Toward a Model of Functional Brain Processes I: Central Nervous System Functional Micro-Architecture

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Abstract

The brain does not function in accordance with standard passive input processing models — e.g., information processing models. Instead, there are multiple endogenously active processes at multiple scales across multiple kinds of cells. In part I of this discussion, a micro-functional model that accounts for these multi-scale phenomena in generating emergent representation and cognition is outlined. In part II, this model is extended to address macro-functioning in the CNS.

Concepts which have proved useful for ordinary things easily assume so great an authority over us, that we forget their terrestrial origin and accept them as unalterable facts. They then become labeled as "conceptual necessities", a priori situations, etc. The road of scientific progress is frequently blocked for long periods by such errors.

A. Einstein[1]

[1] Einstein, 1990, pg. 31.

Introduction

The brain does not contain simple threshold switch neurons; neurons are not the only functional kind of cell; and synapses are not the only mode by which cells influence each other. These and related errors abound in discussions and models of CNS functioning. Instead, the central nervous system functions in multifarious ways, across multiple physical and temporal scales, via endogenous oscillatory processes that engage in ongoing mutual modulatory influences. The complexities can seem bewildering to model and understand.

In this paper, I offer a model of CNS functional processes that accommodates these multiple kind of cells and multiple scales of influence. The first part of the model focuses on micro-functional processes; the second part extends the micro-functional model into the range of macro-functional processes in the brain.

Many of the complexities of CNS functioning are well known, though more are discovered almost daily, but accounting for them in an overall functional model that can address issues of cognition and other mental phenomena is largely absent. Instead, the general passive input-processing model, whether of connectionist or neural net variety, still dominates. These descendents of the classic McCulloch & Pitts model (1943) are still the dominant kind of model of mental processes in the brain (e.g., Carlson, 2000) because they are the dominant framework within which cognitive processes are thought of across multiple disciplines (e.g., Bermudez, 2010). Thus this framework is imposed on discussions and models of brain functioning because that is the only (or the dominant) manner in which it is assumed that cognition ultimately occurs, so this kind of processing *must somehow* be realized in brain processes. This despite the fact that what is known about actual CNS processes is massively unexplained by, and mostly contradictory to, standard information processing models.

I argue that a fundamental conceptual problem blocks the understanding of the emergence of representation and cognition, and thus contributes to the lack of models of actual CNS processing that can make sense of cognition and other mental phenomena. I begin, then, by addressing these conceptual barriers. This requires consideration of both philosophical and theoretical issues.

The Emergence of Representational Normativity in the Brain

Representation has to have emerged: it did not exist several billion years ago, and it does now. Similarly, representation must be emergently realized in brain processes, across multiple species, every day. Understanding this emergence, however, is blocked by fundamental conceptual barriers.

In particular, *emergence* itself is metaphysically suspect. It seems impossible for something fundamentally different to arise out of the basic particles of the world — it's really all just the particles and everything else is epiphenomenal (e.g., Kim, 1989, 1993a, 1993b, 1998, 2005). Furthermore, representation is a *normative* phenomena — representations can be true or false — and the emergence of normativity seems even more impossible. After all, "ought" cannot be derived from "is", and "reasons" seem utterly disparate from "causes".

Conceptual Barriers

I argue that this seeming impossibility of emergence, and of the emergence of normative phenomena, is part of the heritage of conceptual barriers that originated with the Pre-Socratics (Bickhard, 2004, 2009a; Campbell, 1992; Graham, 2006; Mourelatos, 1973). In particular, it is derivative from the assumption that there must be some unchanging substrate for all change — either some sort of substance, such as earth, air, fire, or water, or some sort of particles.

The assumption, or presupposition, that there must be some unchanging metaphysical ground for phenomena has permeated Western thought since Democritus and Empedocles (Gill & Pellegrin, 2006; Graham, 1997, 2006; Guthrie, 1965; Reale, 1987; Taylor, 1997). In many respects, it has served science and philosophy well. Nevertheless, I argue, it is incorrect, and has very serious consequences — consequences that are most serious precisely for studies of normative and mental phenomena.

Working within a presupposition of such an unchanging ground, a presupposition of a "substance metaphysics" (Seibt, 2000, 2002, 2003, 2009; Bickhard, 2003, 2009a) has multiple consequences. Three of the most serious are:

1. Unchangingness — stability and stasis — are the explanatory defaults. Change requires explanation, and nothing can induce change in itself.

2. Emergence is not possible[2]. You cannot get a fifth substance from Empedoclean earth, air, fire, and water.
3. The realm of substance is a realm of substance or matter or particles, factual properties of and relations among them, and causal interactions among them. This realm contains no normativity and no intentionality. Phenomena that involve normativity or intentionality, therefore — with mental phenomena as the primary domain involved — are metaphysically split from the realm of substance or atom. A fundamental metaphysical split between substance, fact, and cause on the one hand and normativity, intentionality, mentality on the other is forced.

This metaphysical split between the realm of substance or matter and that of normative intentionality leaves only three basic possible approaches:

1. Propose two fundamentally different realms, and explain the world in terms of them and their interrelations. This dual realm framework is exemplified in Aristotle's matter and form, Descartes' two substances, and, more recently, the logical positivists' realm of scientific fact split from that of linguistic and social normativities — the realms of reasons and causes.
2. Posit only one realm, that of mind-like properties and phenomena, and attempt to understand the world as constituted solely within such a realm. This yields various forms of idealism, such as those of Hegel, Green, or Bradley.
3. Posit instead a single realm of particles, facts, and causes, and attempt to understand mind and other normative phenomena within such a realm. Such a choice yields various materialisms and physicalisms, versions of physicalistic 'naturalism', such as those of Hobbes, Hume, and much of contemporary science.

The notion that the realm of normativity and intentionality might be integrated with that of particles, facts, and causes via the *emergence* of the first out of the second is blocked

[2] Emergence is precisely what atoms and substances were supposed to avoid: they were intended to satisfy Parmenides' argument against change: Substance A cannot change into substance B because that would require A to disappear into nothingness and B to appear — emerge — out of nothingness (Graham, 2006).

by the same ‘substance/particle metaphysics’ that induces the split in the first place. If this is to be overcome, some more fundamental change is required.

I argue that what is required is, in a sense, a return to Heraclitus — to process metaphysics. The understanding of fire was blocked so long as it was conceived of as some sort of substance. No amount of investigation of the properties of phlogiston could succeed. A fundamental conceptual change was required — from substance to process. In fact, the shift from taking a substance perspective on phenomena of interest to a process perspective is one of the central themes in the history of science (Hull, 1974): e.g., from phlogiston to combustion, from caloric to random kinetic energy, from vital fluid to living processes, from ether to (quantum) fields. Studies of mind and mental phenomena are among the last to cling to classical frameworks. This is likely due to the fact that only studies of mind and mentality encounter directly the problems of emergent normativity — of, among other phenomena, that of representational intentionality.

Adopting a process metaphysics is recommended not only by the historical trend towards process, but by both conceptual and scientific considerations. *Conceptually*, in a world of nothing but point particles nothing would ever happen: the particles would have zero probability of ever encountering each other. *Scientifically*, our best contemporary physics necessitates an ontology of (quantum) fields (Aitchison, 1985; Aitchison & Hey, 1989; Bickhard, 2003; Brown & Harré, 1988; Cao, 1999; Clifton, 1996; Davies, 1984; Fraser, 2008; Halverson & Clifton, 2002; Huggett, 2000; Kuhlman et al, 2002; Ryder, 1985; Sciama, 1991; Weinberg, 1977, 1995; Zee, 2003), and such fields *are* processes.[3]

Furthermore, two of the most formidable barriers to emergence are transcended by such a shift to process. Jaegwon Kim’s arguments against emergence, I argue, presuppose a particle metaphysics, and are not sound arguments in a process framework (Bickhard, 2004, 2009a). And Hume’s argument against deriving norms from facts similarly is unsound because of an unstated premise that all we can derive are combinations of whatever we started with (Bickhard, 2004, 2009a).

[3] The quantizations involved are equivalent to the quantizations of the number of wavelengths in a vibrating guitar string that is fixed at both ends — and there are no guitar sound particles.

So, adopting a process metaphysics is urged by the history of science, as well as by conceptual considerations and by contemporary physics. A process metaphysics, in turn, blocks the anti-normative-emergent conclusions of Hume and Kim. Furthermore, shifting to a process metaphysics undoes all three of the fundamental consequences of a substance assumption:

1. Change becomes the default, and it is stasis or stability that requires explanation;
2. Emergence in new organizations of process becomes a metaphysical possibility;[4]
3. The possibility of bridging the split between factual world and normative intentional mind in terms of emergence can be explored; and
4. Thereby opens up the possibility of exploring the emergence of normative phenomena such as representation.

Heraclitus has not been the only process philosopher in Western history, though they have been relatively sparse. Historically recent process metaphysics have been proposed by, for example, Peirce and Whitehead. Even more recently, Rescher (1996) and Seibt (1996, 2000a, 2000b, 2003, 2009) have proposed process ontological orientations. It is clear, however, that the possibilities inherent in process metaphysics have been much less explored than those of substances and particles. I argue that those possibilities radically alter (among many other consequences) conceptions of representation, cognition, and the brain processes that realize them. The underlying process framework within which I proceed is most similar to those of Peirce, Rescher, and Seibt.

Representation

Adopting a process metaphysical framework enables addressing multiple ranges and kinds of emergence — in particular, emergences of normative phenomena, and, with special relevance to this discussion, the emergence of representation.

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[4] Bickhard (2004, 2009a); Clayton & Davies (2006); Deacon (2006, 2012).

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Representation emerged naturally in the evolution of animals. For any complex agent, one basic issue is how to select and guide actions and interactions. Such a selection must be among interactions that are actually possible in the current situation: it does no good to reach for the refrigerator door if you're in the forest. Agents, then, must have some functional indication of what kinds or ranges of interaction are possible, and must keep it updated with respect to time, events in the world, and their own actions (Bickhard, 2004, 2009a, 2009b; Bickhard & Richie, 1983).

What is crucial to accounting for representational truth value is that such indications of interaction potentialities can be true, or can be false: indication interaction possibilities might in fact *not* be possible. Furthermore, if the organism selects such an indicated possibility and it does not proceed as indicated, it has been falsified in a manner that is functionally detectable by the organism, and therefore available for error corrected behavior or learning.[5]

Thus, we have the crucial normative aspect of representation — truth value — emergent in indications of future interactive potentialities.[6] Because of this emergence of representation in indications of interaction, the model has been called *interactivism*.[7]

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[5] There is no other model in the literature that can address this criterion of organism detectable representational error (Bickhard, 2004, 2009a, 2009b, in preparation-a, in preparation-b). Fodor (1975, 1981, 1987, 1990a, 1990b, 1991, 1994, 1998, 2003), Millikan (1984, 1993), Dretske (1988), and Cummins (1996) all attempt to address the problem of the possibility of representational error per se, but none succeed (Bickhard, 2004, 2009a, 2009b), and none of them attempts to address *organism detectable* representational error. Note that the problem of organism detectable representational error is the focus of the radical skeptical argument: we cannot detect error in our own representations because, to do so, we would have to step outside of ourselves to compare what we are actually representing with our representation of it, and we cannot do that. I argue that this radical skeptical argument is yet another valid but unsound argument, with the faulty premise being a conception of representation that is motivated by underlying substance conceptions, and that also traces back to the Pre-Socratics (Bickhard, 2009a, in preparation).

[6] I have skipped over a preliminary normative emergence — that of normative *function*. I argue that normative function emerges naturally in living systems, in a manner differing from the standard etiological model of function, and that interaction indication is the crucial (normative) function from which representation emerges (Bickhard, 1993, 2004, 2009a; Christensen & Bickhard, 2002).

[7] Bickhard (1993, 2004, 2009a, 2009b); Bickhard & Terveen (1995); Campbell (2009); Hooker (2009); Levine (2009); Seibt (2009); Vuyk (1981).

Indications of interaction possibilities do not seem to be much like more familiar sorts of representations, such as of objects, but these more complex representations can be emergently constructed out of an underlying action base in a manner similar to Piaget's model (Bickhard, 2004, 2009a, 2009b; Piaget, 1954, 1971). In connecting with this action base, the Interactivist model has strong convergences with the process orientation and action framework of Peirce (Rosenthal, 1983). In fact, Piaget is part of this general pragmatist perspective, with the intellectual descent being from Peirce through James and Baldwin to Piaget. Piaget is among the very few in the current scene who has attempted a model of emergent representation, on an action base (Bickhard, 1988a; Bickhard & Campbell, 1989).

The Importance of Timing

There are multiple differences between this interactivist-pragmatist model of representation and standard models. Most important, representation can emerge, according to this model, in constructions of indications of interaction potentialities, and such constructions are functional in nature, not representational themselves. The construction of new representation, therefore, can be out of *non*-representational organization: the representation is emergent.[8]

This interactive model is, like pragmatist models in general, future oriented, not past oriented — not looking backwards down the input stream attempting to "see" where that stream originated. It is not a spectator model (Dewey, 1960/1929; Tiles, 1990). It is this future orientation that makes organism detectable error possible: the indications about future possibilities can be checked by finding out if they are in fact future possibilities (Bickhard, 2004, 2009a, 2009b).

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[8] The impossibility of emergent representation in standard models, e.g., information semantics models, is reflected in arguments for the innatism of a base level of representations (Fodor, 1981). But such a position assumes that representation emerged in evolution, and there is no model of how that could occur, nor is there any argument that such evolutionary emergence could not also occur in a single organism's learning and development (Bickhard, 2009c). Instead:

"I am inclined to think that the argument has to be wrong, that *a nativism pushed to that point becomes unsupportable, that something important must have been left aside*. What I think it shows is really not so much an a priori argument for nativism as that *there must be some notion of learning that is so incredibly different from the one we have imagined* that we don't even know what it would be like as things now stand." Fodor in Piatelli-Palmarini, 1980, pg. 269.

Another difference from standard models is that the Interactivist model is inherently modal. The indications are of interaction *possibilities*. We find that children do not add modal considerations to prior non-modal representation, but, instead, they begin with poorly differentiated modal understandings and develop progressively more sophisticated differentiations within the modal realm (Piaget, 1987; Bickhard, 1988b).

There are multiple additional differences between the interactive model and standard models, important for varying purposes and interests. The crucial difference that I will pursue here is that, in being emergent in interaction systems, representation inherently involves and requires *timing*. Actions can be in error by being too fast or too slow — coordinative timing is what is required (Bickhard & Richie, 1983; Port & van Gelder, 1995; van Gelder & Port, 1995).

This is in contrast to, for example, standard computationalism. Computationalist models are equivalent to Turing machines, and Turing machines have sequence but no timing. Nothing in Turing machine theory changes if the temporal durations between steps are short or long or even highly variable. Sequence is all that matters. Sequence can model sequential steps of symbol manipulations, but sequence cannot capture timing.

Computers have timing, so they are more than just Turing machines. But computer timing is via a clock and dedicated timing circuitry. Organisms require timing, but there is an easier way for evolution to have met this requirement: put clocks everywhere. Clocks are, functionally, just oscillators, so this would become, put oscillators everywhere, and constitute functional relationships as modulatory relationships among the oscillators. On this basis, then, we should expect a range of modulatory functional types and scales to be involved in CNS architectures and processes (Bickhard & Terveen, 1995).

Such an architecture is *at least* as powerful as Turing machines in that the limit of A modulating B is for A to switch B ON or OFF, and Turing machines can be built out of switches. An oscillatory/modulatory architecture is *more* powerful than Turing machine architecture in that it has inherent timing.

And a complex of oscillatory/modulatory architectures is precisely what we find in the brain (Bickhard, 1997).

The Induction of Central Nervous System Attractor Landscapes

In fact, we find that actual CNS neurons are endogenously active, with baseline rates of oscillation, and with *multiple modulatory* relationships across a wide range of *temporal* and *spatial scales*:

- silent neurons that rarely or never fire, but that do carry slow potential waves (Bullock, 1981; Fuxe & Agnati, 1991; Haag & Borst, 1998; Roberts & Bush, 1981);
- volume transmitters, released into intercellular regions and diffused throughout populations of neurons rather than being constrained to a synaptic cleft (Agnati, Bjelke & Fuxe, 1992; Agnati, Fuxe, Nicholson & Syková, 2000);
- gaseous transmitter substances, such as NO, that diffuse without constraint from synapses and cell walls (e.g., Brann, Ganapathy, Lamar & Mahesh, 1997);
- gap junctions, that function extremely fast and without any transmitter substance (Dowling, 1992; Hall, 1992; Nauta & Feirtag, 1986);
- neurons, and neural circuits, that have resonance frequencies, and, thus, can selectively respond to modulatory influences with the "right" carrier frequencies (Izhikevich, 2001, 2002, 2007);
- astrocytes that[9]:
    - have neurotransmitter receptors,
    - secrete neurotransmitters,
    - modulate synaptogenesis,
    - modulate synapses with respect to the degree to which they function as volume transmission synapses,
    - create enclosed "bubbles" within which they control the local environment in which neurons interact with each other,
    - carry calcium waves across populations of astrocytes via gap junctions.

[9] The literature on astrocytes has expanded dramatically in recent years: e.g., Bushong, Martone, Ellisman, 2004; Chvátal & Syková, 2000; Hertz & Zielker, 2004; Nedergaard, Ransom & Goldman, 2003; Newman, 2003; Perea & Araque, 2007; Ransom, Behar & Nedergaard, 2003; Slezak & Pfreiger, 2003; Verkhratsky & Butt, 2007; Viggiano, Ibrahim, & Celio, 2000.

These aspects of CNS processes make little sense in standard neural information processing models. In these, the central nervous system is considered to consist of passive threshold switch or input transforming neurons functioning in complex micro- and macro-circuits. Enough is known about alternative functional processes in the CNS, however, to know that this cannot be correct. The multifarious tool box of short through long temporal scale forms of modulation — many realized in ways that contradict orthodoxy concerning standard integrate and fire models of neurons communicating via classical synapses — is at best a wildly extravagant and unnecessary range of evolutionary implementations of simple circuits of neural threshold switches. This range, however, is *precisely* what is to be expected in a functional architecture composed of multiple scale modulatory influences among oscillatory processes (Bickhard, in preparation; Bickhard & Campbell, 1996; Bickhard & Terveen, 1995).

The Interactivist model of representation, therefore, argues for a kind of functional framework for the central nervous system that we actually find. No other model in the literature can make sense of this complex toolbox of multiple ways in which the nervous system functions (Bickhard, in preparation; Bickhard & Terveen, 1995). In this manner, what is known about micro-functional processes in the CNS *confirms* the implications of the interactive model that functional relations should be modulatory relations among oscillatory processes. The confirmation is by the fact that the nervous system does function in terms of multiple scales of temporal and spatial oscillatory-modulatory relationships.

These basic phenomena of CNS functioning, however, not only *confirm* the basic predictions of the interactive model of representation, they also *entail* the central core of that model:

Entailment

Demonstrating the *entailment* requires explicating a deeper level of the representational model: Recall that, according to the Interactivist model, representational truth value emerges most simply in CNS processes that functionally anticipate the further potentialities for near-future interactive processes. In some circumstances, such anticipations will be correct, and, thus, the implicit presupposition of those circumstances will be true, while in others those supporting circumstances will not hold, and thus the functional anticipations will be false. This constitutes the primitive ground of the emergence of representational normativity: the emergence of *truth value*.

What we find in CNS functioning are wide ranges of spatial and temporal modulatory relationships. The slower more spatially widespread processes will be relatively constant on the time scales of the smaller spatial-scale faster processes. Thus, they will set the parameters within which the faster processes occur. For dynamic systems,[10] parameter setting is the equivalent to programming in discrete systems. The slower processes, therefore — such as of volume transmitters and astrocyte processes — will program the faster dynamics. This local "programming" constitutes a kind of set-up, a *microgenesis*, of dynamic readiness for the anticipated interaction potentialities (Bickhard, 2006, 2009c; Brown, 1991; Deacon, 1997; Werner & Kaplan, 1963).

Such microgenetic readiness, in turn, can be *correct*, if its presuppositions about the environment are correct, or *incorrect*, if those presuppositions are incorrect. Microgenesis, hence, constitutes a functional kind of anticipation, with emergent representational *truth value*. Dynamic microgenesis, thus, yields the anticipatory truth values that ground representation,[11] and the facts of CNS processes, therefore, entail the Interactivist model of representation.

[10] For mathematical dynamic systems theory, see, e.g., Galves, Hale & Rocha (2002); Hale & Koçak (1991); Hirsch, Smale & Devaney (2004); Ivancevic & Ivancevic (2006); Jost (2005); Lyubich, Milnor & Minsky (2001).

[11] E.g., Zacks, Speer, Swallow, Braver, Reynolds (2007).

Thus, when we examine how the nervous system in fact functions, we find precisely the kind of anticipatory processes that are at the center of the emergence of interactive representational truth value. The theoretical model and the facts of CNS functioning *entail each other* — a very strong interrelationship.

In this model, it is the slower microgenesis processes that constitute the core of cognition. Axonal spikes carry the results of more local dynamic "computations" — they do not do the processing themselves. Some further points that provide a broader framework for this perspective include (Bickhard, in preparation; Bickhard & Terveen, 1995):

- transmitter substances have evolved from early colony regulating hormones (Bonner, 2000);
- these became volume transmitters (Nieuwenhuys, 2000);
- classical synapses were a later evolution (Agnati, Bjelke, & Fuxe, 1992; Agnati, Fuxe, Nicholson, & Syková, 2000; Nieuwenhuys, 2000);
- in all cases, transmitters are relatively local hormones, the degree of locality depending on how widely the transmitter substance diffuses;
- in some cases, precisely the same molecule serves as a transmitter in the CNS and as a whole body hormone outside of the blood-brain barrier;
- percentages of astrocytes and other glia increase with increasing CNS complexity — as one review puts the point: "astrocytes tell neurons what to do, besides just cleaning up their mess." (Nedergaard, Ransom & Goldman, 2003, pg 523).

The Dynamics of Attractor Landscapes

The slower microgenetic processes, in setting parameters for faster processes, thereby modulate the dynamics — the dynamic spaces — of the faster processes. This is what "programming" amounts to within an endogenously active framework.

A further perspective on these microgenetic processes derives from recognition that the larger spatial processes (thus the slower processes) induce local “weak coupling” among oscillatory processes, and that such weak coupling, in turn, induces *attractor landscapes* for the faster processes (Hoppensteadt & Izhikevich, 1997). The “programming”, thus, is constituted in the induction and control of the dynamic attractor landscapes in which the faster processes occur.

The Interactivist model, thus, induces a view of CNS functioning based on multiple scale inductions and controls of dynamic attractor landscapes. Control of such dynamic landscape microgenesis, therefore, is the center of the control of action and interaction, including *internal* action and interaction: *thought*. Thought as internal action is a strong convergence of this framework with that of Piaget and pragmatism more broadly, but it is strikingly different from the passive input processing models that still dominate the contemporary literature.

In general, then, temporally slow processes set parameters for — thus modulate — the dynamics of faster processes, and large spatial scale processes can induce weak coupling among smaller scale processes, thus inducing and modulating attractor landscapes in the dynamics of those smaller scale processes.

Toward Central Nervous System Functional Macro-Architecture

Modeling of cognitive brain processes is almost universally in terms of some sort of computational approach, whether symbol manipulation, information processing, or connectionist. Dynamical approaches to cognitive phenomena exist, but tend to be anti-representational (Brooks, 1991; Freeman & Skarda, 1990; Thelen & Smith, 1996; van Gelder, 1995). The Interactivist model, in contrast, provides a fully dynamic, process framework for the modeling of representational and cognitive processes — especially of *emergent* representational and cognitive processes.

The Interactivist model implies an oscillatory/modulatory functional architecture and this implication receives massive empirical support. Furthermore, not only does this approach imply such a functional framework, it is the only model that makes in-principle sense of the multitude of kinds of modulatory relationships actually found. Still further, when the anticipatory nature of microgenetic set-up is recognized, these known properties of neural functioning themselves imply an anticipatory emergence of representational truth value. The model of representation and the phenomena of CNS processing imply each other.

New non-standard modulatory phenomena are today discovered with startling frequency, and these need to be integrated into an overall model. The Interactivist model is uniquely suited to be able to address this integration. It is an ongoing, always-under-construction, project.

Beyond specifics of micro-functioning, however, is the range of issues involved in how local microgenesis is itself modulated. In general, local microgenesis will be modulated by processes occurring within larger scale architectures in the brain. Constructing this part of the model, then, involves integrating what is known about the involvement of more macro-circuits in the CNS within the general dynamic framework of the model. In other words, how is local microgenesis itself controlled (or modulated)?

Such control processes are likely to depend on:

- Modulation of reciprocal couplings between thalamus and cortex, especially the intralaminar and reticular nuclei of the thalamus (Churchland, 1995; Hoppensteadt & Izhikevich, 1998; Izhikevich, 2002; Izhikevich, Desai, Walcott & Hoppensteadt, 2003; Purpura & Schiff, 1997; Steriade, 1996; Steriade, Jones, & McCormick, 1997a, 1997b);
- Loops from prefrontal cortex through thalamus, and through basal ganglia to thalamus, to other regions of the cortex (Crosson & Haaland, 2003; Edelman & Tononi, 2000; Fuster, 1989, 2004; Koziol & Budding, 2009; Marzinzik, Wahl, Schneider, Kupsch, Curio, & Klosterman, 2008; Middleton & Strick, 2000; Smith, Raju, Pare, Sidibe, 2004);

- Baseline chaotic processes from which functional attractor landscapes can be induced and controlled (Freeman, 1995, 2000a, 2000b; Freeman & Barrie, 1994; Bickhard, 2008); and
- Involvements of the limbic system in modulating the overall dynamic process with respect to the evaluative aspects of emotions (Bickhard, 2007, in preparation; Damasio, 1995, 1999; Panksepp, 1998).

As with the local microgenetic processes, a great deal of relevance is known about these more global architectures and processes, and more is being discovered rapidly, but little of it receives a modeling interpretation in terms of a coherent cognitive dynamics model.

The issue of internal interactions with cognitive processes, of the modulation and control of cognitive processes, is one of the advanced edges of this model. It is the issue of the emergent nature of thought. I turn in part II of this paper to an integrative framework for such macro-CNS functioning. CNS architecture is enormously complex. I will not address this complexity in detail; instead I will provide several functional and evolutionary themes that can help make sense of the macro-CNS as fundamentally an oscillatory-modulatory system.

Conclusion

The Interactivist model provides a dynamic approach to emergent cognitive neural and glial functioning. This model constitutes an application of an underlying process metaphysics and model of representation that legitimates emergence, including normative emergence — and including, in particular, emergent representation. The model has novel implications for micro-level functioning, implications, that are in fact supported and, conversely, are themselves implied by what we know of neural and glial functioning.

This framework is ideal for exploring more macro-functioning in the nervous system. It is an alternative to computationalist and connectionist approaches. It involves a model of representation as emergent in certain kinds of dynamic organizations, rather than in transduced encodings or connectionist trained encodings. It is a process model from its non-representational base through the emergence of representational and cognitive processes, and, thus, is optimally suited for exploring the relationships between CNS dynamics and cognitive dynamics.

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