One means of such cross-modal recruitment is imagery. For instance, visual imagery may accompany tactile perception and could play a role in the engagement of visual cortical areas during tactile perception. Such recruitment of visual cortex has now been demonstrated in a variety of tactile tasks involving perception of patterns, forms, and motion, and appears to be quite task-specific, with areas that are specialized for particular visual tasks being recruited by their tactile counterparts (Sathian et al. 2004). An alternative interpretation of this type of cross-modal sensory cortical activation is that the regions involved are truly multisensory rather than unimodal. There is, in fact, increasing evidence that cortical regions traditionally considered to be unimodal are actually multisensory, receiving projections from other sensory systems in addition to their "classic" sources (e.g., Falchier et al. 2002; Schroeder & Foxe 2002). Multisensory emulators could clearly be employed to facilitate such cross-modal recruitment and synthesis.

My point is that, in all these examples of multisensory and cross-modal processing, specific modality tags appear to accompany the relevant sensory representations, which are associated with corresponding coordinate systems. This differs from Grush's account, in which there is an amodal system, devoid of specific modality tags, that is used for perception and for internal emulation. I suggest that such amodal, propositional systems are conceptual and linguistic rather than being perceptual or the substrate for either imagery or sensorimotor emulation. It will be important for future empirical and theoretical research to attempt to distinguish clearly between multisensory and amodal neural systems.

Brains have emulators with brains: Emulation economized

Ricarda I. Schubotz and D. Yves von Cramon

Department of Neurology, Max Planck Institute for Human Cognitive and Brain Sciences, 04103 Leipzig, Germany. **schubotz@cbs.mpg.de cramon@cbs.mpg.de**

Abstract: This commentary addresses the neural implementation of emulation, mostly using findings from functional Magnetic Resonance Imaging (fMRI). Furthermore, both empirical and theoretical suggestions are discussed that render two aspects of emulation theory redundant: independent modal emulators and extra measurement of amodal emulation. This modified emulation theory can conceptually integrate simulation theory and also get rid of some problematic philosophical implications.

Emulators with brains. The emulation account provides a formal way to apply the idea that the brain's default mode is not passive waiting but active prediction, not only in motor control and imagery, but also in perception and perceptual imagery – an extension which fits perfectly with a long series of fMRI studies we performed on voluntary anticipatory processes. These studies made use of the serial prediction task, which requires participants to predict perceptual events on the basis of stimulus sequences. The lateral premotor cortex (PM), pre-supplementary motor area (pre-SMA), and corresponding parietal/temporal areas are engaged in active anticipation of sensory events. Note that this network is activated in absence of motor behavior, and that perceptual input is controlled by contrast computation.

Several functional characteristics of the considered areas render them candidate components of an emulator network. First, in the aforementioned studies each PM field's response is restricted to specific stimulus features: PM fields for vocal movements are engaged in rhythm and pitch prediction, those for manual movements, in object prediction, and those for reaching and pursuit, in spatial prediction. A simplified synopsis of the results indicates that the anticipation of sensory events activates the PM fields of those effectors that habitually cause these sensory events (Schubotz & von Cramon 2001; 2002; Schubotz et al. 2003). This "habitual pragmatic body map" (Schubotz & von Cramon 2003) in PM may precisely reflect Grush's description of an "articulated" body/environment emulator. Second, our findings would also be in line with an emulation network that entails both amodal and modal representations.

Grush proposes motor regions to reflect the controller, and ventral and dorsal processing streams to be the core environmental emulator. We would rather suggest that multiple PM-parietal loops (including the ventral/dorsal stream) function as emulators, with each loop linking both heteromodal and unimodal representations (following the terminology in Benson 1994). One may even hold articulated emulation to be the default mode of PM-parietal loops which are exploited for perception, action, and imageries (see Fig. 1). Visual, auditory, or somatosensory imagery might be generated by efferent signals to and feedbacks from the corresponding unimodal association cortices.

We argue that such a modal emulation cannot be considered to be independent from amodal emulation. Rather, the same signal is concurrently sent to both unimodal and heteromodal association areas, even though current internal and external requirements may then determine which feedback becomes causally effective. Visual, auditory, hand, and foot imagery may introspectively feel different possibly because the controller exploits different premotor-parietal-subcortical loops. But all these networks, first, are made of both unimodal and heteromodal cortices which, second, communicate with ease. Possibly this in turn renders an extra measurement process redundant, as we also argue. On the other hand, "controller" functions (or perhaps better, competitive filter functions) may be realized more restrictedly within pre-SMA, in turn under the influence of anterior median frontal cortices, lateral prefrontal cortex, and extensive feedback projections.

Don't introduce independent modal emulators – even if imagery sometimes feels purely visual . . . An introspectively compelling reason for suggesting independent modal emulation is that some kinds of modal imagery (e.g., a vase) feel purely visual and not at all motor. However, our fMRI findings reveal introspective reports to be unreliable (because introspection does not tell us that motor areas are engaged in non-motor anticipation). Likewise, we are introspectively blind to the empirical fact that perceiving an object includes perceiving what is potentially done with that object (see Gibson [1979/1986] for the notion of an object's affordance, and, e.g., Fadiga et al. [2000] for premotor responses to mere object perception in the monkey). Conversely, it is conceptually inconsistent to assume amodal emulators to be independent of modal emulators, because in the emulation account, perception is sensation, given an interpretation in terms of amodal environment emulators, whereas sensation in turn is the on-line running of modal emulators. It therefore appears that amodal and modal emulation have to be conceptualized as reciprocally dependent[1].

. . . And don't measure the emulators – even if imagery sometimes feels proprioceptive. An introspectively compelling reason for suggesting extra measurement is that motor imagery feels proprioceptive and not at all dynamic/kinematic. This also builds the core premise for splitting emulation from simulation: A motor plan is a dynamic/kinematic plan, whereas full-blown motor imagery is (mock) proprioceptive by nature and therefore must be previously transformed from the former by intermediate emulation and measurement.[2] However, exactly this premise would be rejected by accounts based on the ideomotor principle (e.g., theory of event coding; Hommel et al. 2001). These take motor acts to be planned in terms of desired action effects, that is, expected sensory events, and therefore plans and effects most likely share a common neural code. Comfortingly, emulation theory is not committed to the view that efferent signals are motor by nature. To be an efferent signal is nothing more than to be a delivered signal, no matter whether motor, sensory, sensorimotor, or amodal. Let us assume that the controller speaks "Brainish," the lingua franca spoken by every subsystem in the brain, and that "measurement" is nothing but (and therefore should be termed) feedback from

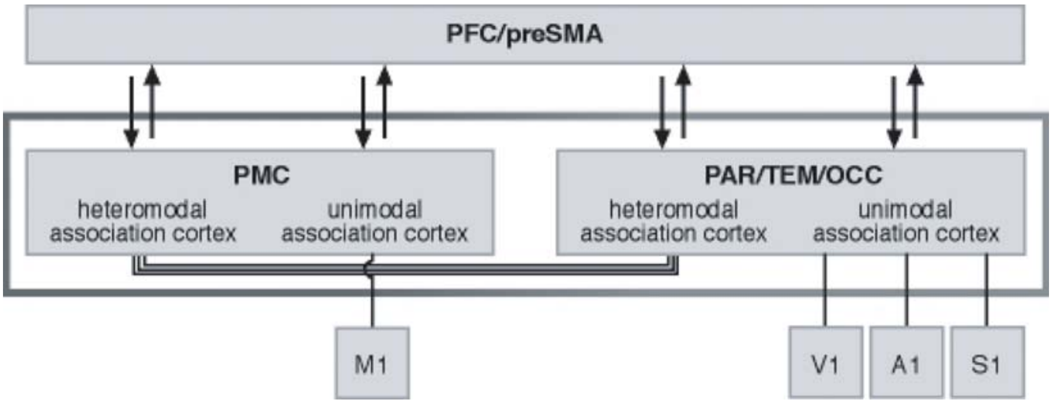

Figure 1 (Schubotz & von Cramon). Suggestion for a simplified neural implementation of a multipurpose emulator system (note that inverse models and/or Kalman filters might be added by cortico-ponto-cerebellar loops). Abbreviations: PFC, prefrontal cortex; PAR/TEM/OCC, parietal, temporal, occipital cortex; M1, primary motor cortex; V1/A1/S1, primary visual/auditory/somatosensory cortex, respectively.

the unimodal components of the general-purpose emulator. Grush correctly reminds us that "the emulator is a neural system: any and all of its relevant states can be directly tapped" (target article, sect. 5.1, para. 5).

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NOTES

1. Furthermore, redundancy emerges in an account that proposes one type of imagery (modal) to spring alternatively from two types of emulators (modal and amodal), but also two types of imagery (modal and amodal) to spring from one emulator (amodal).

2. Grush's pilot-without-flight-simulator metaphor (sect. 3.1) exemplifies the necessity of measurement, but it also expresses how the measurement assumption suggests the introduction of little monolingual homunculi: A Turkish-speaking controller and a French-speaking emulator need a translation – the extra measurement.

Emulator as body schema

Virginia Slaughter
Early Cognitive Development Unit, School of Psychology, University of Queensland, Brisbane 4072, Australia. **vps@psy.uq.edu.au**
http://www.psy.uq.edu.au/people/personal.html?id=35

Abstract: Grush's emulator model appears to be consistent with the idea of a body schema, that is, a detailed mental representation of the body, its structure, and movement in relation to the environment. If the emulator is equivalent to a body schema, then the next step will be to specify how the emulator accounts for neuropsychological and developmental phenomena that have long been hypothesized to involve the body schema.

Grush offers a detailed model of an information processing system that is hypothesized to represent the body as it moves in relation to the environment. His model of a body emulator appears to be consistent with the long-held notion of a "body schema." The term "body schema" was introduced nearly 100 years ago in the neuropsychological literature as a unifying construct relating a number of disorders that seemed to indicate disturbances in the way patients perceived or conceived of their bodies (reviewed in Poeck & Orgass 1971). One syndrome that was originally cited as a disorder of the body schema was the phantom limb, which Grush explicitly mentions as explainable in terms of the operation of his hypothesized body emulator. This suggests that, at least in some instances, the emulator and the body schema are equivalent.

The body schema was conceived as a dynamic representation of one's own body, whose operation was most noticeable in cases of dysfunction (like phantom limbs) but whose normal functioning was thought to include a range of motor and cognitive phenomena from postural control to bodily self-concept. However, since the term was introduced, the notion of a body schema has become increasingly vague and overinclusive rather than more precise, and now there is genuine confusion over what a body schema is supposed to be and how it differs from a body image, body percept, body concept, or body awareness (for discussions, see Gallagher & Meltzoff 1996; Poeck & Orgass 1971; Reed 2002b).

Perhaps Grush's emulator can bring some order to this confused state of affairs. He proposes that the emulator is a cognitive structure that represents the body as it moves and acts within the environment. This is at least part of what a body schema is supposed to be, and Grush's model provides precise detail about how it may be instantiated. If the emulator and the body schema can be equated, this would represent a useful step forward because it can provide the field with a new and more precise definition of body schema, that is, a mental representation of the body that "implements the same (or very close) input-output function as the plant" (sect. 2.2), where the plant is the body being represented and controlled by the emulator mechanism.

Grush discusses how his emulator model can account for a number of low- and high-level cognitive phenomena, from motor control and motor imagery to simulation of another's mental states. If we go ahead and equate the body schema with the emulator, then the model will also have to account for the neuropsychological phenomena that led investigators to postulate a body schema in the first place.

One of those is the phantom-limb phenomenon, which Grush addresses when he suggests that the existence of separate groups of phantom-limb patients who can and cannot move their phantoms can be explained by the amount of time the emulator experienced limb paralysis prior to amputation. This is a neat explanation. However, there are also reported cases of phantom limbs in congenital limb deletions (Poeck 1964; Weinstein & Sersen 1961) which are admittedly very rare but may pose a problem for the emulator model. Another neuropsychological disorder relevant to bodily motion and perception that the emulator should address is hemi-neglect, whereby the patient ignores perceptual information from one side of his visual field and as a result may stop using and lose a sense of ownership for his body parts on the affected side. Ideomotor apraxia is another classic disorder of the body