mapping from motor commands to pictures, a device would need input unique to each picture, a condition certainly not met by motor "plans" for human effectors. Of course, the lay would be different if the device were a model of the pictured object, already activated by other signals and thus all by itself constituting a specific interpretation of the accepted signals. We acknowledge that Grush points to this possibility, but in the case now at hand the input could be anything versatile enough to exploit the capabilities of the respective model.

Another problem of the same kind arises concerning the control of the controller. If Grush's sensory residual is questionable because the idea of picture subtraction does not make sense cognitively (while the idea of structure tests does), then the comparison of "environmentally specified" goal signals to feedback in the same format will work even less – unless the controller is able to use the model realm or, rather, reduces to a servomechanism of the latter. That would render the idea of model control by efference copies gratuitous.

Our arguments imply, or so we believe, that the idea of measuring forward models and Kalman filtering the results, if at all applicable to intelligent organisms, applies only to functions well beneath and possibly up to the level of sensorimotor schemata.

Motoric emulation may contribute to perceiving imitable stimuli

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Abstract: First, I note three questions that need further exploration: how fast the emulator operates, compared to the real-time events it models; what exactly perceptual emulation, with no motor component, consists of; and whether images are equivalent to raw sensations. Next, I propose that Grush's framework can explain the role of motor activation in processing "imitable" stimuli.

A few questions . . . I shall begin by noting a few problems, puzzles, and gaps in the model. These are not intended to detract from the considerable accomplishment of Grush's proposal, but rather to suggest lines along which this set of ideas could be pushed forward.

(1) The timing problem. How closely in sync with the plant (the system being modeled) is the emulator? On the one hand, an emulator is supposed to be fast, bypassing delays in sensory feedback and allowing corrections in motor control to be made in a timely fashion. This requires an emulator that runs its simulation almost simultaneously with (perhaps even slightly ahead of?) the events in the external world. On the other hand, however, an emulator is supposed to correct for measurement error, by running measurement processes in reverse and employing Kalman filters. This is an architecture that adds several processing stages beyond simply sending sensory feedback to the controller, hence actually exacerbating the first problem that the emulator is asked to solve. Can both these functions be served by the same emulator, or is this architecture being asked to do too much?

(2) The perceptual simulation problem. Grush acknowledges that much of human cognition resides within the boxes in his Figure 7, rather than in the functional relations between them. In some respects, this is completely justified. For example, the box modestly labeled "measurement inverse" actually represents all of perceptual processing (to wit, reconstructing the distal stimulus from the proximal stimulus); but providing an account of this box is not the purpose of Grush's project. More problematic, though, is the box labeled "organism/environment model." It is here that, in the "degenerate case" of perceptual imagery without a motoric component, the entire business of imagery happens. And explaining imagery is a central part of Grush's purpose. Somehow, the "organism/environment model" has internalized principles and regularities that allow it to run simulations of the external world. How such a feat of simulation is possible seems to be the real heart of the imagery question. (Some possible beginnings of an answer to this are suggested below.)

(3) The images-aren't-pictures problem. Grush takes at face value the idea that modality-specific imagery is equivalent to unprocessed sensory input. In fact, this idea has been vigorously challenged (e.g., Reisberg & Chambers 1991; Reisberg et al. 1989). If a modality-specific image at all resembles a percept, as opposed to a raw sensory input, then the model in Figure 7 would need to be changed. It would not be possible to generate this kind of imagery by going all the way to an amodal three-dimensional representation (the organism/environment model) and then simply "looking at it" (the second measurement) to recreate the raw sensory input.

. . . and a proposal. Having issued these challenges, though, I would now like to turn to a different area in which Grush's model may offer considerable explanatory power: the perception and representation of stimuli that can be imitated with one's own body. There is growing evidence that such stimuli (which consist primarily of other humans' postures and movements) have a special status in the human cognitive system. Specifically, imitable stimuli appear to have privileged connections to motor representations of performing similar postures and movements with one's own body. Evidence for this comes from the literature on mirror neurons and on stimulus response compatibility, and from a variety of other sources (see Wilson 2001 for review). What is the purpose, though, of activating imitative motor programs in response to perceptual input, when there is no intention to overtly imitate? One possibility is that motor representations may actually play a role in perceptual processing.

As Grush suggests, an emulator which can capture predictable properties of perceptual events and simulate them in real time may serve both to assist perceptual processing and to recreate perceptual events in their absence. Indeed, the operation of just such a system appears to be behind the phenomenon of representational momentum, in which perceptual events are immediately misremembered as having continued beyond the point at which they ceased to be visible.

In most cases, representational momentum occurs for movement trajectories that are predictable based on simple geometric principles, such as rotation about an axis (Freyd & Finke 1984), circular paths (Hubbard 1996), spiral paths (Freyd & Jones 1994), oscillatory motion (Verfaillie & d'Ydewalle 1991), and predictable changes in direction such as bouncing off a wall (Hubbard & Bharucha 1988). These are the kinds of predictions one could build into a perceptual emulator without much difficulty (see Question 2, above). However, representational momentum also occurs for complex human motion (Verfaillie & Daems 2002; Verfaillie et al. 1994).

Based on what principles is the emulator able to predict the trajectories of complex biological motion? A likely answer is: based on principles of body biomechanics. That is, the emulator may have internalized the constraints of human body movement – the range of motion of joints, acceleration properties of muscles, and so on. In Grush's terms, the emulator may be an articulated model, isomorphic in its parameters to the relevant parameters of the human body.

From here it is only a small step to suggest that activation of motor brain areas in response to perception of conspecifics may be a functional part of an emulator, assisting in the perceptual prediction of those events. That is, just as in the case of emulating motor events and the case of emulating perceptual events as they are altered by self-motion, emulation of imitable stimuli may receive part of its drive from the controller. In each of these cases, the controller issues motor "commands" in the service of representation rather than (or in addition to) in the service of overt movement. The perception of conspecifics, then, may form an additional class of cognitive events that the emulation theory can help to explain.

https://doi.org/10.1017/S0140525X04510099 Published online by Cambridge University Press