allow a bottom up neural explanation of behavior to get off the ground in the short run (p.5-6). Similarly, a behavioral systems approach may seem to make behavior excessively complex and effectively to prohibit its study. Within theoretical behaviorism behavior remains at least a manageable topic. I will discuss these two points in the following two subsections.

Loopy structures

If Staddon were to argue that a behavioral systems approach would amount to a brain-behavior account, basically formulated in neural terms, would he be right? Given the plea for a structural characterization of behavior, I take it to be evident that the answer is no. Still, explicitly denying this charge is important because it draws an important contrast not only between a behavioral system approach and neuroscience, but also with behaviorism. What Staddon suggests is that a neuroscientific account for behavior amounts to giving a full blown description of all the processes occurring within the brain and which supposedly should suffice to account for behavioral output. In contrast, the input-output modeling of theoretical behaviorism allows a more coarse-grained description of the internal processes that lead toward behavior. For the record, it must be mentioned that Staddon's depiction of neuroscience is unfair. Neuroscience is nowadays to a large extend a *cognitive* neuroscience, which aims to develop higher-level, computational theories of what the brain is doing (e.g. Koch & Davis, 1994). More to the point for present purposes is that Staddon portrays behavioral explanation both within neuroscience and behaviorism in terms of a serial sequence of events. For neuroscience these are presumably constituted by unidirectional brain-behavior relations, for theoretical behaviorism these are explicitly input-output relations, together with mediating internal states.

A behavioral systems approach, in contrast to serial views, explicitly embraces the bi-directional, circular structure of sensorimotor and perception-action couplings. The term *loopy structures* is appropriate here in both meanings of loopy. The loopy structure of a behavioral systems approach differs in an essential way from any serial brain-behavior view. Influence is by default bi-directional. Outward behavior is not the end result of a set of internal neural processes, but a step in an ongoing series of perception-action couplings. Outward behavior is itself an important co-contributor to neural, bodily and environmental processes that together generate behavior. It can be considered strange that the behavioral facts to be explained are in a sense part of their own explanation. Still this is more a consequence of the make up of behavioral and other biological phenomena than a shortcoming of this kind of explanation. Coming to grips with such loopy structures may be the major challenge for an account of biological structures at any level of organization. It is at this point that fields like dynamical systems theory, self-organization, and recurrent networks are extremely important (see for example, Beer, 1995, Bell, 1999, Kelso, 1995, Van Gelder, 1998).

I want to stress that the importance of loopy structures is not confined to explicitly embodied and situated approaches but is nowadays accepted as a widespread phenomenon within the cognitive sciences. To name just one example, vision is now interpreted as just such an ongoing perception-action coupling in which a visual field is continuously scanned by eye, head and body movements in order to build up and maintain our subjective view of the visual world, and in which afferent and efferent neural activation flows standardly complement one another (Ballard, 1991; Churchland, Ramachandran & Sejnowsky, 1994; Noë, 2002).

Stepping back for a moment and reflecting on the argument so far, a question arises: Does Staddon really endorse the simple serial view on behavior ascribed to him above? His sophistication in behavioral analysis and experimentation and his standard use of feedback functions may make this hard to believe. Yet, Staddon never bothers to deny such serial views while his treatment of neuroscience and behaviorism does definitely suggest them. His short discussion of the study of brain-behavior relations only focuses on the complexity of the neurophysiology involved as the major problem for explicating these relations. In the models that belong to his own theoretical behaviorism, there are often feedback loops, but these remain inside the internal models and do not encompass the environment. Or rather, thinking of Staddon's account of bacterial trial and error behavior, he keeps the environmental feedback external to his models. As a result, the unidirectional view of an input-output mapping remains in place.

One may hold that *learning* provides behaviorism with loopy structures as it provides a feedback loop that changes behavior. However, the stress on perception-action coupling does definitely bring an important theme into the study of behavior that is not present within behaviorism. Perception-action coupling stresses the *constitutive* role of this coupling for any behavioral phenomenon. Ongoing feedback is part of the behavior—or rather perception-action coupling—itself. Learning, on the other hand, merely adds to this constitutive function as a way to change ongoing behavior, making it adapt to new situations. Behaviorism's acknowledgement of the importance of learning cannot be equated with the central claim of a behavioral systems approach.

Building loopy structures into the foundations of behavioral systems theory surely disposes the fear that behavioral science could be subsumed by neural science. Perception-action couplings are a key issue of behavior and will have to be included into its explanation. Behavioral science will never be replaced by a neural science that only deals with internal processing. Behavior is not a derivative of these internal processes.

Parsimonious explanations

As said above, a behavioral systems approach commits itself to articulating elaborate structural (anatomical) descriptions of the perception-action capabilities of behaving organisms. A big issue then becomes the question whether the study of behavior really has to deal with all this detail? Could the analysis of behavior not be done much more parsimoniously, at a more abstract level of description? Staddon's theoretical behaviorism certainly opts for an approach that is more parsimonious. The appropriate reply here is to ask: Does such a parsimonious account suffice as a description and explanation of behavior? Above, I stressed the importance of structural aspects of behavior. From this perspective, a behaviorist account deals only with functional aspects of behavior and not with the whole picture. Behaviorism's parsimony is gained by neglecting important aspects of behavioral phenomena.

However, one problem must be addressed in this context. Given the sheer complexity of the perception-action couplings constituting behavior, is it remotely plausible that a full scale behavioral systems approach can ever get off the ground? The appropriate reply here is that this is exactly what the many different sciences and fields related to the study of behavior are nowadays working on. A behavioral systems approach to the study of behavior will involve areas falling under behavioral science, neural science, cognitive science, biology, psychology, and many of its subdisciplines. A behavioral systems approach does not aim to substitute these different sciences and replace the work done there by its own separate approach. A behavioral systems approach is itself constituted by work coming from many different disciplines. It is itself nothing more (or less) than the articulation of tendencies within these disciplines that stress the relevance of embodiment, situatedness and dynamics for intelligence. A behavioral systems approach can simply ride with ongoing developments in the study of behavior or behavior-related phenomena.

There is an important contrast here with behaviorism. Behaviorism has its own particular, and exclusive, method and interpretation of behavior. Behaviorism is much more an -ism that tends to keep itself apart from alternative approaches to the study of behavior-related phenomena.

But, if a behavioral systems approach is as inclusive as suggested, what does it add to the regular ongoing work in the many and diverse sciences dealing with behavior-related phenomena? In what sense does it make a difference? The value of a behavioral systems approach consists of it being a conceptual framework that makes perception-action coupling the kernel of behavior and intelligence. The conceptual implications of this move are far-reaching. It provides a straightforward conceptual link between the most basic forms of animal behavior and human action. The notions of intelligence and cognition become spread out widely over the phylogenetic scale. Intelligence is involved in many fine-grained perception-action problems that are so habitually solved by our own nervous systems that we ourselves have a hard time noticing that anything intelligent is occurring at all. Picking up and manipulating objects is already such a task. Human, deliberate thought no longer acts as the touchstone for a universal kind of intelligence, a kind of intelligence that may or may not be present in other animals. For a behavioral systems approach the latter is a parochial interpretation that disregards the kind of problems that are habitually and continuously solved in perception-action coupling. The difficulty of these problems only becomes evident when they are specifically targeted as they are in fields like robotics and neuroethology. A behavioral systems approach highlights these problems and the direct relevance of simple behavioral systems for understanding more complex ones like us.

The behavioral systems picture of intelligence and cognition is controversial. A behavioral systems approach is not the passive sum of all ongoing research but a specific view on its outcomes and a different yardstick for measuring relevance for filling in the larger picture of animal and human behavior and, consequently, intelligence. To summarize, a behavioral systems approach builds on and incorporates many different kinds of research on behavior and behavior-related phenomena. To this it adds a rough general outlook as to how the whole picture could plausibly come together.

I want to round off this section by briefly mentioning two topics that are of specific importance for a behavioral systems approach when it comes to the issue of overall feasibility. The first concerns measuring behavior. While body structures have for centuries been available for minute analysis, the fine-structures of behavior have for a long time been too fleeting for such treatments. Film made a change, but now video is providing a breakthrough for the study of the fine-structure of behavior by generating cheap stable records of what animals and humans really do. Cools, remarking on the increasing popularity of studying behavior with the help of video, states “only video recordings can show all aspects of the situation in which humans or animals interact with each other or with their environment” (2000). Such recording make it possible to study not only simultaneously performed behavior patterns in detail, but also kinematic variables (such as order parameters) that do not necessarily assemble in fixed, synchronous behavior patterns (ibid.). When such recordings are supplemented by automated interpretation techniques they can come to mean for the study of behavior what the microscope meant for the study of physical body forms. One place where such techniques are now increasingly important is behavioral genomics where it is used to quantify behavioral patterns associated with specific mutations, for example in *C. elegans* (Butcher, Courtney, Gill & Lithgow, 2000). The systematic measurement of behavioral detail is important to overcome the initial hurdle for the structural characterizations of behavior as envisioned by a behavioral systems approach.

Another important topic that must be addressed for a behavioral systems approach consists of a solid theoretical treatment of the loopy structures that make up the bulk of living and behavioral phenomena. As said above, dynamical systems theory in general and theories of self-organization and recurrent neural networks are now making inroads into these problems. What must be added here is that such theoretical generalizations over the multitude of neural, behavioral and environmental detail will be essential to bring down the complexity involved. An all out description of all the details involved will never do, and ways must be developed to bring down the complexity to more manageable levels.

So, in the end, Staddon's call for parsimonious models is, as it ought to be, heeded after all within a behavioral systems approach. The difference with his theoretical behaviorism comes mainly from the sheer bulk of the many diverse structures and processes that must be taken into consideration for a functional *and* structural account of behavior.

Cognitive behavior

There is one final point that requires attention. Both behaviorism and a behavioral systems approach are not at their best as an account of classic cognitive tasks, such as playing chess. At the same time, classic cognitive tasks are generally considered as the most important or even the defining characteristics of intelligence. How do both approaches cope with this situation?

The old, Skinnerian rejection of internal states generated a fundamental problem for a behaviorist explanation of high-level cognitive tasks. Staddon's theoretical behaviorism with its acceptance of internal states and mechanisms overcomes the principled aspects of this hurdle. The main subsequent problem seems to be the extent in which theoretical behaviorism remains different from cognitivism. Staddon holds that his internal mechanisms are not cognitive and do not reflect intuitive notions of cognitive processing. Therefore, in his view, these models are different from cognitive ones. Interestingly, this point bears directly on a discussion on the behavioral systems approach and its challenge to cognitive, representation-based explanations.

A behavioral systems approach is thought to face problems similar to Skinner's radical behaviorism. Its central examples consist of motor-related tasks, while the notion of representation is criticized. Even when motor-tasks are accepted as a genuine part of cognition, the question remains: How can a behavioral systems approach deal with classic cognitive topics? The problem seems principled as a behavioral systems approach stresses the immediate *on-line* aspects of perception-action coupling while the traditional examples of cognition cast it as an *off-line* process that occurs independently from any interaction with the immediate environment: I can lie on the beach and still be industriously composing and arranging arguments to be included in this text. Margaret Wilson puts the contrast very strongly: "our ability to form mental representations about things that are remote in time and space, which is arguably the sine qua non of human thought, in principle cannot yield to a situated cognition analysis." (Wilson, 2002, p.626). This generally perceived implication of radical versions of embodied cognition—such as the behavioral systems approach—have led a number of authors to argue that such a radical approach is fundamentally limited (Bechtel, 1998; Clark, 1997; Grush, 2003; Wilson, 2002). A possible remedy are *dual* or *hybrid* views of cognition that combine a perception-action component with more conventional kinds of cognitive modeling (Bonasso, Kortenkamp & Murphy, 1998; Sun, 2002). The perception-action component is supposed to deal with the on-line, embodied aspects of cognition, while a representation-based cognitive system handles the off-line aspects that require representational processes.

The alleged limitation of the behavioral systems approach to on-line perception-action coupling hinges on its skepticism concerning the usefulness of representational explanations as they are traditionally used in the cognitive sciences (Brooks, 1991a; Keijzer, 2001; Van Gelder, 1995). Rejecting or criticizing the use of representations is then taken to imply a view that solely relies on the immediately present environment for guiding perception-action couplings. However, within a behavioral systems approach one can, and must, acknowledge the need to incorporate internal states as relevant factors in the off-line guidance of perception-action couplings. Still, as Staddon also notices, acknowledging internal states does not require a commitment to a representational interpretation of these internal states.

In a structural characterization of behavior a whole embodied, acting agent has to be accounted for. In doing this, it soon becomes evident that internal states are required for all behavior, however basic. At first sight, one may tend to equate the behaviorally relevant internal states of a cognitive system with something like intentional states or cognitive representations. But this interpretation is very much tied up with a functional view of behavior. Closer attention to the structural complexities of behavior makes it clear that the notion of internal states applies much more widely. For example, insect wing beating is controlled both by on-line external feedback from the wing's movements and by off-line internal oscillators that set a basic rhythm independent of such feedback (Simmons & Young, 1999). The point is easily generalized by taking into consideration the universal presence of neural and other regulatory factors that modulate all ongoing behavioral processes. Perception-action coupling is not the sort of strict on-line control that occurs in a simple thermostat. Internal states that initiate, guide, and modulate these couplings are always present. When it comes to humans, we call some forms of behavior automatic and treat it in terms of direct (on-line) perception-action relations, as we do not intentionally control it. Yet, again, such automatic behavior requires specific internal states for its execution and is not strictly on-line closed-loop control.

Given these considerations, it makes no sense to cast perception-action coupling as on-line and cognitive processing as off-line. All behavior combines on-line and off-line components. And, it would be a case of representational overstretch if the traditional notion of representation is applied to all kinds of internal states required to account for different aspects of the whole spectrum of behavior, from the most basic invertebrate behavior to the most complex cognitive tasks.

Two messages come to the fore. First, the intuitively plausible dichotomy between on-line perception-action coupling and off-line cognition is called into question, and replaced by an unspecified set—and plausibly a gradient—of internal modulatory factors that guide immediate perception-action couplings on various time-scales and with respect to various aspects of the environment (Keijzer, 2001, 2003). Second, there is no principled limitation of a behavioral systems approach to a strict on-line interpretation of perception-action coupling, as it can avail itself of internal modulatory factors for the off-line guidance of behavior.

How does this help a behavioral systems approach to account for cognitive behavior? As in the previous section, it must be stressed that a behavioral systems approach cannot and does not aim to replace regular scientific work on behavioral and cognitive processes. Doing the necessary science is the only way to produce a real account of behavior, including cognitive behavior. A behavioral systems approach consists only of a conceptual framework that aims to provide and articulate a rough and general prediction of the kind of picture that will emerge from actually doing that science. For this limited—yet not unpretentious—purpose, the two messages just given are highly relevant.

On the one hand they break down the idea that there is a fundamental break between a radically embodied view on cognition that is critical of the current use of the representation concept and much of the current behavioral and cognitive sciences that cannot do without some such concept. A radical view can happily accommodate the notion of internal states while questioning their universal interpretation in terms of cognitive representations. Internal processes are necessary and important, the point is merely how to characterize them.

In addition, a behavioral systems approach clearly contextualizes so-called classic cognition as an evolutionary late extension of operational behaving agents, rather than an abstract domain of problem solving that can be arbitrarily dissociated from its behavioral context. Of course, one can dissociate the performance of classic cognitive tasks from more direct behavioral ones, but the point is that they remain tied to a particular kind of behavioral system, such as human beings. Problem solving does not occur in the world in a disembodied way. It is always performed by particular kinds of systems and this will be reflected in the detailed characteristics.

Interestingly, Wilson (2002), who is very critical about claims related to making perception-action coupling the core of cognitive processes, gives at the same time a very favorable overview of the importance of bodily factors in some classic aspects of cognition, such as imagery and memory. To quote: "some version of a sensorimotor model appears to be the only viable way to account for the large body of data on working memory" (p. 633). However, as these sensorimotor systems are neural and used off-line, Wilson takes them as examples of off-line embodied cognition, where "rather than the mind serving the body, we find the body (or its control systems) serving the mind." (p.635). I find it puzzling that Wilson claims on the one hand that "off-line embodied cognition is a widespread phenomenon *in* the human mind … reflecting a very general underlying principle of cognition" (ibid. emphasis added), while on the other, she retains the idea that the mind remains an independent conceptual and empirical entity that can be dissociated from its behavioral context.

In contrast, I think that the behavioral systems approach sketched above is in general agreement with these recently developing views in the behavioral and cognitive sciences. This approach also provides a more coherent general view on cognition that makes perception-action coupling the core of cognition, while high-level cognition is cast as a collection of specific means to extend perception-action capabilities to new domains and longer time scales. The fundamental difference is that it abandons common sense intuitions which base the notion of cognition on a consciously accessible realm of thought, keeping it separate from its natural and more general basis in biological agents. So far, the behavioral and cognitive sciences have fought an uphill battle, overcoming aspects of this intuition-backed view of cognition in a piecemeal way. A behavioral systems approach provides a different general view of cognition where consciously accessible processes form only a component of a larger perception-action entity. Such a view could catalyze rather than slow down the acceptance of empirical indications for cognition as an intricate structure made up from connections between brains, bodies, and environments.

Concluding

Behaviorism and embodied cognition both stress the importance of behavior when it comes to conceptualizing cognition, or more generally the mind. The radical, behavioral systems, version of embodied cognition that has been discussed here even shares with behaviorism a version of the claim that cognition is constituted by behavioral—perception-action—phenomena (Hurley, 2001).

Nevertheless, I hope to have shown convincingly the deep differences between the two views, even when behaviorism is updated and internal states become part of its explanatory vocabulary, as in Staddon's theoretical behaviorism. First, the two differ in the very conception of behavior itself. Behaviorism highlights the functional regularities of behavior, while a behavioral systems approach stresses in addition the need for an anatomy of behavior: a structural description of the physical behavior itself. Second, behaviorism remains phrased in unidirectional terms, while a behavioral systems approach builds on loopy structures where almost any influence between components is reciprocal. Third, as a result of their different conceptions of behavior, the approaches differ markedly in their estimation of the complexity involved in behavioral phenomena. Fourth, theoretical behaviorism remains different from cognitive approaches by keeping its models as simple as possible while still accommodating the behavioral data. In contrast, a behavioral systems approach sets cognition itself in a behavioral context. Thus it retains its identity even when the mechanisms involved become increasingly complex and more like classic cognition.

The differences between these two theoretical analyses of behavior are systematic. Behaviorism, including theoretical behaviorism, has a strong methodological motivation. Behavior has always been the outwardly visible aspect of any internal—mental, cognitive or neural—process. By targeting outward behavior, behaviorists kept a firm objective footing in solid observable data and hoped to avoid questionable cognitive and overly complex neural mechanisms. The motivation behind a behavioral systems approach is different. This approach turns to behavior because it holds that outward perception-action coupling is an intrinsic aspect of the processes making up intelligence. In addition, behavior also provides the whole evolutionary rationale for any internal—mental, cognitive or neural—process. Behavior is set center stage because it is of central importance for intelligence, irrespective whether it is easily accessible or not. The seeming accessibility of behavior is even put into question as it turns out to be rather difficult and complex to access the fleeting dynamical structures of behavior.

Having compared the two theoretical approaches to the study of behavior, I find any methodological reasons for turning to behavior much less convincing than behavior's intrinsic importance. So, while treasuring its techniques and empirical knowledge, I want to conclude that there is no question of a current return to behaviorism. Behavior*ism* remains as dead—or alive if you want—as it ever was, even when the scientific study of behavior must be considered of primary importance.

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