Disembodied Cognition (*draft*):

Psychopharmacological priming for natural user interface optimization

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Abstract:

Large technology companies are investing heavily in the development of natural user interfaces that are capable of responding to a greater range of human input (i.e. hand gesturing, natural language, etc.). Yet a widespread acceptance of these interaction types – in Smartphone touch-screen use, for example – has yet to result in more *sophisticated* gesture vocabularies. Empirical data suggests that the best way to optimize these gesture-oriented interfaces, and augment our existing computer controls, is a hybrid methodology that generates a standard set of commands based on consensus and then augments the general vocabulary on a user-by-user basis.

This hybridized approach to NUI design demands a conceptual shift away from external hardware (the computer) and a refocusing on internal, *neurophysiological* "hardware". Critically, NMDA receptor antagonists (e.g. Ketamine) have been shown to reliably induce distortions in body-schema by interfering with the integration of multi-modal sensory information that takes place in the brain's temporo-parietal junction. In this perceptually distorted mental state – epitomized by the Out-of-Body experience - agents are temporarily disengaged from their bodies as well as notions about what constitutes the physical reach thereof.

Insofar as the development of a robust gesture vocabulary requires a set of custom commands generated by the individual user, psychopharmacological priming via NMDA receptor antagonists is a potentially valuable tool because it breaks down the phenomenological boundaries that exist between the user and the environment (and the computer interfaces therein). When the user is chemically primed, the body – that *default* tool set – is defined by a state of unbiased transparency that is ideal for the generation of a sophisticated gesture vocabulary, an interface vocabulary defined by mental flexibility rather than bodily convention.

Keywords: Natural User Interface, Extended Mind, Temporo-parietal Junction, NDMA-antagonist

In mid-2013 the semiconductor giant Intel earmarked $100 million in funding for the purpose of advancing a special project it refers to as ‘Perceptual Computing’ (Farber 2013). Specifically, the money is going towards the research and development of next generation computer systems that are sensitive to a broad range of human input, including hand-gestures, natural language, and facial cues. The ostensible long-term goal of Intel (and others) is the development of a robust *natural user interface* that accommodates a much broader range of input and thereby facilitates human computer interaction in a way the keyboard and mouse alone simply cannot achieve. Private space transport company, Space X, provides a sneak peek at what is possible given this technology.[1] Aerospace engineers at that firm are integrating gesture controls into the rocket component design process using computer interactions that are likened in the media to the sort used by Tony Start aka Iron Man. For a less Hollywood perspective, one need look no further than the nearly 1.75 billion (!) smartphone users worldwide whose computer interactions are increasingly mediated via a touchscreen. The vast mobile market, and its success at incorporating intuitive gesture commands, is undoubtedly one of the many reasons Intel is willing to invest so heavily in the design of natural interfaces. Beyond the incorporation of swipes, pinches, and taps, into the control scheme, however, there is still some question as to exactly how a robust natural user interface will function.

I’ll attempt to provide a non-traditional way forward for NUI design via the following steps: First, I’ll outline some of the relevant literature concerning the generation of robust gesture vocabularies, a corpus which suggests that a hybrid consensus/customized gesture set is ideal for the generation of such interfaces. Next, I will reintroduce the *user* – and their body-centric idiosyncrasies – as critical (and malleable) elements in the NUI design process. After that, we

[1] http://www.cbsnews.com/news/elon-musk-unveils-iron-man-like-design-tech-for-spacex-rockets/

will dive deeper into the neurophysiological characteristics that define the user's tool use and tool adoption capabilities. Finally, I'll present the paper's core hypothesis – that the temporo-parietal junction (the portion of the brain that integrates multisensory data streams associated with tool use) is susceptible – via a family of chemicals known as NMDA agonists – to the sort of deliberate perturbation that characterizes a maximally flexible tool adoption mindset.

1. Gesture Vocabulary Design & Limitations

A central problem facing engineers as they set out to create the next generation of user interfaces is the design and optimization of *gesture vocabularies,* defined by Stern, Wachs, and Edan as, "[T]he association (matching) of each command with a gestural expression" (Stern, Wachs, and Edan 2008, 1). Despite a worldwide adoption of touchscreen technology, potential interactions are of a functionally limiting complexity level (i.e. swipes, pinches, etc.). A fully realized natural user interface, as researchers in the field are already aware, will be responsive to a much larger set of gestures. But beyond Norman's observation that heretofore overlooked control parameters like *momentum* are underutilized, the way Intel and others plan to go about implementing gesture-centered user interfaces is basically undetermined (Norman 2010, 3). Indeed, Stern, Wachs, and Edan go as far as to observe that "There has been virtually no research concerned with the issue of how to design an optimal gesture-based control vocabulary", and, moreover, that there may be an implicit constraint on the extent to which a purely gestural system may be capable of executing the sheer variety of tasks we demand (Stern, Wachs, and Edan 2008, 2). Norman phrases the problem of developing a robust gesture-friendly interface thus:

> It is also unlikely that complex systems could be controlled solely by body gestures because the subtleties of action are too complex to be handled by

> actions – it is as if our spoken language consisted solely of verbs. We need ways of specifying scope, range, temporal order, and conditional dependencies. As a result, most complex systems for gesture also provide switches, hand-held devices, gloves, spoken command languages, or even good old-fashioned keyboards to add more specificity and precision to the commands. (Norman 2010, 4)

How, then, might we optimize gesture vocabulary design given the subtlety of the tasks with which contemporary computer users are engaged? *Intuitiveness* is one quantifiable measure for determining the value of a given gesture vocabulary, at least according to Stern, Wachs and Edan (2008) who set out to determine a generally manageable vocabulary by giving individual users the opportunity to define for themselves the gestures they would use to complete a car navigation task. The researchers ultimately concluded that a maximally intuitive natural user interface would comprise a *hybrid* system wherein "…most of the vocabulary is fixed [decided by consensus, in their case], but each user has the flexibility to select several gestures that are highly individualized" (Stern, Wachs, Edan 2008, 7-8). The notion that the idiosyncrasies of the individual user will be critical to the natural user interface optimization process demands a conceptual shift away from a purely technological – and hence, *standardized* - design perspective towards a customized, user-centered approach to interface optimization.

2. Refocusing the Interface Design Process

The premise that a truly powerful tool is essentially invisible will be critical to the development of hybridized natural user interfaces. Indeed, technical progress in general is defined by the ease with which goals are achieved not the complexity of the tool (Osiurak, Jarry, Le Gall 2010). Gesture vocabulary design analysis, is – at the conceptual level – reminiscent of a burgeoning philosophy of mind referred to as 'extended mind', wherein the complex feedback loops with which human cognition is realized "…promiscuously criss-cross the boundaries of brain, body, and world" (Clark 2010). At a very basic level, the tighter the coupling between a user and their externally localized tool literally resembles the sort of implicit relationship a person might have with a repertoire of internalized cognitive "tools" (i.e. memory, computation, imagination, etc.). This critical intimacy - between the user and the capabilities of their own mind/brain - represents a desirable *transparency* or accessibility that we can strive to help overcome the aforementioned "bottleneck" in natural user interface design. As Smart (another extended mind theorist) emphasizes, next-generation digital tools, which function as a "perceptually direct" connection between the mental agent and their end goal, will be deemed useful only insofar as they succeed in mitigating the cognitive weight of the tool itself (Smart 2012, 13).

Further, interface customization/optimization shouldn't necessarily be bound by bodily convention. Some computer-centered tasks would actually benefit from a reduction of pre-processing on the part of the embodied mental agent. From the engineer's perspective, for example, a temporarily fluid distinction between the body and world might prove useful for the purpose of analyzing a CAD model of a centered, non-human engineering component, like a centrifuge.[2] It's quite difficult to recognize the true extent to which our bodies influence research/design/scholarship of this sort. Consider, for example, the work of Barbara Tversky, who details the origin of our most pervasive body-centered mental conventions. She describes how we are *essentially*:

> "…upright creatures with three axes: an elongated, asymmetric head-to-feet axis that is aligned with gravity, which is a strong asymmetric axis of the world; and two axes that are not aligned with gravity, a front-back axis that is asymmetric, and a left-right axis that

[2] http://www.paraview.org/gallery/

> is for the most part symmetric. We have four mobile appendages, two legs that can move us preferentially in one direction on the ground, the direction we call "forward", and two arms that are free to manipulate objects in the world, preferentially in the forward direction. We have a set of sense organs oriented in the direction of movement." (Tversky, 2008, pg. 201)

Due to its inescapable role in mediating the exchange of information between the internal and external world, mental structure presupposes and depends implicitly upon these bodily structures. Wilson (2011) succinctly describes the associated theoretical position – often called embodiment, and closely related to the extended mind - as the idea that, "…the agent's beyond-the-brain body plays a significant causal role, or physically constitutive role, in that agent's cognitive processing", and Gallagher (2005) further illustrates the concept with a seemingly trivial statement about how "…perception and action are perceptively spatial…" due to our body-mediated interaction with an inherently spatial world. As our potential actions and perspectives are typically constrained by these corporeal idiosyncrasies (e.g. the force and direction of gravity), so too are our potential *thoughts*, and, while it may have been strictly necessary preserve the impact of such bodily relations while performing survival-oriented activities like knapping a flint or drawing a bow, such influences need not necessarily be preserved when analyzing multi-dimensional scientific data via a next-generation natural user interface. There, in a digital analysis environment - where something like the impact of gravity on our head-to-feet axis is functionally irrelevant, but nevertheless cognitively presupposed - it might be beneficial to disengage one or more of body-centered conventions before calibrating an interface and manipulating an abstract (but spatially represented) data set.

So, the transparency criterion (however broad or seemingly trivial) is useful because it effectively refocuses the problem of interface design on the *human* half of the hybrid interface design relationship, rather than solely on digital system engineering, as has traditionally been the case. No matter how complicated the tool, it should be essentially invisible to the user, thereby imitating the sorts of internal *mental* functions that we depend upon implicitly. Also, the potential circumvention certain body-centered mental conventions are similarly important insofar as something like (the experience of) gravity's subversive pull on data visualization may inadvertently, and undeservedly, skew a researcher's analysis.

A transparent and unbiased approach by the user of these interfaces is desirable, and a comprehensive exploration of potential approaches to optimization should thus include reference to that inscrutable host of cognitive activity: the brain.

3. Tool use and the Brain

As Giummarra (et al. 2008) point out, movement planning and execution depend an initial mental mapping of the agent's body that takes place in a handful of key neurophysiological regions, namely: the superior parietal lobule, the parieto-insular region and temporo-parietal junction. These brain regions are responsible for unifying multi-modal input – whether it is proprioceptive, or visual, or vestibular – into a functionally useful representation of the agent's body. Importantly, this multi-modal body schema incorporates various significant parts of the environment to effectively execute movement. As Tsakiris, Constantini, and Haggard (2008) point out, this "[M]ultisensory integration is essential for the demarcation one's body as a physical object distinct from external objects and other agents". Importantly, the temporo-parietal junction (or TPJ) has been directly linked to the incorporation of new *tools* into the body-schema.

Hihara (et al., 2006) conducted a study on Japanese monkeys (*Macaca fuscata)* trained in the use of tools (in this case a rake-like tool used to reach food).[3] Basically, these researchers discovered novel cortico-cortical connections present in the TPJs of the monkey group trained in tool-use, but not in the naïve control group. The region central to integrating information and generating a multi-modal sense of self (as separate from the environment) was modified by tool-use. With regard to the phenomenological characteristics of processes by which a tool might be incorporated - via the TPJ into a mental agent's repertoire - Hihara and his team speculate that "…the tool is seen as an extension of innate body parts and induces a temporary mismatch with an existing body image stored in the intraparietal region, and thus requires recalibration driven by the monkey's own intention to incorporate the external object (tool) into the internal representation of its body." (Hihara et al.2005, 10).

While the literature concerning body-schema modulation is rich, Bassolnio, Serino, Ubaldi, and Ladavas (2010) provide perhaps the most relevant example of the phenomena for our current purposes. By capitalizing on certain measureable invariances in the relationship between tactile/auditory experience and reaction time these researchers were able to determine the extent to which the computer-mouse is integrated into body-schema.[4] The results demonstrated that,

[3] The experiment design was as follows: "For retrograde mapping, five monkeys were injected with fluorescent tracer in the anterior bank of the IPS posterior to the somatosensory forearm regions. Four monkeys were injected with an anterograde tracer in the temporo-parietal junction (TPJ) areas that displayed distinct retrograde labeling only after training. In each experiment, animals were classified into a tool-use trained group or an untrained (control) group; injections were made to only one hemisphere of the brain of each monkey. Five of the monkeys (three for retrograde tracer studies and two for anterograde traces studies) were trained to use a rake-shaped tool to retrieve a piece of food placed out of reach, as described previously. After 3 weeks of training, monkeys became over-trained for the task, and surgery for the tracer injections was performed. Injections made into the hemisphere contralateral to the hand trained to use the tool. The monkeys were then anaesthetized and perfused for neurohistochemical analysis. Four monkeys were used as controls. These monkeys underwent the same procedures, however, they were not trained before or after surgery" (Hihara et al. 2006, 2-3).

[4] Specifically, researchers in this instance relied on the APPS (auditory peripersonal space) paradigm to determine the extent to which the introduction of auditory stimuli can modify detection time and/or reaction ability of tactile experience. In terms of experimental methodology, "… participants sat in front of the computer screen and were requested to verbally respond as fast as they could to a tactile target administered on their right hand, while

after using the mouse, a durable representation of onscreen activity is functionally equivalent – from the agent's perspective - to their own hands. Moreover, this particular study is remarkable because its design transcends most other studies on tool incorporation. The use of a cane, for example, reliably collapses the distinction between far and near (that is, *reachable*) spaces, but a cane is also a recognizably arm-like extension of the limb itself and might thereby be perceived as fundamentally different from the sort of digital tools we are hoping to understand (Serino et al. 2007). However, the computer-mouse study seems to "…suggest that in order to promote plastic reorganization of spatial representations, a functional, but not necessarily a physical, interaction between near and far space is required" (Bassolino et al. 2010, 8). In principle, then, there is no reason why a mental agent cannot incorporate a digital tool just as easily as they incorporate a physical hand-tool, given the TPJ is adequately stimulated.

So, where does this leave us? We know that natural user interface needs further optimization in order to extend functionality beyond the most basic gesture controls we currently encounter, but a dearth of research on the topic coupled with a conceptual bottleneck – focused on interface engineering, but not on the ways in which brains best use tools - has impeded progress. By examining the neurophysiologic structures responsible for tool incorporation, and keeping an eye towards eliciting a level of unbiased transparency between the user and the interface, it might be possible to revitalize the interface design process. To that end, it's clear that the successful use of a natural user interface (or any tool) might benefit with the deliberate modification of body-schema, and, as Hihara et al. imply, a "temporary mismatch" between agent and environment is critical to such modification (Hihara et al. 2006, 10).

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concurrent task-irrelevant sounds were presented either near the stimulated hand (near sounds) or 70 cm away from the hand (far sounds)" (Bassolnio, Serino, Ubaldi, Ladavas 2010, 2).

4. Disrupting the Body-Schema

A full 10% of the population experiences such a sensory mismatch in the form of an out of body experience (OBE) (Blanke et al. 2005, 2), and the literature unsurprisingly indicts to the Temporo-parietal junction as the seat of this phenomena. Examination of patients who had prior OBE experiences consistently found lesions in the TPJ (Lopez, Halje, Blanke 2008), and Blanke and Arzy (2005) concluded that, "…OBEs are related to an integration failure of proprioceptive, tactile, and visual information with respect to one's own body (disintegration in personal space)…due to a paroxysmal cerebral dysfunction of the TPJ" (Blanke & Arzy 2005, 7). Interestingly, Tsakiris, Constantini, and Haggard (2008) went as far as inducing, via transcranial magnetic stimulation (TMS) of the TPJ, OBE-type phenomenology in healthy subjects who had never before experienced them, and thereby determined that:

> Disruption of r[right]TPJ eliminated the differential treatment of multisensory stimuli that are used in the maintenance of a coherent representation of one's body by blurring the boundary between corporeal and non-corporeal stimuli. An object (i.e. a rubber hand) that would normally have been perceived as part of the participant's own body came to be treated in a manner more similar to a neutral non-corporeal object. When rTPJ processing was disrupted by TMS, discrimination between the multisensory evidence that may or may not be attributed to one's body became less definite, rendering the distinction between corporeal and non-corporeal stimuli more ambiguous (Tsakiris, Constantini, and Haggard 2008, 4).

According to the sort of neurophysiological data presented by Hihara and others, this disruption represents the ideal state for incorporating new tools into the body schema because it is during this period that the mental agent temporarily objectifies the default human "tool set" – the limbs, for example - thereby placing apparatuses typically considered *external* to the body-schema on a level playing field, functionally, with ingrained mental structures. In cases where normal functioning of the TPJ is interrupted, the hand ceases to represent the boundaries of the agent's reach. Critically, there are *chemical* agents that have been shown to reliably invoke out-of-body type experiences under clinical conditions, thus providing an avenue by which we might invoke these pliant mental states at will.

Ketamine, for example, has been shown to induce 'illusory movement experiences' in approximately 91% of users, while about 83% of users reported (more extreme) out-of-body experiences (Wilkins, Gerard, and Cheyne 2011). The drug - which acts on a specific (*N*-Methyl-D-aspartic acid) receptor set in the brain – effectively disintegrates or disrupts "… the transmission of data from all sensory modalities", and researchers concluded that such disruption "…affects the availability of sensory information critical for its successful integration, such as that mediated by the TPJ" (Wilkins, Gerard, Cheyne 2011, 7). This chemical represents one method for consistently inducing the fluid mental state most closely associated with new tool use, and nowhere in the literature has the viability of Ketamine for that incorporation been demonstrated more fully than a study conducted by Moore et al. (2011), which concluded – based on a combination of action-binding testing (for agency) and questions specific to The Clinician Administered Dissociative States Scale – that perceptions of one's own body are effectively mutable under the influence of the drug.[5] In their own words:

> …ketamine may preferentially influence a neural system for monitoring action. As a result of this deficit, actions on ketamine become mutable and vulnerable to capture by other events…The mutability hypothesis discussed earlier may provide an explanation: If ketamine engenders mutability in the experience of an action, then the more one's experience of action is "captured" by external sensory events

[5] According to Moore et al. (2011), "Action binding represents the difference between action time estimates in the agency condition and action time estimates in the baseline condition. Previous studies have found that the experience of isolated action, as in the baseline condition, is anticipatory: On average, participants are aware of moving slightly before the actual onset of movement. This suggests that motor experience in this context is not based on feedback generated by the actual movement itself" (Moore et al. 2001, 11).

> the greater the externalization of bodily experience may be, resulting in the feeling of "disconnection" from one's own body" (Moore et al., 12).

Susceptibility to capture by external events is precisely the sort of quality that natural user interface designers should be seeking out if they hope to transcend current user-centered limitations on the creation of robust gesture vocabularies.[6]

Recall that an ideal natural user interface will be the result of a hybridized design process that takes into account the intuitions of the individual user. If the user is primed chemically, and "captured" by external sensory events as the literature suggests, gestures that corresponded more closely to the external stimuli – not bodily convention/limitation - can be readily provoked. In effect, the subject of future studies could be *primed* – via the NMDA antagonist, Ketamine – to engage more *directly* with a computer-based set of external stimuli (an onscreen data visualization, perhaps).[7] That sort of uncompromised engagement would be useful in the calibration of natural user interfaces insofar as the gestures that are evoked in this temporarily disembodied state will reflect idiosyncrasies of the external stimuli, *not* the limitations of the user's body. In the course of the abovementioned feedback loops, our mental processes must pass through two profoundly impactful filters before reaching and manipulating the object of our

[6] Critically, the effects of Ketamine are dose-dependent and exist on a spectrum, which means more *extreme* instances of the OBE (where the user may not be capable of functioning at all) can be avoided in favor of small perturbations which have been shown to affect the limbs specifically (i.e. illusory movement experiences) (Wilkins, Girard, and Cheyne 2011, 5).

[7] Relevant body-schema transformations have also resulted from 5-HT $_{2A}$ agonist administration under controlled conditions. Specifically, Strassmen's research (2001) on the effects of DMT (Dimethyltryptamine) revealed a myriad of self-reports that suggest a central role of these chemicals in the disintegration of the multi-modal self. According to Strassmen, phrases like "I no longer had a body," "My body dissolved – I was pure awareness", were common, and, further, test subjects reported that "There seemed to be a clearly identifiable sense of movement of consciousness away from the body, such as "falling"," "lifting up," "flying," a feeling of weightlessness, or rapid movement" (Strassmen 2001, 146).

computer-centered focus: the body and the interface. Why not take the body out of the equation and allow the user to engage with the content in a more direct way so as to refine the interface?

As Yee explains, "… gesture vocabularies are poised to expand beyond basic navigation tasks into productivity applications. Indirect or "abstract" gestures are increasingly common and can now be used to initiate, manipulate, and complete activities that are not associated with direct one-to-one visual representations" (Yee 2009, 3). However, the responsibility for developing these more advanced natural user interfaces need not fall to hardware/software *engineering* considerations alone. Rather, it may be useful to consider the possibility that calibration of these next-generation interfaces might occur via processes occurring *inside the agent* – via chemical means, perhaps – thus facilitating human computer interaction in ways that were previously impossible.

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