Title: Is cognition a matter of representations?: Emulation, teleology, and time-keeping in biological systems

Running title: Cognition, representation and time-keeping.

Authors:
Ángel García Rodríguez, Universidad de Murcia, Departamento de Filosofía

(Corresponding author) Paco Calvo Garzón, Universidad de Murcia, Departamento de Filosofía.

Phone: +34 868 88 34 60
Fax: +34 868 88 39 67
Email: fjcalvo@um.es

Mailing address: Departamento de Filosofía, Edificio Luis Vives, Campus de Espinardo, Universidad de Murcia, E-30100 Murcia – Spain
Abstract. Contemporary literature distinguishes two ways to defend the claim that cognition is a matter of representations: one, cognition involves representation-hungry tasks; two, cognition involves a complex form of informational covariation between subcomponents of a system with an adaptive function. Each of these conceptions involves a different notion of representation, and promotes a particular view of the architecture of cognition. But despite the differences, each of them aims to support the claim that cognition is a matter of representations on architectural constraints. The objective of this article is twofold: one, it is argued that architectural constraints do not entail either of those two ways to defend the claim that cognition is a matter of representations; two, it is claimed that both notions of representation share an objectionable common element – namely, the idea of a model that grounds the representational reading – that must be abandoned, in favor of a more economical explanation in terms of causal relations, in order to get a clear view of cognition.

Key words: cognition; representation; emulation theory; closed-loop architecture; tropism; circadian oscillator.
1. Of sunflowers and men.

Here is an intuition pump. Do both sunflowers and humans engage in cognitive tasks? Some readers will probably give a negative answer, on the basis of the following asymmetry: unlike humans, who engage in offline reasoning often enough, the sun-tracking behavior of sunflowers always unfolds online, without internal representations of the trajectory of the sun. Hence, it may be said, sunflowers behave reactively, rather than cognitively. Furthermore, it may be added, what a positive answer to the initial question would demand is that sunflowers behave as “super-sunflowers” (Haugeland 1991); that is, systems whose adaptive behavior is independent of the presence of the environmental stimulus – rain or shine. For under those circumstances, the adaptive behavior of those systems would presumably be explained in terms of inner states representing the trajectory of the sun.

So may run a typical answer to our initial question, but here is another possible answer. Unlike sunflowers, humans behave cognitively, but this asymmetry is not a matter of the lack of representational states in sunflowers (unlike humans), for both sunflowers and humans are representational systems. Rather, the asymmetry is a matter of the complexity of the representations of human cognitive systems (unlike sunflowers), given the complexity of human adaptive behavior to their environment. But, despite this difference in complexity, representations are already in place in such non-cognitive systems as sunflowers.

Different though these intuitions are, they share a common commitment to the view that cognition is a matter of representations (even if the existence of representations extends beyond the realm of the cognitive, as in the second answer above). This article will explore whether this is a tenable commitment. To this end, a distinction between two different notions of representation will be introduced.
According to the first, representations are states of a system that explain cognitive success in the absence of environmental stimuli. According to the second, representations are teleologico-informational states of a system that explain cognitive success, even when environmental stimuli are present. The relevance of these two notions for our understanding of the notion of cognition will be introduced in turn. First, sections 2-4 will explore the link between cognition and representation-hungry cases. Later, sections 5-6 will focus on the link between cognition and a teleological notion of representation not tied to representation-hungry cases. As will progressively emerge, both notions of representation share a common element (namely, the idea of a model as a ground for the representational reading of such systems); an element that makes the (perhaps) initially intuitive view that cognition is a matter of representations rather less attractive than (generally) assumed, and must therefore be abandoned (section 7). But freed of this objectionable common element, one may look sympathetically at the view that cognition is a matter of representations, for this view amounts to no more (and no less) than the thesis that successful adaptive behavior in human and non-human systems alike can be explained in terms of similar architecture.

As stated, the main focus of this article is the question whether cognition is a matter of representations. But it may be felt that an answer to this question requires a prior characterization of the cognitive as such. And here, it may seem, lies a deep difficulty for the whole conception of the article, as there is no contemporary consensus regarding what counts as cognitive, or how to draw the dividing line between cognitive and non-cognitive systems. Thus, although (hopefully) everybody recognizes human systems as cognitive, and many are happy to include also certain types of animals, perhaps even invertebrates (Carruthers 2004), only some would count plants as cognitive (Calvo and Keijzer 2009), and probably less would allow talk of “a cognitive robotics” (Clark and Grush 1999). So, given this lack of consensus, shouldn’t one begin
with a characterization of the cognitive/non-cognitive divide, before exploring the relationship between cognition and representation? It may seem so, but in fact authors often rely (albeit unwittingly) on the relation between cognition and representation to offer their own characterization of the cognitive.

As a token, consider the following quote from two prominent authors whose views will be further explored below: “But what makes a phenomenon cognitive in the first place? We suggest that the truly cognitive phenomena are those that involve offline reasoning, vicarious environmental exploration, and the like. It is worth underlining the fact that this stance places us somewhat at odds with an increasingly influential view that either rejects the idea of a cognitive/non-cognitive divide altogether or (more commonly) expands the realm of the cognitive to include all kinds of adaptively valuable organism/environment coupling” (Clark and Grush 1999, 12). Here, no characterization of the cognitive is offered independent of the relation between cognition and representation, for the notion of cognition is glossed in such terms (“offline”, “vicarious”) that it entails representations (stand-ins). It is for this reason that this article is premised on the methodological point that the nature of cognition should be clarified by exploring the question whether cognition involves representations.

Beyond that, the only assumption made from the outset is that cognitive systems are successfully adaptive systems, and therefore that cognition is a form of adaptation. This is narrower than what features as the alternative to Clark and Grush’s preferred view of cognition as “offline” and “vicarious environmental exploration”, for not “all kinds of” adaptive behavior are assumed to be cognitive. The objective of this article is to clarify what type of adaptive behavior counts as cognitive, and for that purpose it is guided by the widely-held assumption that architectural constraints are crucial. In a nutshell, the paper aims to show that what counts as cognitive, and whether cognition is
a matter of representations, are questions that should be addressed by exploring the architecture underlying the adaptive success of different types of biological systems. If it turns out that there are architectural similarities between such systems, then the question about their cognitive status should be answered similarly. So, without further ado, let us get started.

2. The emulation theory of representation and cognition.

The thesis that cognitive processes involve representations is largely driven by the intuition that cognition includes representation-hungry cases (Clark and Toribio 1994). This is not the question-begging thesis it appears to be, but rather the idea that certain cognitive abilities involve dealing with distal, absent or counterfactual objects and states of the world, such as rotating a mental image of an absent object or tracking the sun when occluded. Another label for this kind of cognitive tasks is offline. Thus, the intuition is that the explanation of offline cognitive abilities requires representational processes, insofar as the relevant object or state of the world is not available at the time, and cannot be part of the explanatory cognitive process.

This intuition is compatible with the existence of online (i.e., not offline) cognitive tasks, where objects and states of the world are available for manipulation by the human cognitive subject. The idea here is that there are different types of cognitive tasks – namely, offline and online cognitive tasks; but only the explanation of the former involves representational processes.

Online cognitive tasks appear to be particularly amenable to explanation in terms of coupled processes; i.e., processes that obtain courtesy of a closed-loop architecture (Grush 2003). An open-loop architecture will serve, by way of contrast, to introduce what a closed-loop architecture is.
Open-loop architectures consist of a component called “controller” (a brain, for instance) connected to what shall be broadly called a “body/world” component. Information in open-loop systems flows feedforward from a desired state to the actual outcome (output behavior of the system) via a control signal between controller and body/world (Figure 1). Take a conventional oven for purposes of illustration. Information flows feedforward from a desired state, say, ‘beef nicely roasted’, to the actual outcome (roasted beef) via a control signal between controller and body/world (in this case, beef/oven) that determines the amount of time the oven must be on and the beef in. It is important to notice (especially, for the high-tech minded) that the oven of this example is a traditional one, where there is no re-adjustment of cooking times on the basis of newly available information about the current state of roastedness. Take the beef out of the oven for ten minutes, and it will be undercooked (example adapted from Grush 2003).

By contrast, outcome information in closed-loop architectures is fed back to the system (Figure 2). For a classic example, take thermostats, which get updated with room temperature measurements, permitting on/off re-adjustments in the heater in order to maintain the desired room temperature. For a second favourite example in the philosophical literature, take sunflowers’ adaptive coupling to the sun, as it moves from east to west.
Although online cognitive tasks appear to be particularly amenable to explanation in terms of coupled processes, the proposed explanation of offline cognitive tasks in terms of representational processes is not intended to entail that the systems in question are not coupled. Thus, the defence of representational processes to explain offline tasks has recently relied on the notion of an emulator.

An emulator (Grush 2003) is a subsystem that has been supplemented to the closed-loop system composed of controller and body/world. The resulting architecture is a pseudo-closed-loop system (Figure 3). The key aspect is a secondary source of feedback that obtains as the emulator is fed with a copy of the control signal being sent to the body/world component. This second feedback loop is faster than the loop involving the body/world component, which allows the system to predict the future, or as Grush puts it, “to evaluate sensorimotor counterfactuals” (2003, 70). When Rafa Nadal serves at a speed of one hundred miles per hour, his opponent does not wait for proprioceptive information to be fully processed before getting ready to return the ball. This is emulator-based adaptive coupling!

As described so far, pseudo-closed-loop architectures include the following three aspects:

(i) the whole system involves two subloops (the controller-body/world loop, Figure 4(a); and the controller-emulator loop, Figure 4(b));

(ii) the controller-emulator subloop is an offline process (in the sense introduced above, according to which an aspect of the world is not currently available); and
(iii) the emulator’s kicking in in anticipation accounts for the cognitive success of the system in the world.

[Insert figure 4 about here]

Now, emulators are introduced precisely to signal the differences between types of coupled systems. Thus, the architectures in Figures 1-3 could be arranged in a continuum that goes from the non-representational open-loop and closed-loop systems to the genuinely cognitive (hence, representational) pseudo-closed-loop system. But such an arrangement relies upon a particular reading of pseudo-closed-loop architectures, according to which

(iv) the explanatory work done by emulator-involving processes in the system as a whole is a function of their (full-blooded) representational nature.

In this respect, consider the following definition of a full-blooded representation:

“a creature uses fullblooded internal representations if and only if it is possible to identify within the system specific states and/or processes whose functional role is to act as de-coupleable surrogates for specifiable (usually extra-neural) states of affairs. Motor emulation circuitry, we think, provides a clear, minimal and evolutionarily plausible case in which these conditions may be met.” (Clark and Grush 1999, 8). The idea is, then, that emulator-involving processes explain cognitive success because they stand in for currently unavailable states of the world.ii

Now, in virtue of what does motor emulation circuitry specifically permit a system to meet the aforementioned conditions for representation? A key feature is the
exploitation of a *model* of the target domain. The idea of a model is that of a structural isomorphism between two domains, which in turn leads to the idea that the constituents of the model stand in for aspects of the target domain (Calvo Garzón and García Rodríguez 2009). Bluntly put, if an explanation involves a model, we have a good reason to believe the explanation relies upon representations. Although not common currency (most non-classical theories do not rely upon structural isomorphisms), some of the better positioned (in terms of neurobiological plausibility) theories of cognition subscribe to such a model-based reading. Ryder (2004), for instance, exploits these architectural constraints in order to put forward a cortical network model of mental representation known as SINBAD (“Set of INteracting BAckpropagating Dendrites”). SINBAD cortical networks are structurally isomorphic to the environment they are trained in.

Grush’s emulation theory is equally model-based. As Grush (2004) notes, “an articulated emulator is a functional organization of components (articulants) such that for each significant variable of the MSS [musculoskeletal system], there is a corresponding articulant, and these articulants’ interaction is analogous to the interaction between the variables of the MSS.” (378). Grush’s emulation-based framework, therefore, relies upon the idea of a structural isomorphism between the body/world subsystem and the emulator of Figure 4. The system builds up an emulator circuitry and relies upon it as a model of the body/world. The key is not the one-to-one correspondences among components belonging to the body/world subsystem and the emulator, taken in isolation, but rather how the set of relations among constituents – Grush’s articulants – in the emulator (the model) matches the set of relations among constituents in the body/world subsystem (the target).
Structural isomorphism was required for our tennis player in the aforementioned example to return Rafa Nadal’s serve. Grush (2004) continues: “For example, there would be a group of neurons whose firing frequency corresponds to elbow angle; and this group makes excitatory connections on another group that corresponds to arm angular inertia, such that, just as an increase in elbow angle results in an increase in arm angular inertia, an increase in the firing rate of the first group of neurons instigates an increase in the firing rate of the second.” (379-80). In the tennis example, the structural isomorphism between the parameters in the emulator and the parameters of the body/world allows for an optimal performance, as the player is getting ready to return the ball, despite the fact that proprioceptive information has not been fully processed yet. All of this leads to the idea that the constituents of the emulator stand in for aspects of the body/world target domain, and to the related idea that a structural isomorphism grants the representational import of the model. Following Ramsey (2007), we shall call the notion of representation that exploits structural isomorphisms ‘S-representation’. Thus, motor emulation circuitry acts as a decoupleable surrogate for body/world states of affairs by $S$-representing the extra-neural states of affairs in question.iii

3. Coupled-cum-representational systems?

Emulators are supposed to account for the specific nature of certain aspects of human cognition (offline tasks) within the continuum from the non-representational (hence, non-cognitive) to the offline-and-cognitive (hence, full-blooded representational). Therefore, emulators are supposed to do two related jobs: first, explain what is distinctive about offline cognition in terms of full-blooded representational processes;
and second, give a plausible account of how these cognitive-qua-representational processes appear at a particular point in the continuum. But both points are problematic.

It is unlikely that emulators will help clarify the nature of the processes underlying offline cognition, since offline tasks (as characterized above) involve dealing with distal, absent or counterfactual objects or states of the world, whereas the explanatory value of emulator-involving processes is a function of the relation between the controller-emulator subloop and the controller-body/world subloop. In other words, the processes involved in the controller-emulator subloop help explain cognitive success only insofar as they are adequately affected (updated) by the controller-body/world subloop – i.e., processes involving the real world. In this respect, pseudo-closed-loop systems differ crucially from what is shown in Figure 5, where feedback information from body/world has been removed.

[Insert figure 5 about here]

The problem being raised here is not a problem either about the existence of emulators simpliciter, or about the existence of controller-emulator subloops as part of a larger system including also controller-body/world subloops, in the sense specified above. Rather, the problem is about the full-blooded representational reading of such systems. To be more precise, the point being made here is that emulator-involving processes do not support a view of typical human offline abilities as coupled-cum-representational. Qua coupled, the explanatory value of emulator-involving processes is not independent of the connection to controller-body/world subloops. Qua representational (in a full-blooded sense), the explanatory value of emulator-involving processes is supposed to be a function of the fact that they S-represent or stand in for
something else; in other words, emulators kick in in the envisaged circumstances to do explanatory work precisely because there is a structural isomorphism between the emulator and the body/world components, to the effect that if in the circumstances feedback from the body/world is absent, the emulator steps in to secure cognitive success. But these are incompatible demands on emulator-involving processes: the coupled nature of emulator-involving cognitive processes is an obstacle to their full-blooded representational nature.

It is important to note that the problem is not averted by stressing that the explanation in terms of emulator-involving processes requires only temporal, as opposed to full, decoupleability; in other words, that there are temporally decoupleable processes within a coupled system. As Clark and Grush put it: “the surrogate states are not fully decoupleable from ongoing environmental input. Instead, the surrogates act to provide a kind of fine tuning for environmentally coupled action. Such cases constitute the most minimal example of a representational strategy. [...] What matters is that the basic strategy of using inner states to stand in for (in this case temporarily) absent states of affairs is here in place.” (1999, 10). At first sight, this sounds like the perfect recipe for having your coupled-cum-representational cake. But all the appeal to temporal decoupleability means is that there is a temporal gap, insofar as the controller-emulator subloop kicks in to account for cognitive success in certain circumstances, before information from the body/world reaches the controller. There is, indeed, room for the notion of a temporal gap (anticipation) in coupled systems. But why should this get a full-blooded representational reading, however minimally characterized? Is such a reading really necessary for the explanation of adaptive fine tuning for environmentally coupled action?
Now, it is just possible that the full-blooded representational reading of such systems is brought in because we are dealing with human cognition. So, it might be useful to consider other, non-human, cases that apparently involve similar loops. In the following section we review the case of a non-human biological system that is normally considered not to involve full-blooded representational (or cognitive) processes, but whose adaptive behavior is independent of the continuous presence of environmental stimuli. In particular, we examine the possibility of pseudo-closed loops to account for leaf heliotropism in plants.

4. Pseudo-closed-loop architecture in plants.

The heliotropic behavior of sunflowers constitutes an online form of coupling. In the case of sunflower heliotropism, a closed-loop architecture permits the flower to track the sun. But no anticipatory behavior obtains, unlike the imaginary case of a super-sunflower (Section 1). Invertebrates, by contrast, do show offline capacities, being able to anticipate the position of the sun. In a series of experiments, Dyer and Dickinson (1994) concluded that bees can estimate the position of the sun in the absence of daylight by means of some form of internal time-keeping mechanism that “incorporates spatial and temporal features of the sun’s course that they have never directly seen.” (4471).

But in order to find non-human pseudo-closed-loop systems, we do not need to rely upon thought experiments, such as Haugeland’s super-sunflowers, or upon the ‘simple minds’ of invertebrates (Carruthers 2004). Nocturnal reorientation by plant leaves, not flowers, represents a qualitative change with respect to online sun-tracking. Unless sunflowers are exposed to light in the morning they will fail to reorient to sunrise, remaining at a random orientation throughout the night. By contrast, leaf
laminas of *Lavatera cretica* show anticipatory behavior when they reorient during the night to face the position of sunrise. Furthermore, this anticipatory behavior is retained for a number of days in the absence of solar tracking (Schwartz and Koller 1986). That is, the laminas reorient during the night and keep facing the position of sunrise even after a few days without tracking the sun, and without sensing the position of sunset (Calvo and Keijzer 2009).

Nocturnal reorientation confers a clear advantage to plants as the absorption of photons to synthesize food is critical to their survival, and some of the processes prerequisite for photosynthesis take place just before dawn. Anticipation of sun-light allows plants to optimize their light intake (Kreps and Kay 1997), avoiding the overlap of incompatible metabolic processes. This anticipatory behavior is accomplished courtesy of a cellular mechanism that generates reliable oscillations that keep time by approximating the duration of the day cycle on Earth – *circa* (about) and *dies* (day).

Circadian mechanisms control many processes at different levels, such as olfactory responses of *Drosophila melanogaster* (Krishnan et al. 1999), or the anticipation of day/night cycles by *Arabidopsis thaliana*, the ‘drosophila’ of the plant sciences where the genes and proteins implicated in plant circadian time-keeping were first discovered.iv

There is a common way to understand circadian mechanisms as involving, as separate components, endogenously generated rhythms and entrainment by external cues, roughly as follows (this view of circadian mechanisms will be critically reviewed in section 6 below). Circadian mechanisms consist of a number of oscillators that serve to generate circadian rhythms. Although circadian rhythms are generated endogenously, the phase of the oscillators needs to be reset on a regular basis in order to facilitate synchronization with external cycles (otherwise, one would be permanently jetlagged.
after a transatlantic crossing, say). Plants are entrained (updated) by environmental \textit{zeitgebers} (time givers) such as light onset, dawn and temperature. In this way, \textit{zeitgebers} provide the external cues that entrain a circadian cycle that confers fitness, insofar as the period, phase and amplitude of the rhythms that the oscillator outputs synchronize with planetary cycles. Figure 6 schematically shows a circadian mechanism formed by an oscillator and input/output pathways. The output pathway allows the oscillator to coordinate with the physiology, metabolism and development under rhythmic control. On the other hand, physiology, metabolism and development require an optimal tuning with environmental features to take place. An input pathway thus permits the oscillator to be entrained by external rhythms (light and temperature, primarily). A pseudo-closed-loop system (Figure 7), similar to the one introduced in Figure 3 above, illustrates the feedback loops involved.

[Insert figure 6 about here]

[Insert figure 7 about here]

In this case, we have an oscillator, instead of an emulator, but the architecture remains the same as in Figure 3. The output of the oscillator regulates the behavior of the plant as the oscillator feedbacks to the controller. But this feedback (equivalent to the one that obtains in Figure 4b) only accounts for the generation of internal rhythms. Circadian phenomena are likewise characterized by the external entrainment of the system by environmental cues. \textit{Zeitgebers} output by the body/world component are thus processed by the controller and fed in turn to the oscillator for resetting purposes. Taken together, this explains plant nocturnal reorientation for up to four days in the absence of
sunrise stimulation. The phenomenon can be understood in terms of pseudo-closed loops, where controller-oscillator subloops operate in anticipation of zeitgeber stimuli, a process that is preserved only for a limited period of time, thereby showing that processes involving oscillators have explanatory value in connection with processes involving the world.

It is unlikely that the existence of pseudo-closed loops to account for leaf heliotropism will get a full-blooded representational reading, unless one is prepared to conclude that plants are cognitive systems (given the close relation between cognition and pseudo-closed loops defended in the emulation theory). A causal notion of information (i.e., the existence of causal relations in each subloop as part of the larger system) will do all the necessary explanatory work, instead. But, if such a full-blooded representational reading is not forthcoming in cases of leaf heliotropism, why do architecturally similar emulator-involving explanatory processes get a full-blooded representational reading in the case of human offline cognitive tasks? Whatever the real reason turns out to be, it is clear that the existence of emulator-involving loops cannot be the reason.

5. A teleologico-representational theory of cognition.

To sum up the last two sections, it has been argued, first, that insofar as emulators explain human offline cognition, the full-blooded representational reading is quite alien to their explanatory work; and second, that pseudo-closed-loop architecture can be found at points in the continuum that are normally considered not to involve full-blooded representational (or cognitive) processes.

It is a consequence of this that the explanation of human cognition is on a par with the explanation of other, non-human, coupled systems (e.g., plants). The crucial move
here is that coupled processes are not representational (in a full-blooded sense); a move that can be defended on the basis of certain considerations about symmetry, as follows: if the explanation of certain human cognitive abilities makes reference to processes that are architecturally similar to typical non-representational (in the full-blooded sense) coupled systems, then the explanatory processes in question are not representational (in the full-blooded sense).

Nonetheless, it may still be argued that leaf heliotropism could be accounted for in representational terms; and similarly, that sunflowers, and even thermostats, are representational systems, in a sense yet to be made precise. So far, the thesis that cognition involves representations has been pumped by hungri ness-related intuitions, but it need not be driven by such intuitions. If this is the case, the emulation theory of representation is not the one and only way to signal the distinction between the non-representational and the cognitive. There is in fact a more basic, non-full-blooded, notion of representation, which may be taken to mark the relevant dividing line here.

Insofar as this different notion of representation is not tied to hungri ness-related intuitions, absence of decoupling must be a central feature. Bechtel (1998), for instance, favors a teleological notion of representation that does not demand decoupling, according to which even non-biological systems are representational systems. Bechtel is quite ready to read thermostats and other closed-loop systems in (minimal) representational terms. According to Bechtel, representations will obtain in any closed-loop architecture that contains a subsystem that draws on a relation of covariation between two other subcomponents for adaptive success (biological or otherwise) in a given environment.

To take a well-known illustration, Bechtel (1998) interprets Watt’s centrifugal governor in these (minimal) representational terms. To remind the reader, the Watt
governor (Figure 8) was attached to a steam engine in order to keep constant the speed of a flywheel. To perform this speed-preservation function, the governor consists of a spindle with two arms attached to the flywheel in such a way that the rate that the arms fall and rise at, as the spindle rotates slower or faster, covaries with the speed of the flywheel itself. As the angle of the spindle arms vary, a valve opens and closes accordingly. In this way, as the flywheel speeds up, the arms rise faster and the valve closes. This in turn reduces the amount of steam, slowing down the rotation of the spindle. As the flywheel slows down, decrease in centrifugal force allows the arms to fall, with the result of the valve opening once again, and, with more steam coming in, the cycle begins again. The overall effect of this positive/negative feedback loop is the maintenance of the constant speed of the steam engine.

Now, as mentioned, contrary to Grush’s non-representational reading of such a closed-loop system, Bechtel interprets the centrifugal governor in representational terms. The angle of the arms serves as a teleological representation insofar as it carries flywheel speed information. The angle of the arms covaries with the speed of the flywheel for the opening/closing of the valve to achieve success (i.e., constant speed of the steam engine).

This is, in a nutshell, a teleological, as opposed to an emulation, notion of representation. The distinction between these two notions, and the architectural constraints associated with them, gives two different ways of arranging the systems in Figures 1-3 above. On the one hand, according to Grush’s emulation theory, there is a continuum that goes from the purely non-representational open-loop and closed-loop
systems to the genuinely cognitive (hence, representational – in a full-blooded sense) pseudo-closed-loop system. On the other hand, according to Bechtel’s teleological notion of representation, there is a continuum that goes from the purely non-representational open-loop system to the genuinely representational (whether cognitive or not) closed-loop and pseudo-closed-loop systems. The point to assess next is whether this teleological notion of representation is in a better position than the full-blooded notion of the emulation theory, to account for the intuition that cognition is a matter of representations.

6. Circadian oscillators and entrainment in biological systems.

Leaving to one side the intuitive plausibility, or otherwise, of the representational reading of the Watt governor, or other such mechanical devices, Bechtel’s teleological notion of representation offers the possibility of a realist unified understanding of representation in biological systems, from simple life-forms to language-using creatures. Thus, according to Bechtel’s picture, the representational states that explain typical human cognitive tasks are nothing other than a more complex form of the representational states already present in more simple biological systems (and indeed beyond, in non-biological systems). In a related vein, Bechtel’s recent pioneering work on the mechanisms of time-keeping in animals has aimed to show how the notion of representation needed for cognitive explanations is anchored biologically. But, as will be argued next, although Bechtel’s work helps understand time-keeping in biological systems generally (not only in animals), there is a big question mark over the teleologicorepresentational reading of such systems.

As research on *Drosophila* shows (Konopka and Benzer 1971), the role of genes in the process of generating circadian oscillations responds to the aforementioned
(positive/negative feedback) closed-loop architecture. In particular, the
positive/negative interaction among molecular level components generates the rhythm.
The mechanism is the following: *per* is the gene that translates into a PER protein via
the transcription into mRNA.\textsuperscript{vii} PER inhibits its own expression by feeding back onto
*per* mRNA transcription (see Figure 9). The PER protein inhibits the transcription of
*per*, in such a way that when PER is low enough transcription can begin again. As more
PER obtains inhibition starts again.\textsuperscript{viii} In this way, what we have is a cycle of
inhibition/transcription that conforms to the constraints of the Watt governing loop.

[Insert figure 9 about here]

Topological differences aside, plant oscillators pretty much resemble animal
oscillators. Although the proteins involved in time-keeping in plants differ from those
found in animals, their roles in feedback loop oscillations as the protein levels drop and
rise are functionally identical across eukaryotes. Plant circadian mechanisms are formed
by transcriptional morning and evening oscillators. These are positive/negative feedback
loops of reciprocal regulation among molecular components. The key components in
the *Arabidopsis* circadian mechanism are the genes that encode transcription factors
CCA1 (CIRCADIAN CLOCK ASSOCIATED 1) and LHY (LATE ELONGATED
HYPOCOTYL), and TOC1 (TIMING OF CAB1).\textsuperscript{ix} As the night unfolds, the positive
part of the loop takes place with TOC1 inducing the expression of CCA1 and LHY. The
negative side, on the other hand, takes place in daylight, with CCA1 and LHY
repressing in its turn the transcription of TOC1. But as CCA1 and LHY levels drop
towards dusk, the expression of TOC1 boosts again. The result of this regulatory
process between TOC1 and LHY/CCA1 is exactly the same sort of positive/negative feedback closed loop reviewed earlier.

Bechtel’s point is that representations, understood realistically, go all the way down to emulators and circadian oscillators insofar as they are all coupled systems that involve control via positive/negative feedback loops. Behavioral coordination in this way is the way to ground representations teleologically. In other words, circadian oscillators are adaptive mechanisms whose function is to represent geophysical periodic cycles.

For present purposes, we are interested in just the more basic form of feedback loop, but what we really find is a series of interlocking feedback loops whose details are yet to be elucidated. Nevertheless, once the whole picture is finished, a complete causal account of how oscillations are generated and of how entrainment works will be in place. But does such a causal explanation itself support a representational reading of the adaptive behavior of biological systems? As Bechtel (personal communication) points out, if circadian oscillators were not representing time of day, how could their function within the system be understood? In particular, why pay attention to the entrainment of circadian oscillators unless their function as cellular clocks is clear from the start?

Bechtel’s reasoning here parallels his interpretation of the Watt governor. As he notes in respect of the Watt governor, arm angles “stand in for the speed of the steam engine … and it is because they so stand in that the governor is able to regulate the flow of steam appropriately. If someone did not immediately perceive how the governor performed its function, what one would do is explain how the angle of the arms respond to the steam with which the flywheel is turning (i.e., it carries information about the speed), thereby making this information available in a format that can be used by the linkage mechanism to control the flow of steam and the speed of the flywheel at a future
time” (2001, 335). Likewise, the circadian oscillator stands in for geophysical periodic cycles, and it is because it so stands in that the plant is able to anticipate the sun. In fact, the argument would go, if someone did not immediately perceive how the oscillator performed its function, what one would do is explain how the periods, phases and amplitudes of the rhythms that the oscillator outputs synchronize with planetary periods, phases and amplitudes.

In Bechtel’s picture, then, biological oscillators perform their function as clocks because of entrainment. The underlying thought appears to be that entrainment prevents oscillators from free-running that deviates from 24-hour cycles. This, in turn, supports a view of the architecture of time-keeping in biological systems where oscillation and entrainment come apart. Roughly put, the oscillator subcomponent is already in place, doing its job, before entrainment is introduced to adjust oscillation to planetary periods. Here, adjustment is in fact modelling: oscillators perform their function by modelling 24-hour planetary periods – i.e., they are biological clocks. Therefore, biological oscillators must be understood in teleologico-representational terms.

This reconstruction of Bechtel’s picture makes it clear that the teleologico-representational reading comes for free, as it were, with the architectural point about the separation between oscillation and entrainment. But an alternative architecture is possible, based on the idea that oscillation makes no sense in the absence of entrainment; so entrainment is not an extra, added on to avoid free-running that deviates from 24-hour cycles.

The crucial point – namely, that there is no such thing as endogenous free-running rhythmicity in the absence of environmental stimulation – has already been forcefully made by Roenneberg and Merrow (2003). They claim: “The circadian clock is not entrained because its free-running period deviates from 24 h, but it is able to free run
because of how it evolved to work optimally when entrained. This is supported by the fact that there is no exact circadian period because it depends on the nature of the constant conditions [...] Thus, the correct statement should be the following: The circadian clock has evolved to fine tune biological functions to specific times within the day or night, and, when put into constant conditions, it free runs close to 24 h! To fully appreciate the function of the circadian system, we have to understand how clocks entrain to the environment.” (183; emphasis added).

The outcome of all this is that there are two possible ways to approach circadian mechanisms. According to the first approach, favoured by Bechtel, oscillation and entrainment are kept separate from the beginning, and the role of entrainment is quite simply to adjust the independent oscillatory rhythm to the environment. According to the second approach, the existence of an oscillatory rhythm is not prior to entrainment, but rather the result of entrainment; so oscillation and entrainment cannot be kept apart. In the first approach, oscillatory rhythms are decoupled, or at least decoupleable, from the environment (as cases of free-running deviating from 24-hour cycles make clear); whereas in the second approach oscillatory rhythms are, even must be, coupled to the environment. In the terms introduced above, the first approach pushes towards a pseudo-closed-loop architecture, and the second fits a closed-loop architecture, instead.

The relevance of this for the purposes of this article is twofold. Firstly, although Bechtel’s notions of representation and cognition are not based on intuitions about hungriness, in the end his underlying reason for viewing circadian mechanisms as representational systems (namely, the separation between internally-generated oscillatory rhythms and entrainment to the environment) pushes towards a view of the architecture of cognition pretty similar to the view defended on the basis of intuitions about hungriness. Secondly, insofar the separation of oscillatory rhythm and
Entrainment is not compulsory, neither is a teleologico-representational reading of circadian mechanisms.

But, at this point, the following question would be well-posed: even if it is not compulsory, are there any further reasons to abandon a teleologico-representational reading of circadian mechanisms?

7. An objectionable common view of cognition.

As mentioned in the last section, Bechtel’s view of the architecture of time-keeping in biological systems as oscillation-plus-entrainment invites a gloss in terms of models – that is to say, oscillators model (hence, represent) planetary cycles. It is interesting to note that such a gloss points to a crucial similarity between Grush’s emulation and Bechtel’s teleological theories of cognition. There is a similarity in the view, subscribed by both theories, that cognition is a matter of representations. At the end of the last section, it was further suggested that there is a pressure towards architectural convergence. As will be argued now, this is also related to the fact that both theories subscribe to an S-representational view of cognition in the sense introduced in section 2 above – namely, there is a relation of structural isomorphism between subcomponents within the system. As already mentioned, the key aspect in the relation of structural isomorphism is how the set of relations among constituents in the model matches the set of relations among constituents in the target domain, not the one-to-one correspondences among components belonging to each set, taken in isolation. Thus, it is the structural isomorphism between real world geophysical periodic cycles and relations within the oscillator that makes the circadian oscillator representational. Or more precisely, according to the teleological view, it is the use of this structural isomorphism by one subsystem that brings in the representational reading of the circadian oscillator.
Similarly, as seen earlier, it is the structural isomorphism between emulator and body/plant that makes emulator-involving tasks, or systems, representational.

Now, there is something objectionable in the view of cognition as involving S-representational states; namely, the fact that alleged examples of modelling relations can be given an alternative, more economical, explanation without the idea of a model – more economical, that is, in terms of the conceptual resources employed. To make this point, the remainder of this section will take a critical look at an alleged example of mindless (i.e., non-human, even non-biological) modelling systems due to Ramsey (2007).

To provide some of the relevant background, Ramsey introduces his example as part of a broader strategy to show that explanations of success involving the idea of a model are genuine representational explanations; genuine insofar as such explanations would meet the job description challenge. In Ramsey’s words, this is the challenge to provide “some sort of account of just how the structure’s possession of intentional content is (in some way) relevant to what it does in the cognitive system. [...] We need, in other words, an account of how it actually serves as a representation in a physical system; of how it functions as a representation” (2007, 27). As should be clear from the beginning, there is nothing in the job description challenge, nor in the notion of a representational explanation, to suggest that only human systems can meet the challenge and therefore be genuinely representational. Thus, Ramsey considers representational explanations in mindless systems. Against this background, the aim of Ramsey’s example is to provide a contrast between different types of mindless systems, some where success is explained in representational terms, so the job description challenge is met, and some where it isn’t. As already mentioned, for Ramsey, genuine representations are S-representations (i.e., models or structural isomorphisms). So,
Ramsey’s example must provide a contrast between mindless systems, and contrasting explanations of success, where only some of them do involve, but crucially must involve, S-representational states.

Here is Ramsey’s example. Consider several different cars that move through a curved segment of a walled track. Car A manages to navigate the track courtesy of two rods sticking out from the corners of the front bumper. Whenever one of the rods is pushed inwards as the car touches one of the walls, a servomechanism is activated, turning the car away from the wall. According to Ramsey, such a straightforward causal dependency relation prevents the example from being given a representational reading. Bluntly put, the states of the car that explain its navigational success causally covary with external conditions. Car B, by contrast, successfully navigates through the same track courtesy of a rudder that fits into a groove along the middle of the track. This time, changes in the rudder as the car moves along the groove bring about changes in the car’s steering wheel and front wheels. The simple explanation is that the groove is shaped as the track itself, and hence serves as a model of the track. Hence, according to Ramsey, unlike car A, car B is a modelling or S-representational system.

Further, Ramsey compares cars A and B with car C, a completely unguided vehicle that simply makes its way along the track by bouncing off the walls over and over again. “Its course”, Ramsey points out, “is determined only by its brute interactions with the physical structure of the path it is on” (194). The idea is that insofar as car A’s navigational success gets explained in terms of the causal interactions themselves, with no need to invoke models or isomorphisms, it falls in the same non-representational category as car C. On the other hand, car B is an S-representational system insofar as the groove where the rudder fits is a model of the track itself. The
The underlying thought is that the very existence of a model, as used by a mindless system, is sufficient to explain navigational success in representational terms.

But is it correct that car B, but not car A, is an S-representational system? This can be doubted, for it can be argued that the differences between cars A and C, on the one hand, and car B, on the other, are in the eye of the beholder; or more to the point, the differences are only a matter of the way the example is presented. To see this, consider a modified version of car A, car A*, where the car plus the two sticking out rods is as wide as the walled track itself. Crucially, car A* would not bounce off the sides of the track, but would rather slide smoothly along the track, much like car B appears to do with the help of rudder and groove. In fact, there are interesting similarities between car A* and car B, not only in their behavior, but also in the explanation of such behavior. For insofar as there is no bouncing off, or zig-zagging, involved in the way car A* navigates through the track, car A* also looks like an S-representational system. In other words, like car B, the explanation of car A*’s success involves S-representational states, so the job description challenge is met. Briefly put, like the shape of the groove, the shape of the wall is isomorphic with the curve of the track itself. So, if car B’s use of the groove makes it an S-representational system, car A*’s use of the wall must make it an S-representational system, too. But (and this is the crux), if the original, unmodified car A also makes use of the wall to successfully navigate through the track, why is it claimed that it is not an S-representational system?

The former appears to suggest that all three cars are S-representational systems. But, to counter this, consider this further detail in car B: namely, if the rudder fits comfortably into the groove, there must be room for some level (however minimal) of zig-zagging as the car moves on courtesy of the rudder’s position in the groove. (Compare this with what happens with railway travel, where passengers experience
slight shaking as the wheels of the train move along the railroad track and the inner sides of the wheels bounce off the sides of the track as the railroad bends.) The significance of this is that if car A’s and car C’s bouncing off and zig-zagging behavior makes them non-representational systems, insofar as navigational success is a matter of brute causal relations, then the same must be the case with car B; so the explanation of car B’s behavior cannot be a matter of S-representational states, but rather a matter of causal relations. What this shows is that all cars (A, A*, B and C) bounce off one thing or another, making the wheels turn, either as the rods touch the wall, or as the rudder moves in the groove. All that changes is the sophistication and length of the causal chain involved.

Summing up, Ramsey’s example was meant to provide an illustration of an S-representational mindless system; that is, a system where the explanation of (navigational) success was a matter of S-representational states. But the example only shows this because of the specific description offered of the systems involved; whereas attention to some aspects of the examples shows instead that success must be explained in terms of a set of structures and states acting as causal mechanisms or relay switches. Hence, contrary to Ramsey’s objectives, no contrast emerges between two types of mindless systems, some where success is explained in terms of models, and some where it isn’t. Rather, what emerges is that success can be more economically explained in terms of causal relations.

The important point, for the general objectives of this article, is that the lesson can be carried over to the role of emulators and oscillators in the explanation of cognitive (or generally, adaptive) behavior in biological systems. Thus, as claimed at the end of section 4, all the explanation of the anticipatory behavior of certain systems in terms of emulator-involving loops needs is the idea of a causal loop, where different
subcomponents interact in accordance with certain temporal parameters. Similarly, all the explanation of cognitive (or in general, adaptive) success in terms of oscillators needs is the idea of a causal connection between subcomponents, much like in the case of the Watt governor, where success (i.e., constant speed of the engine) is explained in terms of causal relations between the position of valve, the speed of the flywheel and the angle of the spindle arms. But if these more economical explanations are available, why do emulators and oscillators get an S-representational reading? One thing seems clear: architectural constraints do not force an S-representational view of cognition.

8. Is cognition a matter of representations?

To sum up, this article began with the following question: Do both sunflowers and humans engage in cognitive tasks? In previous sections, the following two (apparently) intuitive answers have been discarded. One, only humans engage in cognitive tasks, because only humans engage in tasks involving temporal decoupleability; hence, only humans engage in tasks requiring explanation in terms of full-blooded representations. Two, although both sunflowers and humans engage in tasks requiring explanation in terms of teleological representations, only humans engage in cognitive tasks, for only the explanation of human adaptive behavior requires complex teleologico-representational states. Despite other differences, both answers are committed to the view that cognition is a matter of representations, and to the view that this follows from architectural constraints on the relevant tasks (whether pseudo-closed-loop, as in the emulation theory; or closed-loop, as in the teleological theory). In reply, it has been argued, first, that a representational reading of the relevant architectures is not compulsory – neither a full-blooded representational reading of pseudo-closed-loop system, nor a teleologico-representational reading of closed-loop systems. And second,
that both readings share in common an objectionable view of cognition, where explanatory states are models of, or structurally isomorphic with, a target domain.

At this point, a third possible answer to our initial question emerges – namely, the only thing wrong with returning a positive answer to the original question whether sunflowers and humans engage in cognitive tasks is the assumption that the explanation of cognition involves representational processes, either in the full-blooded or teleological senses. Without this assumption, what the positive answer amounts to is the thesis that successful adaptive behavior in humans and plants alike can be explained in terms of similar architecture.

What similar architecture? If there is indeed a symmetry between the adaptive behavior of sunflowers and humans, and the explanation of entrainment in biological time-keeping defended at the end of section 6 is correct, then the right architecture must be closed-loop. This does not amount to an outright rejection of emulator-involving loops, or pseudo-closed-loop architectures, but only a rejection of the idea that pseudo-closed-loop architectures differ substantially from closed-loop architectures (see footnote xii). There is no problem with the idea that pseudo-closed architectures are a special type of closed-loop architectures, on account of the more complex causal relations between components. But this does not bring in substantial differences. The idea that they are substantially different architectures is, all over again, the idea that temporal anticipation involves decoupleability and this, in turn, full-blooded representations. Without this optional representational reading, all there is is a closed loop of causal relations, albeit more complex than other such loops, on account of the temporal parameters involved. Basically, the sort of complex temporally-sensitive closed loop already in place in the relations between genes and proteins in Arabidopsis,
where different positive/negative feedback loops are triggered as night unfolds or daylight approaches, as shown in section 6 above.

So, is cognition a matter of representations? As one anonymous referee correctly points out, the aim of this article is not to furnish a final answer to this question. Rather, more modestly, the paper should be read ultimately in the context of an already established research tradition that the reader familiar with the contemporary discussion will have identified with the embodied cognitive science literature, writ large (see Calvo and Gomila, 2008, and the references therein); a tradition that questions on empirical grounds the link between cognition and representation that is our overall target. With this proviso, the gist of this article is that, for architectural reasons, cognition is not a matter of full-blooded or teleological representations, the most prominent options in the contemporary scene. Rather, on architectural reasons alone, cognition is a matter of causal relations, with the representational readings as unnecessary and objectionable extras.
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References


Figure 1 An open-loop (feedforward) system composed of controller and body/world subsystems

Figure 2 A closed-loop (feedbackward) system composed of controller and body/world subsystems

Figure 3 A pseudo-closed-loop system composed of controller, body/world and emulator subsystems
Figure 4 Subloops within a pseudo-closed-loop system (Figure 4(a): controller-body/world subloop with feedback information about body/world; Figure 4(b): controller-emulator subloop with feedback from emulator)

Figure 5 A pseudo-closed-loop system composed of controller, body/world and emulator subsystems, with feedback information about body/world removed
Figure 6 Schematic representation of the input/output pathways of a circadian mechanism

Figure 7 A *pseudo*-closed-loop system composed of controller, body/world and oscillator subsystems

Figure 8 Flywheel speed of a steam engine is kept constant courtesy of Watt’s centrifugal governor. The governor consists of a spindle with two arms attached to the flywheel and linked to the throttle valve. The rate that the arms fall and rise at, as the spindle rotates slower or faster, covaries with the speed of the flywheel itself. As the angle of the spindle arms vary, the throttle valve opens and closes accordingly, releasing more or less steam, thereby controlling flywheel speed.
Figure 9 Schematic representation of the circadian mechanism in Drosophila as an inhibition-transcription cycle, after Hardin, Hall, and Rosbash (1990). Gene per translates into protein PER via the transcription into mRNA (transport of mRNA from nucleus to cytoplasm ommitted from figure). PER feeds back onto per-mRNA transcription, thereby inhibiting its own expression. When PER is low enough transcription begins. As more PER obtains inhibition starts again. (Nucleus and cytoplasm are separated by dotted line.)
This article is concerned with biological systems, sidestepping the issue whether hybrid or non-biological systems count as cognitive.

Although someone may object to Clark & Grush’s definition of a full-blooded representation in terms of necessary and sufficient conditions (note, for example, that the fact that some cases of sensorimotor coordination call for emulation does not close the door to other notions playing the required representational role in other activities), we shall respect their “if and only if” own wording.

Chemero (2009) objects to the very idea of an emulator theory of representation that allows for the representation of the body itself, rather than the world, as the target domain. Although sympathetic to Chemero’s overall approach, we may nonetheless speak quite freely of a single (extra-neural) body/world subsystem for present purposes, as nothing bears on Chemero’s finer-grained distinction.

Most of what we know about plant clocks is due to research on Arabidopsis. Thus, since the molecular components recruited do not seem to vary across plant species, and with apologies to the Lavatera family, we shall restrict our discussion in what follows to work on Arabidopsis.

In fact, theories of representation that do not demand decoupling abound in the literature. The informational theories of Dretske (1981) and Fodor (1987) are well-known cases in point. Bechtel’s approach is nonetheless inspired by Millikan’s (1984) teleological theory of representation. Someone may worry however that Millikan’s appeal to teleology does not commit her to the idea that intentionality involves representation, or at least does not commit her to a form of representationalism as directly as in the case of Dretske and Fodor and their respective informational approaches (although for a representational reading of Millikan see Ramsey, 2007,
ch.3). But, for present purposes, we need not dwell on this issue since we shall be concerned only with Bechtel’s own adaptation of Millikan’s teleological account; a position that grants a form of representationalism that need not be shared by Millikan. In what follows, and for the sake of illustration, we shall simply follow Bechtel in assuming under his teleologico-representational account the idea that intentionality involves representation. We thank an anonymous referee for bringing this point to our attention.

vi The Watt governor was initially used by van Gelder (1995) as an illustration of his anti-representationalist stance. Given the amount of ink devoted to discussing the vices and virtues of van Gelder’s proposal in the last fifteen years, we shall spare the details to the reader, and only go over the key architectural features with which this article is concerned.

vii Following standard usage, genes and proteins are named in italics and capital letters, respectively.

viii For simplicity’s sake, much detail is omitted here. PER can only work indirectly on its own DNA, as it cannot regulate per transcription directly (for a thorough review of the missing components herewith, see Bechtel in press; Bechtel and Abrahamsen in press).

ix Again, the picture herewith presented simplifies the topology and processes involved. In fact, a number of additional transcription factors needed to complete the interlocking process have only been discovered in the last few years, such as ELF4 (EARLY FLOWERING 4), GI (GIGANTEA) and LUX (LUX ARRYTHMO) (see Más 2008, and references therein).

x This broader strategy relates to the idea that scientific explanations, and explanations in cognitive science in particular, are often regarded as reductive, in the sense that
explanandum and explanans belong to different levels in Marr’s (1982) seminal analysis. The anti-representationalist stance taken in this article is directly related to Marr’s analysis, insofar as the idea that the explanans in cognitive science requires representational states is rejected (see Calvo Garzón and García Rodríguez 2009). But this entails that there is something in need of explanation, i.e. cognitive abilities with intentional properties. So, no general intentional eliminativism at the level of the explanandum follows from the stance taken in this article.

xi Thanks to Gustavo Fernández for coming up with the following examples.

xii An anonymous referee worries that such subcomponent interactions, and our subsequent interpretation in causal terms, may be the result of having focused too narrowly upon ‘control theory’ itself. In fact, insofar as biological plausibility is concerned, Grush’s emulation theory relies upon enriching pseudo-closed-loop systems with more sophisticated resources from ‘signal processing’ such as Kalman filters (Wolpert, 1995). A Kalman filter is a dynamical system that combines input and output system flow in order to attain appropriate estimations in, say, sensorimotor integration; estimations that are optimized courtesy of a Kalman “gain” that serves to weight differentially the contribution being made by each subcomponent. In this way, by choosing different values for the parameters, the Kalman filter can rely more or less heavily upon endogenous as opposed to exogenous information, and vice versa. Such weighting usually shifts during processing as a function of both the reliability of the system’s sensors and the predictability of the signal (see Grush 2004, and the references therein). Thus, an estimation of a rather predictable signal, in the context of an otherwise unreliable sensor, is given more credit than an estimation of a more unpredictable signal, in the context of a reliable sensor. Now, the worry is that depending on how the Kalman gain is applied, optimal estimation may end up being the
result of inner dynamics exclusively. Reasons of space prohibit us from extending
further but, succinctly, the core idea of an interactive causal loop remains untouched.
After all, regardless of the bells and whistles (see Wolpert, 1995, for the details), a
Kalman filter is nothing but a linear dynamical system that combines the inflow and
outflow resources available for the purposes of adaption. In other words, the added
value of Kalman filters for biologically realistic systems resides in the very possibility
of exploiting a trade-off between the emulator/oscillator and the plant. Certainly, as a
limiting case (Kalman gains set to 0 or 1), we have systems that do not exploit the trade-
off. Although such systems are idealizations of theoretical interest, we are concerned
with Kalman gains ranging somewhere between 0 and 1: i.e., Kalman-enhanced pseudo-
closed loop systems that filter the signal in such a way that more or less weight may be
placed on the output of the emulator or on the proprioceptive information, accordingly.
But, such systems, however the different weights are shifted, involve a closed-loop
architecture, and therefore, for obvious reasons, the worry cancels out.