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

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Abstract

Standard semantic information processing models — information in; information processed; information out (in the form of utterances or actions) — lend themselves to standard models of the functioning of the brain in terms, e.g., of threshold-switch neurons connected via classical synapses. That is, in terms of sophisticated descendants of McCulloch and Pitts models (1943). I argue that both sides of this framework are incorrect: cognition and thought are not constituted as forms of semantic information processing, and the brain does not function in terms of semantic information processing neural nets. An alternative framework is developed that models cognition and thought *not* in terms of semantic information processing, and, correspondingly, models brain functional processes also not in terms of semantic information processing.

As alternative to such models:

- I outline a pragmatist oriented, interaction based (rather than reception based), model of representation;
- Derive from this model a fundamental framework of constraints on how the brain must function;

- Show that such a framework is in fact found in the brain, and
- Develop the outlines of a broader model of how mental processes can be realized within this alternative framework.

I also offer a discussion of an approach to brain functioning that has some similarities with, as well as differences from, the model presented here: sometimes called the Predictive Brain approach.

Part I of this discussion focuses on some criticisms of standard modeling frameworks for representation and cognition, and outlines an alternative interactivist, pragmatist oriented, model. In part II, the focus is on the fact that the brain does *not*, in fact, function in accordance with standard passive input processing models — e.g., information processing models. Instead, there are multiple endogenously active processes at multiple spatial and temporal scales across multiple kinds of cells. A micro-functional model that accounts for, and even predicts, these multi-scale phenomena in generating emergent representation and cognition is outlined. That is, I argue that the interactivist model of representation outlined offers constraints on how the brain should function that are in fact empirically found, and, in reverse, that the multifarious details of brain functioning entail the pragmatist representational model — a very strong interrelationship. In part III, this model is extended to address macro-functioning in the CNS. In part IV, some comparisons are made with a family of approaches known as predictive brain models (and various other terms).

Keywords: Encodingism; Interactivism; Philosophy; Psychology; Neuroscience; Philosophy of mind; Epistemology; Representation; Learning; Emotion; Memory; Functional brain model; Brain attractor landscapes; Microgenesis; Astrocytes; CNS oscillatory modulation; Neural loops; CNS self-organization; Predictive brain

> 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.
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> A. Einstein[1]

Introduction

Assumptions that representation is constituted as some form of encoding of what is represented dominate the contemporary scene — in philosophy (e.g., Fodor, 1990a, 1998), psychology (e.g., Matlin, 2012), cognitive science (e.g., Bermudez, 2010), and studies of the brain (e.g., Carlson, 2013). Most commonly, this takes the form of an assumption of semantic information processing, in which perceptual inputs generate presumed informational encodings of the sources of such inputs, thus providing resultant signals and processes with representational content concerning those sources. Neural processes then, so it is assumed, process that semantic information via complex neural nets, and, ultimately, may generate outputs in the form of language or action.

I argue to the contrary that, while encodings certainly exist, such as Morse code and computer codes, the assumption that all representation is constituted as encodings — *encodingism* — is conceptually fatally flawed. Correspondingly, the brain cannot function in terms of such semantic information processing: an alternative framework for modeling brain functioning is required that transcends the flaws of standard models.

In the first section of this paper, I depict a few of the (rather large) family of arguments against encodingist, semantic information processing, models, and offer an alternative interaction based (rather than reception based) model of representation. In section II, I argue that the brain does in fact function in ways that are consistent with, and even predicted by, this alternative functional framework. That is, philosophical and theoretical considerations impose constraints on how the brain could function, and these

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[1] Einstein, 1990, pg. 31.

constraints are in fact honored in what we know about how the brain does in fact function. These discussions will proceed with a focus on the micro-functioning of the brain, laying the ground for a discussion in section III of a macro-functional model that is consistent with the micro-functional model.

In section IV, some comparisons are made with a family of approaches known as predictive brain models (and various other terms).

Part I: Representation: Encoding or Anticipation?

1

Underlying Metaphysical Problems

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. The conceptual problem is the presupposition of a substance metaphysical framework, which, among its consequences, blocks the possibilities of emergence,[2] and, in particular, possibilities of normative emergence such as that of representational truth value. Representation is the heart of cognition, so a conceptual framework that blocks a naturalized model of representation thereby blocks a model of how cognition is emergently realized in the brain. Conversely, so I argue, recognition that the fundamental ontology of the world is that of process (Rescher, 1996; Seibt, 1996, 2000a, 2000b, 2003, 2009), not substance or entity or atom, enables models of emergence, and, in particular, of the emergence of representation and cognition (Bickhard, 2009a, 2009b). These points are argued extensively elsewhere; for the purposes of this discussion, I will assume that normative emergence is a metaphysical possibility, and address the emergence of representation within that framework.

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[2] For discussions of emergence, see Bickhard (2004, 2009a); Clayton & Davies (2006); Deacon (2006, 2012).

2

Representation

Arguing for an alternative model of representation and cognition involves, among other things, demonstrating that there is a need for an alternative model: that current models are unsatisfactory. I begin with a overview of some fatal flaws of standard models.[3]

2.1

Problems with Encodingism

Normativities of representation have been problematic for millennia. How can you point to something that doesn't exist, or to something that is false? How can you have an encoding correspondence with something that doesn't exist, or something that is false? How can a representational correspondence exist but be false? If the correspondence exists, then the represented end of the correspondence exists, and the representation is true. If the correspondence does not exist, then the representation does not exist. There is no third modeling possibility for accounting for a representation that exists but is false.

There is, in fact, a large family of arguments and problems with encodingist models of representation, some of ancient provenance, and some discovered or created more recently. Here are a few:

An encoding can be defined in terms of other encodings, but this requires some base level of encoding atoms in terms of which all others can be defined. How could such a base level exist, how could it come into being? Fodor, among others, has argued that it must be innate (Fodor, 1981; Carey, 2009). But Fodor offers no model of how it could have emerged in evolution, nor, assuming that it could emerge in evolution, why such emergence of representation could *not* occur in individual level learning and development.

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[3] For extended critiques of standard models, including Fodor, Millikan, Dretske, Cummins, computationalist, connectionist, and information processing models, see Bickhard (1980, 1993, 2000a, 2009a, in preparation-b; Bickhard & Terveen, 1995).

Worse, if that base level is assumed to itself be constituted as encodings, an incoherence is encountered. An encoding definition is a form of borrowing content: the defined term becomes a representation, becomes an encoding, by borrowing the content specified in the defining term or phrase or clause. But presumed base level encodings cannot borrow their content from other encodings, else they would not be base level. So, they would have to "borrow" their content from themselves: "X" represents the same as "X". This does not provide any content to "X", thus does not transform "X" into an encoding, so no such base level of atomic encodings can exist. Encodingism, the assumption that *all* representation is constituted as encodings, is an incoherent position (Bickhard, 1993).

Most commonly, of course, the assumption is that some kind of factual, perceptual or conceptual, correspondence is what yields (or even constitutes) content for perceptual and cognitive encodings. But such assumptions directly encounter the normativity problems — how could they be false?

There are many other problems with, and arguments concerning, models of representation. One is Piaget's copy argument: if our representations of the world are in some sense copies of that world, then we would have to already know the world in order to construct our copies of it. Various forms of such circularities often emerge in examining models of representation (such as the circularities of definition in the incoherence argument above). Note that Piaget's construction argument carries less weight if it is assumed that representation is simply impressed into a passive mind like the form of a signet ring into wax, or contemporary versions of signet rings such as "transduction", but such models again directly encounter the problem of how representations could possibly be false.

An argument that has been around a long time is the radical skeptical argument (Rescher, 1980). This addresses not just the possibility of representational error, but the possibility of *organism detectable* representational error. The basic argument is that, in order to detect whether my representations are correct, I would have to step outside of myself, have some independent epistemic access to what I am representing, and compare my representation with what is actually there to determine if my representation is correct or not. Such stepping outside of myself is not possible, so consequently it is impossible for me (or any other organism) to determine the truth or falsity of our own representations. This conclusion seems unacceptable, but, nevertheless, the argument has stood for centuries.

But the conclusion is in fact unacceptable: if organism detectable error is not possible, then error corrected behavior and error corrected learning are not possible. We know that error based behavior and learning occur, so something has to be wrong with the radical skeptical argument; it cannot be simply ignored as a merely armchair philosophical problem. Not just representational "error" per se has to be modeled, but *organism detectable* error must be modeled.

I argue that the radical skeptical argument is a valid argument, but that it is unsound. The faulty premise is that of the background assumption that (all) representation is some form of encoding correspondence; that we know our worlds by somehow looking backwards down the perceptual input stream to the sources of such streams — by being spectators of our worlds (Dewey, 1960/1929; Tiles, 1990). If our representations of the world are some kind of encoding correspondences with the world, then the only way to check the accuracy of those correspondences is to be able to compare both ends of the correspondence, but we only have access to one end, the representation — the other end is what is supposedly being represented.

In place of such a backward looking, past oriented, assumption, I offer a model of representation based on future oriented anticipation — anticipation of future interactive possibilities. Note, among other characteristics, that any such model is intrinsically active: there are no passive signet ring impressions (or transductions).[4]

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[4] "Transduction, remember, is the function that Descartes assigned to the pineal gland." (Haugeland, 1998, pg 223).

2.2

Representation as Anticipation

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 (Bickhard, 2009a).

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 indications of what kinds or ranges of interaction are possible, and must keep them updated with respect to time, events in the world, and their own actions (Bickhard, 2004, 2009a, 2009b; Bickhard & Richie, 1983). Setting up such indications of interaction potentiality is similar to Gibson's notion of picking up affordances (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: indicated interaction possibilities might in fact *not* be possible. Furthermore, if the organism selects such an indicated possibility and it does not proceed as indicated, then it has been falsified in a manner that is, at least in principle, functionally detectable by the organism, and therefore available for error corrected behavior or learning.

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. As mentioned, 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. This is an unsound argument, with the faulty premise being a conception of representation that is motivated by underlying substance conceptions, and that traces back to the Pre-Socratics (Bickhard, 2009a, in preparation-a; Campbell, 1992; Graham, 2006; Mourelatos, 1973).

Thus, we have the crucial normative aspect of representation — truth value, and truth value *for the organism itself* — emergent in indications of future interactive potentialities.[5] Because of this emergence of representation in indications of interaction, the model has been called *interactivism*.[6]

2.2.1
More Complex Representation

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).

Consider, for example, a frog who might have opportunities for tongue flicking in one direction for a fly, in another direction for another fly, and downward straight-ahead for a worm: indications of interaction possibilities can branch into multiple such possibilities. Furthermore, if the frog were to shift to the left a bit, that might open up the possibility of a tongue flick for a different worm: indications of interaction possibilities can iterate, with some creating or detecting the conditions for others.

Such branching and iterating indications can become extremely complex, forming webs of anticipations of interaction possibilities. Within such a complex web, perhaps in an infant or toddler, consider the subweb for interacting with a child's toy block. There are multiple visual scans and multiple manipulations that are available with the block,

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[5] I have (in this discussion) 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). Interaction indication is the interface between functional normativity and representational normativity.

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

and they are all interrelated in such a way that any one scan or manipulation can be made available from any other with the appropriate "setting up" or intermediate manipulation(s). The subweb for interacting with the toy block is internally completely *reachable* — any point from any other point.

Still further, this internally reachable subweb of interaction possibilities is itself *invariant* under a range of other activities that the child can engage in, such as dropping the block, leaving it on the floor, putting it in the toy box, and so on. It is not, however, invariant under all activities, such as crushing or burning it. Such internally reachable, invariant under manipulations and transportations, subwebs constitute a candidate for a child's representation of a toy block. This is "just" Piaget's model translated into the terms of the interactivist model (Piaget, 1954).

Such borrowing of Piagetian models is possible because of the common action base. The "toy block" model illustrates how an action framework for representation can account for more complex representations, such as of physical objects.[7]

In connecting with Piaget's 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).

There are also additional convergences: for example, any action based model forces an embodied model (Bickhard, 2008a), and the interaction aspect of this model has interesting convergences with classical cybernetics and certain configurations of abstract machine theory (Ashby, 1960; Bickhard, 1973, 1980, in press, in preparation-a, in-preparation-b; Bickhard & Richie, 1983). There are also intuitive convergences with notions of autopoiesis and enactivism (Maturana & Varela, 1980, 1987; Varela, 1997;

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[7] This is just an illustration, and leaves multiple issues unaddressed. For example, how can abstractions, such as the number three, be represented within an interactivist framework? The answer is again roughly Piagetian in spirit, though with more changes than for small physical objects (Bickhard, 2009a). The general programme of modeling the myriad kinds of representations requires addressing each kind in its own terms.

Varela, Thompson & Rosch, 1991), though important differences as well (Bickhard, in preparation-a, in preparation-b; Christensen & Hooker, 2000; Di Paolo, 2005; Moreno, Etxeberria, Umerez, 2008): most centrally, enactivism focuses on a system reproducing its components, while the interactivist model focuses on a far from thermodynamic system maintaining its (ontologically necessary) thermodynamic relationships with its environment (Bickhard, 2009a).[8]

3

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.[9]

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.[10] 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 central idea is that processes that are inherently far from thermodynamic equilibrium must be maintained, perhaps via (recursive) *self*-maintenance, in those far from equilibrium relationships with their environments. Examples range from candle flames to living organisms. Maintenance of such far from equilibrium conditions is, thus, contributory to — normatively functional for — the existence of the system (Bickhard, 2009a).

[9] 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.

[10] As mentioned, it is not a spectator model (Dewey, 1960/1929; Tiles, 1990).

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 on top of 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*. (Inter-)actions with the environment can be in error, can fail, 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 "putting clocks everywhere" becomes "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).

Part II: Central Nervous System Functional Micro-Architecture

1

(Micro-)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. Assumptions to the contrary (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 kinds 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, 2013) because they form 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 (so the reasoning goes) *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.

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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); such neuromodulators can reconfigure the functional properties of "circuits" and even reconfigure functional connectivity (Marder & Thirumalai, 2002; Marder, 2012);
- 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[11]:

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[11] 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,

- 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.

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-a; 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 contemporary literature can make sense of this complex toolbox of multiple ways in which the nervous system functions (Bickhard, in preparation-a; Bickhard & Terveen, 1995). There are individual models of many of these phenomena, but they are in general

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2003; Perea & Araque, 2007; Ransom, Behar & Nedergaard, 2003; Slezak & Pfreiger, 2003; Verkhratsky & Butt, 2007; Viggiano, Ibrahim, & Celio, 2000.

at the neural and molecular level and do not connect with more general functional models. Those that do posit functional realizations do so within a semantic information processing framework. Such a framework is not only not correct (Bickhard, 2009a), it could not explain the existence of such an array of kinds of modulatory dynamics: (semantic) information processing does not require anything like such an array, so why does such an array exist? Why did evolution create and maintain such a superfluous array of kinds of dynamics? If oscillatory modulations are the central form of functional dynamics, however, then it makes perfectly good sense that evolution would have created a range of such kinds of dynamics for multiple kinds of modulatory functioning.

In this sense, 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:

2.1

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 presuppositions concerning 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 larger scale, temporally slower, processes modulate the intercellular environments within which faster and smaller processes take place. Smaller scale processes, such as neural oscillations and impulses, take place in relation to the ambient environments — e.g., membrane potential in a neuron is a relation between ionic concentrations inside the neuron and concentrations in its local environment. Larger scale processes, thus, modulate the activities of smaller, faster processes via modulations of these local environments.

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,[12] 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; Ogmen & Breitmeyer, 2006; 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.[13] The facts of CNS processes, therefore, entail the interactivist model of representation.

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

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[12] 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).

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

do not do the processing themselves.[14] Some further points that provide a broader framework for this perspective include (Bickhard, in preparation-a; 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).

2.2

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”

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[14] In doing so, they engage in larger scale oscillatory/modulatory processes. They do *not* engage in the transmission of semantic information.

among smaller scale oscillatory processes. The weak coupling follows from the larger scale: multiple smaller scale processes will have similar local modulatory environments from particular larger scale processes, and will, thus, be (weakly) coupled via those local environments.[15] 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 (inter-)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 faster, smaller scale processes.

3

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.

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[15] Such coupling via larger scale processes will be a meta-modulation of local coupling modulations among small scale processes that occur via shared local extra-cellular environments.

The interactivist model implies an oscillatory/modulatory functional architecture and this implication receives strong empirical support. Furthermore, not only does this approach imply such a functional framework, it is the only model currently on offer 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 interactivist model. In other words, how is local microgenesis itself controlled (or modulated)?

Such 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, 2004, 2008; 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, 2008b); and
- Involvements of the limbic system in modulating the overall dynamic process with respect to the evaluative aspects of emotions (Bickhard, 2007a, in preparation-a; 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 edges of this model. It is the issue of the emergent nature of thought. I turn in part III 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.

4

(Micro-)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 suited 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.

Part III: Central Nervous System Functional Macro-Architecture

1

(Macro-)Introduction

In part II, a micro-functional model was presented in which large spatial scale and slower temporal scale processes — involving, for example, volume transmitters, astrocytes, silent neurons, and other phenomena — modulate the dynamics of smaller and faster scale processes, such as classic synapses. Such modulation sets the parameters of the faster dynamics, and is the dynamic system equivalent of "programming".

Further, the large scale processes induce weak coupling among the smaller, faster processes, which, in turn, can induce attractor landscapes in those dynamics (Hoppensteadt & Izhikevich, 1997; Izhikevich, 2007). The form (and dynamics) of those landscapes, and of the attractors within them, enable and constrain the fast neural processes.

Such a micro-functional model generates the question of how those dynamic (attractor) landscape modulations are themselves regulated. What controls or modulates the micro-dynamic landscape modulations? The ultimate answer to this question must involve a model of the macro-functioning of the brain: modulations, enablings, and constraints across the entire system must engage each other in accordance with the macro-functional organizations available, and thereby determine the overall flow of CNS processes, including the ongoing modulation of ranges of fast, local processes.

Most broadly, what generates and modulates the flow of macro-processes in the brain? Clearly, the answer cannot be some highest level executive: that answer simply generates a version of the classic homunculus regress. It is this issue that I will pursue in this paper, presenting some themes of macro-evolution, learning and development, and self-organization within and among various cortical-subcortical loops as perspectives on the macro-functional processes.

2

Foundations of a Macro-functional Model

Functional coherence in brain processes is attained (when it *is* attained) as an emergent of multiple simultaneously inter-modulating processes in all parts of the brain. In this section, the foundations for how such coherence could emerge are limned. The central notion is that distributed processes tend to recruit connected processes into an overall coherent functional mode — a functional self-organization. How that could happen is the theme of this discussion.

2.1

The Dynamics of Learning

The human brain is evolved for learning and development, and for learning to learn. It is not (just) for engaging in interactions with the world. In that sense, homo sapiens is maximally adapted to niches of adaptation (Bickhard, 1973, in preparation-a; Bickhard & Campbell, 2003).

I will present first a perspective on the dynamics of learning, and then turn to how these kinds of dynamics have been involved in the macro-evolution of the brain. The reason for first addressing learning per se is that learning, like perception, cognition, language, and so on, is not a matter of transduction, induction, symbol manipulation, or information processing.[16] Such passive models of mental phenomena are the descendants of the classic signet ring impressing its form into wax, and they do not explain the phenomena to which they are addressed any better than the signet ring (Bickhard, 2009a).

If, however, representation and cognition and other mental processes are recognized as emergents of interactivity between the organism and its environment, then there is no temptation to think that competent (inter-)action systems can be impressed by the world into a passive mind. Learning (and development) *must* be *constructive* processes.

In the absence of prescience, these constructions must be trials that may be in error, variations on what has been constructed before that may be selected out if they fail. An action based model of cognition, in other words, forces a variation and selection constructivism, an evolutionary epistemology of learning and development (Campbell, 1974).[17]

I have argued that normative truth value emerges in processes that anticipate what further processes might be successfully engaged in.[18] This *might* be conceived of in terms of anticipation of *environmental* consequences of interaction, but such kinds of environmental anticipation already presuppose the emergence of representation *of* that environment, and, thus — on pain of circularity — cannot be the most basic form of representational anticipation (Bickhard, 2009a). More locally, these anticipations are constituted as local microgenesis for further processes, and the success or failure can be locally constituted as success in the local process flow remaining within the range of what the microgenesis has prepared for, and failure as the deviation of that process flow

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[16] Further, the dynamics of learning enable the dynamics of functional self-organization.

[17] Generalizing the model of variation and selection beyond biological evolution to epistemological phenomena is the core of evolutionary epistemology (Campbell, 1974). Selection principles can, in fact, be generalized even further to almost any kind of non-accidental and non-designed fit to criteria (Bickhard & Campbell, 2003). In such broad form, models that make selection phenomena central are sometimes known as forms of Universal Darwinism (Dennett, 1995). It should be noted, however, that, just as for any other explanatory principle, variation and selection principles can be used in incorrect models as well as correct models.

[18] For discussions of emergence, see (Bickhard, 2009a; Bickhard & Campbell, 2003; Clayton & Davies, 2006; Deacon, 2012; Thompson, 2007).

from the range that has been prepared for.[19] Anticipations, thus, are constituted in the microgenetic *preparations* for further process flow, and *actual* process flows may support those anticipations or may render them false. The crucial microgenetic anticipations, thus, are of local process flow, not of the environment per se nor of inputs from that environment (though environments and inputs from environments will certainly *influence* that local process flow).

If microgenetic processes tend to stabilize with such local microgenetic anticipatory success, and destabilize with failure, we have a microgenetic variation and selection process that will tend toward stability with local, thus anticipatory, thus interactive, success. *Microgenesis, thus, is the locus of learning* (Bickhard & Campbell, 1996).

2.1.1

Kinds of Learning

I turn now to some illustrations of how this model of microgenetic evolutionary epistemology can address various kinds of learning — that is, illustrations of how this model of learning can account for all learning.

2.1.1.1

Habituation

Consider first habituation. If there is available a way of interacting with an input stream in a “matching” or “subtractive” manner, then a successful interaction will be one that correctly anticipates that input stream and “subtracts” it to zero. This can be constituted as successful microgenetic anticipation of the influences on process flow of registrations of the inputs. This is effectively what happens with classic habituation (Bickhard, 2000b; Thompson, 2009).[20]

2.1.1.2

Classical Conditioning

Suppose now that no such subtractive process is possible. One example would be if a tone becomes pain, and pain is an input that permits no successful interaction (to a first

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[19] And local anticipatory success and failure constitute truth and falsity of the anticipatory set-ups, thus ground representation. See Part II and Bickhard (2009a).

[20] See later discussion for a comparison with ‘predictive encoding’ models.

approximation). How can an input flow of tone-pain (e.g., shock) be successfully interacted with?

By avoiding the pain; jumping off of the shock grid.

2.1.1.3
Instrumental Conditioning

Consider now a case in which the input activity is generated by some part of the CNS itself — perhaps activity in the hypothalamus evoked by low blood sugar. Ultimately, the only way to successfully interact with such a signal is to eat, and thus raise blood sugar. This requires a great deal of learning about how to go about this in various circumstances, such as in a forest or a restaurant or in the vicinity of a refrigerator. As infants, we are aided in this complex learning by simple responses, such as crying, which, in supportive environments, will accomplish the interaction, but adult responses can vary situationally and culturally. Hunger, in whatever environment, will tend to evoke activity that results in eating, and this is a standard example of instrumental conditioning.[21]

2.1.1.4
Other Kinds of Learning

These forms of learning are not exhaustive — incidental learning, for example. Most fundamentally, memory is a multifarious kind of learning (see below for further elaboration). I address these elsewhere (Bickhard, in preparation-a), and take it as established for current purposes that microgenetic variation and selection processes are a candidate for being able to account for all of learning.

2.1.2
Development

It is possible for the variations in simple learning in simple organisms to be always generated from the same dynamic base, as variations in those dynamics. Perhaps, for example, just variations in synaptic strength, if synaptic influences are the only relevant dynamics. More complex learning, however, occurs if *previous* constructions can be

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[21] It should be noted that this quick model is at best a first approximation. There are multiple delays in eating and blood sugar feedback, that have resulted in multiple forms of detection and feedforward and feedback processes to regulate eating (Carlson, 2013). These complexities, however, do not alter the basic point in the text.

used as resources for *later* variations, either as units of construction or as organizations within which variations can be induced.

Such recursive constructive processes can yield multiple further properties. For example, it may be that some complex constructions are, as a practical or probabilistic matter,[22] not possible without certain prior preparatory constructions (Bickhard, 2005b). Such preparatory construction possibilities can form trajectories of possible construction, in which earlier constructions enable later constructions. Such trajectories of possible construction, in turn, can split and join, forming complex partially-ordered spaces of possibility. Such enablings and constraints of recursive constructive processes is the subject matter of *development* (Bickhard, 1980, 2006).

A still more powerful form of learning would be if the variation and selection constructive processes can themselves be learned and developed. This constitutes learning to learn. Heuristic problem solving would be an example, in which the heuristics for trial constructions are themselves learned, as well as, perhaps, the criteria against which the trial constructions are compared. Such an internal process of learned constructive processes and learned selection criteria constitutes an internalized evolutionary epistemology (Bickhard, 2002, in preparation-a).

All forms of learning, and learning to learn, emerge as forms of variation and selection constructive processes. Examining how such forms are themselves enabled and constrained within the nervous system yields a perspective on the macro-evolution of the brain.

2.2

Learning: A Macroevolutionary Theme

One powerful perspective on the macro-evolution of the nervous system notes how various physiologically differentiated regions and units have evolved to serve functionally differentiated processes, such as modality differentiated perceptual systems, basal ganglia specialized for action, and so on. What is less commonly noted is that such

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[22] E.g., too complex for any non-foresighted constructive process to happen to hit upon it (Simon, 1969; Campbell, 1974). See also discussions of functional scaffolding (Bickhard, 1992, 2005c).

functional process differentiation and specialization *ipso facto* constitutes differentiated and specialized resources for learning. I will use this point as a focal theme for integrating a brief overview of the macro-evolution of the brain.

The central recognition is that all learning is constituted as variation and selection processes, and that variations are necessarily variations in some functionally *already available* space of possible processes — variations must be functionally accessible from already available organizations of processes. Variations, in other words, are not free — e.g., they are not from a uniform probability distribution across a space of all conceptual possibilities. They are enabled and constrained by the kinds and organizations of the dynamics within which and out of which they occur.

Possible learning variations in the simplest cases might be variations in the concentration of some local hormone that regulates other activity — perhaps precursor to a synaptic neurotransmitter (Nicholson, 2000; Nieuwenhuys, 2000). Such possibilities for variation are inherent in the dynamics involved, and are constrained by those same dynamics. Release of such substances, or generation of a synaptic connection in a more sophisticated organism, are not fixed. Synapses are not soldered wires. They are *relative* steady states of ongoing turnover and maintenance relative to such turnover of particular configurations of cellular processes.

Such "steady states" are not absolutely steady, but will inherently involve some variation. If that variation narrows toward a successful value or process when success is encountered, then we have a primitive version of variation and selection learning.

The crucial point here is to note how the space of possible variations is a property of the dynamics in which those variations can occur. Changing the *organization* of those processes, then, will also change the spaces within which variations and selections, thus learning, can occur. And changing the *architecture* within which those processes occur can change their organization, thus the spaces of possible (or at least easily accessible) variations.[23]

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[23] That the processes by which variations are generated are themselves aspects of adaptability follows directly from the nature of variation and selection processes (Bickhard & Campbell, 2003). But it is an aspect that has often been overlooked in the focus on selection effects per se (for related discussions, see

Central nervous system differentiation and specialization for interactive functioning, thus, *ipso facto* constitutes differentiation and specialization in support of variation and selection learning.

2.2.1

Some Differentiations and Specializations

The evolution of the nervous system has involved multiple such differentiations and specializations for kinds of functions — and that enable further evolution. Early evolution generated architectures that enabled flexibility in processes as well as in further evolutionary differentiation — for example, as neural *networks* became nervous *systems* with (head) ganglia and chordate organization (Fritzsch & Gloverb, 2007). This constitutes a partial differentiation between processing and communication, and enables partially independent further evolution for each.

Functional modularization is an important theme in the macro-evolution of the nervous system. Such modularization enables *functional* specialization, and also variation generating *learning* specialization, as discussed above. Another important theme is that some architectural developments enable much simpler further evolution. For example, differentiation of relatively specialized nuclei not only enables relatively specialized functioning and concomitant learning, it also permits partially independent further evolution of nucleus architectures supporting those processes. I will mention one crucial example of this below: the emergence of the laminar organization of the cortex. Yet another theme in the macro-evolution of the nervous system is a progressively more powerful exploitation of the properties and powers of microgenesis.

Differentiations of processes that regulate conditions and processes *internal* to the body are an early functional differentiation, (partially) distinct from those that coordinate interactions with the external world. Architectural and functional differentiations can also generate and enable further macro-evolutionary emergences, such as the co-evolution of synapses, muscles, and skeleton (Moreno & Lasa, 2003; Nieuwenhuys, 2000).

Brooks & Wiley, 1988; Brooks, Collier, Maurer, Smith & Wiley, 1989; Weber, Depew & Smith, 1988; Kauffman, 1993).

Within architectures for interacting with an environment, differentiations and specializations emerged for interactions that *detect* properties and conditions in the world as distinct from selecting and guiding *action and interaction* with the world. Within forms of detection interactions, specializations evolved for differing modalities within which important kinds of detection occurred, for coordinations among those modalities, and, regarding interactions with the world, for varying sorts of coordinations of multiple muscle and skeletal groups, and, most importantly, for increasingly complex and sophisticated anticipations of what organizations of (inter-)action are possible and for selections within them (Arnal & Giraud, 2012; Kovach et al, 2012; Zacks et al, 2007). In more complex organisms, these evolved toward perceptual systems, supported by the thalamus, and environmentally interactive systems, supported, for example, by the basal ganglia (Redgrave, Prescott, Gurney, 1999).

I will be mostly focused on a few major differentiations in the human brain, using these to illustrate how a system of oscillatory processes engaged in ongoing mutual modulations can constitute a functional system (Levine, Brown & Shirey, 2000) — a system that does not function in terms of (presumed semantic) information flows and information processing.

2.2.1.1
Emotion

A crucial aspect of the interactive model is its model of emotion, and of the role that emotion has played in macro-evolution and learning. The central notion of this model is that it can be advantageous to an organism not only to respond to novel situations with learning trials, in which previous microgenetic learning is not already stabilized around processes that anticipate successful interaction, but to be able to respond *in interaction* as well as in learning to the fact that the organism is dynamically ‘uncertain’ about how to proceed. That is, it would be advantageous if the organism could “*detect*” (or be modulatorily influenced by) its own condition of uncertainty about what to do next, and develop categorizations of *types* of such uncertainty and concomitant *orientations toward heuristics* of how to successfully interact with such types of uncertainty-situations.

An ability to respond to *kinds* of uncertainty situations enables the organism to, for example, categorize situations involving an unknown large animal in such a way as to elicit the general heuristic of getting away from that situation — e.g., run like hell. This can avoid the risks involved in more primitive trial and error learning in uncertainty situations (Bickhard, 2000b).

Emotion processes, I propose, are future oriented evaluative arousals of kinds of heuristics for dealing with (kinds of) uncertainty within microgenetic processes (Bickhard, 2007a, in preparation-a; Damasio, 1995, 1999; Panksepp, 1998).[24] Microgenetic uncertainty, in turn, corresponds to dynamic uncertainty[25] about how to interact with the eliciting situation.

Support for such interactive responses to uncertainty should evolve within the general *anticipatory framework* of detection and interaction processes, and, therefore within the framework of nervous system supports for detections and interactions. It is with respect to encounters with and anticipations of failure and success that uncertainties (or the lack thereof) are evoked. More powerful abilities to respond to uncertainty, thus, should co-evolve with more powerful abilities to anticipate — to anticipate success, failure, and further uncertainty. The emotion (limbic) system fits both the macro-evolutionary sequence prediction of this model, and also the architectural and functional tight integration with thalamus and striatum.

Within these supports, it is to be expected that there may be partial differentiations and specializations for centrally important kinds of emotional uncertainty detections and resultant future orientations, such as for fear, for example, and these too are found in the overall limbic organization (Panksepp, 1998). Further emotional differentiations and orientations can be learned in socially and culturally specific contexts (Adolphs & Heberlein, 2002; Harré, 1986).

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[24] The identification of such processes as 'emotion' requires further elaboration and argument (Bickhard, 2000b, 2007a, in preparation-a). The central point for current purposes is that the ability to interact with microgenetic uncertainty constitutes a powerful adaptive possibility, and, therefore, that it is a plausible phase in the macro-evolution of the central nervous system.

[25] Perhaps dynamically constituted in chaotic processes.

2.2.1.2

Episodic Memory

Primitive anticipations are of very general possibilities, such as “a swimming situation” or “a tumbling situation” (e.g., of a bacterium). These become more specific and differentiated with more complex agents, such as “a tongue flicking and eating in such-and-such direction situation” (e.g., a frog).

As they become increasingly specific, differentiated, and complex, they also inherently become increasingly context-dependently historistic — dependent on the particular and contingent experience of the organism (e.g., the frog’s recent visual interaction with a worm in a particular direction). Web organizations of an organism’s conditionalized anticipations of what it could do[26] constitute that organism’s knowledge of the interaction potentialities of its current situation — its *situation knowledge*.[27] A major organizational principle of such contingent bases for interactive anticipation is space (O’Keefe & Nadel, 1978), and, of course, anticipation is already inherently temporal: situation knowledge is inherently here and now as well as there and then. A general ability to explore organismic historistic experience for possible anticipations constitutes episodic memory; explorations of *variations* on such contingencies constitutes future and counterfactual thinking (Atance & O’Neill, 2005; Bickhard, in preparation-a; Botzung, Denkova, Manning, 2008; Hassabis & Maguire, 2007). These are important particular versions of general anticipatory and learning phenomena.

Support for this special form of learning and anticipation should evolve along with emotion — which involves powerful anticipatory functions — and in integrated functional architecture with supports for the learning and construction of situation knowledge organizations, and for the potentialities for success and failure within those organizations (Murray, 2007). In accord with this point, the hippocampus and the amygdala have evolved in concert from early pallium (Broglio et al, 2005), and maintain close functional relationships (Grahna, Parkinson, Owena, 2009; Mizumori, Puryear, Martig, 2009; Pitkänen et al, 2000; Price, 2002).

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[26] E.g., it could do X if it first did (conditional on first doing) Y and then Z.

[27] Indications of the possibilities of interacting with a toy block in front of a toddler would be an example of part of the situation knowledge for that toddler.

2.2.1.3

Dynamic Modulation

Microgenesis in simple nervous systems is itself relatively simple, perhaps involving "just" variations in synaptic strength. But one major theme in the macro-evolution of nervous systems is the progressive further exploitation of the powers and enablings of microgenesis. The advantages of partial specialization and modularization — for both interactive functioning, and for the emergence of powerful spaces of potential variations in learning — has been mentioned.

Another major step in the exploitation of microgenesis is the development of the ability for microgenetic uncertainty to evoke not only (micro-)learning destabilizations, but also to influence directly the (macro-)resolution of what to do next — an evolutionary development that permits the organism to interact with its own condition of microgenetic uncertainty: emotion.

A further phase in this exploitation of microgenesis, to be outlined now, is the evolutionary emergence of the ability for some parts of the CNS to interact directly with the microgenetic processes in other parts.

There are several aspects to the emergence of this ability. One is the evolution of partially differentiated microgenesis and interactive processes. One basis for this differentiation is the progressive increase in glia, both absolutely and in percentages, over the course of macro-evolution (Baumann & Pham-Dinh, 2002; Nieuwenhuys, 2000; Verkhratsky & Butt, 2007). This, along with further development of silent neurons, volume transmitters, and other differentiations of scale, permit modulations of large scale microgenetic processes that are partially differentiated from small scale faster processes. This is the central point of Part II of this discussion.

Another aspect is the evolution of the laminar architecture of the cortex — in which the differentiation of microgenesis is at a maximum. This laminar architecture is a very general dynamic support with high flexibility in the potential microgenetic modulations that it permits. It is an approximation of a(n endogenously and concurrently active) dynamic systems version of a "programmable" central processing unit (though there are also specializations within that basic architecture).

A concomitant enabling of a laminar architecture is that it makes the evolutionary generation of more processing support relatively “easy”. The internal micro-architecture of nuclei can be detailed and complex, and, therefore, relatively difficult to usefully modify and expand. A laminar architecture (to a first approximation) can, in contrast, “simply” be expanded into more *area* of laminar organization (Aboitiz, 1992).

2.2.1.4

Internal Interaction: Reflection

Powerful exploitation of these potentials, however, also requires some degree of modularization and specialization of supports for (internal) interactions with microgenesis. In the mammalian line, this has emerged as an extension of interactive — motor — cortex with an ability to internally interact with multiple domains of the CNS, and with microgenesis processes, especially elsewhere in the cortex. This is the pre-frontal cortex. Pre-frontal cortex co-evolved with possibilities of internal dynamic modulation of microgenesis: dynamic modulation possibilities enabled internal interaction with microgenesis processes.

This constitutes a kind of internal interaction with internal microgenesis and situation knowledge processes: these *internal* processes constitute the “environment” for such internal interactions in a manner similar to that of the external environment for external interactions. In the sense in which external interactions represent and know that environment, the internal interactions represent and know those internal cognitive and emotional processes — they constitute internal ‘knowing’ processes, internal reflection.

The cortex, thus, is, to a first approximation, a general “programmable” dynamic processing architecture. There are, however, several disanalogies with a programming model. One is that the cortex, along with the rest of the nervous system, is *endogenously* active, rather than constituted out of passive elements, as in a computer. Another is that it is *concurrently* active across its entirety. A third is that modulations among endogenously active processes are not definitive “instructions” in the manner of a computer. And a fourth is that the pre-frontal cortex does not *command* such instructions to the rest of the CNS — just how the global CNS arrives at resolution of what to do next is further addressed below.

2.3

Forms of Metamodulation

Microgenesis in various parts of the CNS, especially the cortex, is modulated via a macro-interconnected system of several major divisions. It is important to note that these macro-scale architectures support macro-level oscillatory processes: they are not (semantic) information processing circuits, though they are most commonly interpreted in that guise.

2.3.1

Thalamus-Cortex

Among the most important of these macro-scale architectures are the reciprocal projections between thalamus and cortex (Churchland, 1995; Hoppensteadt & Izhikevich, 1998; Izhikevich, 2001, 2002; Izhikevich, Desai, Walcott & Hoppensteadt, 2003; Purpura & Schiff, 1997; Steriade, 1996; Steriade, Jones, & McCormick, 1997a, 1997b). Such reciprocal connections are ideal organizations for oscillatory processes within the reciprocal organizations.[28]

Together with the multiple intra-cortical connections, these loops introduce a fascinating possibility. Some neurons have natural resonance frequencies, and neural circuits, especially loops, can also have natural resonance frequencies. If one area of cortex generates signals with a particular carrier frequency, broadcast broadly to many other cortical areas, only those other areas that have that same (or close enough) resonance frequency will pick up those signals. This could constitute a general broadcast of signals, that are nevertheless targeted for those other areas with the same resonance frequency. This is formally akin to FM radio (Hoppensteadt & Izhikevich, 1998; Izhikevich, 2001, 2002; Izhikevich, Desai, Walcott & Hoppensteadt, 2003).

Furthermore, the thalamic loops with cortical areas are ideally placed to *influence* those resonance frequencies, and could tune them variously in an ongoing fashion. As various areas of the cortex are induced to have similar resonance frequencies, they

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[28] "Re-entrant" is a common term for this kind of architecture, but it carries the connotation that what is being "re-entered" is semantic information, and that is false.

become functionally connected and integrated via being able to “pick up” each others’ signals. The thalamus, thus, could, in effect, reconfigure the functional architecture of the cortex in an ongoing fashion — the thalamus could “tune” the functional architecture.

Further, insofar as the thalamic loops connect with the larger scale, slower processes in cortex (ascending reticular, etc.: Lewis & Todd, 2007; Steriade, 1996), these modulations and reconfigurations will be with respect to the microgenesis processes taking place in those cortical areas.

These points, of course, raise the question of what modulates the influences of the thalamus? What regulates the thalamic regulations of cortical processes and functional configurations?

2.3.2
Prefrontal-Striatum-Thalamus-Prefrontal

The ultimate answer to this question, of course, is the overall global activity of the CNS, but one particular architecture is worth examining in a little more detail in order to illustrate how this might work.

The architecture that I will expand is the loop from pre-frontal cortex to striatum to thalamus and back to pre-frontal (Crosson & Haaland, 2003; Edelman & Tononi, 2000; Fuster, 2004, 2008; Koziol & Budding, 2009; Marzinzik, Wahl, Schneider, Kupsch, Curio, & Klosterman, 2008; Middleton & Strick, 2000; Smith, Raju, Pare, Sidibe, 2004).[29] This loop is now recognized as participating in cognitive processes, contrary to the classical view of the basal ganglia as being dedicated exclusively to motor processes (e.g., Balleine, Delgado, Hikosaka, 2007; Koziol & Budding, 2009). But the loop is, as is by now familiar, interpreted as supporting information flow and information processing, where the information is assumed to be semantic (representational) information. The general critique of encoding models, which include information semantic models (Bickhard, 2009a), renders this an unacceptable interpretation.

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[29] This is much more complex than I will expressly take into account: the striatum is itself differentiated into rough architectural components, the loop in some respects is a four (or more) node loop, not just three, and there are within-nuclei differentiations as well as between-nuclei differentiations. One example of the latter point is that the head of the caudate is more specialized for cognitive processes, while the tail of the caudate is involved in more traditional motor processes (Koziol & Budding, 2009).

To understand this architecture within the general oscillatory-modulatory functional framework, consider first that a multi-node loop is just as capable of oscillation as is a two-node loop. So the loop itself could support oscillatory processes. Furthermore, the loop is most commonly presented as if the projective segments of it are unidirectional, from pre-frontal to striatum to thalamus to pre-frontal. We know, however, that virtually all projections in the CNS are reciprocal (Adolphs & Heberlein, 2002; Deacon, 1989, 1997; Ohye, 2002), and that this holds at least for some parts of this particular larger scale loop as well (Fuster, 2008; Middleton & Strick, 2000).

If so, then not only is the large loop potentially oscillatory, so also is each segment. Instead of linearly carrying semantic information, then, this loop, and others like it, can participate in various forms of intra-loop modulations of activity that can, in turn, modulate other processes. One set of other processes that can be modulated by processes in this loop are the thalamic modulations of cortical activities and cortical functional configurations.

This is a fundamentally different framework for understanding CNS functional processes. Note that, on standard information processing views, it is superfluous for such loops to exist, and for such reciprocal projections to exist. This is similar to the sense in which, on standard views, it is superfluous for volume transmitters, silent neurons, astrocyte processes, and so on to exist.

2.3.3
Other Prefrontal Loops

Other major loops involving the pre-frontal cortex are with the cerebellum and thalamus, and the limbic system and thalamus (Koziol & Budding, 2009; Price, 2002). There is convergence of these loops in the general area (and subdivisions) of the pre-frontal cortex, and in various subdivisions of the thalamus, thus permitting joint influence on each other as well as other processes in the cortex and other subcortical structures. Limbic loops are involved in emotional processes and memory, while cerebellar loops exert fine feedback system control over motor, cognitive, emotional, motivational, and sensory processes (Koziol & Budding, 2009; MacLeod, 2012; Molinari, 2002).

There is also high interconnectivity of prefrontal cortex with other areas of the cortex, primarily *not* those relatively dedicated to sensory or motor functions (Fuster, 2008), so there are oscillatory and modulatory loops within loops that connect prefrontal cortex with sub-cortical areas, back to prefrontal, as well as to other portions of the cortex, and again to prefrontal. Prefrontal cortex is part of central connectivity networks in the brain (Sporns, 2011). Prefrontal cortex, thus, is in ideal architectural position to engage in mutual and integrating influences with subcortical areas, and *with other areas of the cortex itself.*

We now have a rough outline of a model of CNS functioning organized around:

- well-habituated feedback control, with little anticipation of the possibility of error, via the cerebellum;
- ongoing planning and feedback control, not necessarily well habituated, via the striatum;
- more complex anticipations, including of possibilities of error, via the limbic architectures;
- finer and more elaborate differentiations of situation knowledge, increasingly specific to here and now (and there and then) for corresponding power in planning and in anticipating possible successes and errors, via limbic and hippocampal structures (with partial sub-differentiations for types of emotional responses);
- and elaborations of frontal (motor) cortex that interact with microgenesis in other parts of the brain, especially other parts of the cortex.

Learning *within* the microgenesis processes in pre-frontal cortex, thus, constitutes learning of dynamic modulational "programming" for *other* areas of the CNS.

2.4

Thought as Internal Interaction

The model as outlined so far has a number of interesting properties. The basic framework of anticipation and interaction yields consequences that the processes are inherently situated and embodied because the interactions require a body in some situation (Bickhard, 2008a). The flow of interaction as influenced by the anticipatory organizations of situation knowledge is inherently contentful, and, in sufficiently complex organisms, is saturated with emotional tone and memory.

The internal interactions of the prefrontal area with other processes in the CNS capture a second level of knowledge: knowledge of the organizations and flows — and attractor landscapes — of first level interactive processes (Campbell & Bickhard, 1986). This fits Piaget's notion of thought as internal interaction. I have argued elsewhere that "experiencing of experiencing" emerges in these internal interactions, yielding what are mis-labeled "qualia" (Bickhard, 2005a).

Second level, internal, interactions are suited for examining situation knowledge in order to more powerfully anticipate possibilities and impossibilities in further interaction with the environment — for planning, future exploration, counterfactual exploration, holding goals and values in relative stability, exploring new possibilities of variational construction and selection criteria, various kinds of self-regulation, and so on (Lewis & Todd, 2007). They are suited for powerful forms of learning to learn.

In multiple respects, then, the model offers an emergence interface between the functional/biological level of process and the cognitive/phenomenological realm. These are explored more fully elsewhere (Bickhard, 2009a, 2009b, in preparation-a).[30]

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[30] For a model of language within this framework, see Bickhard (2007b, 2009a, in preparation-a). For perception, see Bickhard & Richie (1983) and Bickhard (2009a, 2009b, in preparation-a). In the standard information processing framework, perception is construed as an input flow into cognition, and cognition, in turn, generates an output flow into action or language. These presumed input and output flows are among the most seductive pulls into an information processing view. This seductive power fades, however, if it is recognized that perception, cognition, action, and language (not to mention emotion, etc.) are *all* interactive processes, not semantic-information flows.

3

Macro-CNS Processes

A basic issue that remains to be addressed is that of how the global processes in the CNS achieve a functional and pragmatic coherence. As mentioned, the “obvious” answer that the prefrontal area enforces such a coherence suffers from a serious homunculus regress — how does the prefrontal area “decide” what it, and therefore, everything else, is supposed to do?

The general form of the answer has already been introduced: self-organization. Multiple processes that are endogenously and concurrently active may form multifarious resultant kinds of processes. They may be chaotic, and chaos is in fact a highly functional form of process for some conditions, such as when awaiting some further determination of activity (Freeman, 1995, 2000a, 2000b; Freeman & Barrie, 1994; Bickhard, 2008b). They may exhibit instability that is a form of incoherence — of *conflicting* orientations and kinds of preparedness — rather than of chaos, but note that such global instability also forces local microgenetic anticipations to fail, and, thus, to evoke learning processes. So a lack of global coherence contains its own instabilities.

Or they may exhibit self-organization into some coherent trajectory of further processing. Self-organization occurs when multiple micro-level processes compete to recruit other local processes to themselves — as when “random” molecular motions in a pan of heated water recruit neighboring motions into macro-level boils of water. Self-organization is a macro-perspective on the results of micro-level recruitment competition. In the brain, there are many ongoing processes that participate in such self-organization. These processes, as mentioned above, involve interactive anticipations; situation knowledge anticipations of success and failure and uncertainty; emotional orientations to attempt to deal with various forms of uncertainty; use of memory, future, and counterfactual organizations of contingent possibilities, enablings, and failures to enhance anticipation and planning; and so on. These processes modulate and compete with each other, yielding the potential for the self-organization of globally coherent activity. Pre-frontal cortex is in a position to maximally support such process and functional coherence — multiple kinds of process can integrate there — but it is not a supreme command-issuing executive.

3.1

Self-Organization: Multiple Considerations

The differentiated processes that participate in the global self-organizing flow of CNS activity are specialized for differentiated kinds of sensitivities and modulations. All local activities in the CNS tend to evoke other processes that generate successful interactions with the given local activities, but there is constant ongoing competition among them. Thus, the overall self-organizing process (a flow, with no final self-organized state) tends to maintain self-anticipatory success among interactions with the external world, with respect to situation knowledge, with the body (e.g., hunger), with relatively stable set points or goals, with more stable guidances at higher knowing levels (meta-goals, meta-attitudes, values), with emotional heuristic anticipations, and with internal thought processes.

Self-organization of the CNS, thus, is with respect to competitive modulations from all areas. Local processes will have functional effects in terms of what they tend to elicit or modulate in other processes, and these effects compete in the overall self organization al process. The functional efficacy of such local processes is massively constrained by architecture, but also massively constrained by learning — learning what sorts of local modulations and processes will succeed with respect to neighboring modulations.[31]

3.1.1

Synergetics

As the adversions to self-organization make clear, both micro- and macro- brain dynamics are instances of synergetic processes: resultants of ‘cooperative’ activity within complex systems (Haken, 1980, 1983, 2010). In one sense, this is necessarily the case, and can be seen to be necessarily the case once it is recognized that all parts of the brain are dynamically coupled, and ongoingly, endogenously, and concurrently active — there

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[31] Variants on models of CNS self-organization can be found in, for example, Arbib (1972) and Juarrero (1999).

are no passive pure recipients of inputs. Consequently, any activity will be the result of synergetic mutual influences among the multifarious components. The notion of *control* parameters captures part of such mutual influence, though it is not as clear that the notion of *order* parameters is directly applicable: all processes are engaged in transient dynamics, and it is only with respect to much higher order functional properties that are both relational and time varying that full self-organization occurs, so there would not seem to be any fixed order parameters. Perhaps this could be approximated with a complex foliation of center manifolds within which the control parameters induce trajectories (Izhikevich, 2007).

4

(Macro-)Conclusion

There is a strong consilience of theory and evidence that the CNS functions in terms of oscillatory processes that modulate each other at multiple scales and within multiple architectures. There is an inherent anticipatory aspect to these processes, which gives rise to representation and cognition. The multiple modulations give rise to an overall ongoing self-organization of activity that resolves the flow of process in ways that are sensitive to multifarious considerations, such as interaction, thought, planning, emotion, and memory. This flow is inherently contentful, situated, embodied, saturated with meaning, anticipatory, and, via internal reflective interaction, capable of experiencing the flow of experiencing (Bickhard, 2005a).

Such a theoretical framework is in strong contrast to standard assumptions that the nervous system processes semantic information. There are a large family of arguments that this cannot be the case (Bickhard, 2009a). Information *in the technical sense* (i.e., covariation, in this model, via modulatory influence) is necessarily involved, but this does *not* constitute semantic or representational phenomena (Bickhard, 2000a).

This model is an interpretive framework that fits with extant knowledge of brain architectures and processes, as well as with multiple theoretical and philosophical considerations. It is hoped that it provides a fruitful framework within which to explore, develop, and correct more detailed models.

Part IV: Prediction, Anticipation, and the Brain

1

The Predictive Brain: A Comparison

There are some interesting convergences between the interactivist model and a family of related models called variously the predictive brain, the Bayesian brain, or action oriented predictive processing (Clark, 2013). In particular, both approaches emphasize future oriented prediction or anticipation. This is especially evident regarding Sokolov habituation, which both approaches characterize in terms of anticipations which are, in effect, 'subtracted' in comparison with input flow, thus yielding a zero result if the anticipations are accurate, and a residual signal inducing arousal or further processing if they are not accurate.

Nevertheless, there are major differences between the approaches, and I would like to outline some of them here. The predictive brain family of models is large and complex, and has developed multiple variants over the last decades; I will address some of the most basic framework differences but focus here primarily on a few differences with regard to functional characteristics of the brain.[32]

1.1

Predictive Brain Models

The predictive brain program developed out of a Helmholtzian framework for perception, in which input sensations are presumed to form the basis for inference to representations of the world. Two major advances within this framework were the *analysis by synthesis* movement of the 1960s and the related recognition that actions might be performed for the sake of the *inputs which they induce* from the environment. In the analysis by synthesis movement, synthesizing, or predicting, input sensations — a form of abduction — was substituted for more classical induction and deduction forms of inference from sensations to the world (MacKay, 1956, 1969; Neisser, 1967).

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[32] For a more detailed critique of predictive-Bayesian-free energy models, see Bickhard (in press).

Recognition that interaction could induce perceptual inputs grew out of the cybernetics movement (Powers, 1973) and resonates with Gibson's notions of sensory interactions (Gibson, 1966, 1979).[33]

An important elaboration of these ideas was to postulate Bayesian decision procedures (or approximations thereof) as the form of the predictive processes. Bayes procedures involve prior probability distributions that are modified into posterior probability distributions on the basis of current data. Those posterior probability distributions constitute the (probabilistic) predictions concerning the input. What is being predicted, thus, is the probability distribution of the input pattern or flow.

Bayes requires a source of *prior*, initial, probability distributions, and this lends itself to postulation of a hierarchy of levels of Bayesian procedures, each predicting the inputs from the level below, and sending those predictions to the level below. The lowest level predicts sensory inputs and sends the errors of those predictions upward to the next level, which, in turn attempts to predict those discrepancies from the lower level. Collectively, then, such a hierarchy can account for the "errors" of prediction resulting from lower levels until, optimally, all of the distributional patterns of the inputs are accounted for. It has been proposed that such a hierarchy constitutes the basic functional architecture of the brain (Friston & Stephan, 2007).

Friston has also proposed an integrating framework for such models centered on a statistical notion called "free-energy":

> "The basic premise we start with is that biological systems must keep $\tilde{y}$ ["$\tilde{y}$ can be regarded as sensory input"] within bounds (i.e. phase-boundaries) through adaptive changes in α.["effect[s] of the system on the environment"] Put simply, adaptive systems or agents should minimise unlikely or surprising exchanges with the environment." (Friston & Stephan, 2007, p 425)

That is, they should minimize free energy. The reason that agents will tend to minimize free energy (surprise, or unpredicted input) is that ancestral organisms that did not so minimize would fail to keep inputs "within bounds" and thus cross phase boundaries and

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[33] Though they are strictly inconsistent with Gibson's claim that perceiving is not based on intermediate representational sensing (Gibson, 1979; Bickhard & Richie, 1983).

cease to exist. Such evolutionary dissolution would tend to eliminate those agents who did not minimize free energy, and, thus, select for such a tendency to minimize in future populations.

Friston argues that, within this framework, there is no need to postulate normative phenomena such as goals or preferences or values: Higher level "expectations" will yield actions that produce "expected" consequences. These higher level expectations are constituted by higher or highest level Bayesian priors, that are ultimately innate. Such expectations yield actions that produce outcomes that are generally thought of as desirable, but without any explicit consideration of utility or value — value considerations are built into the evolutionary setting of the higher level expectations. Thus, minimizing free energy — surprise — drives both evolution and action.

1.2

Some Problems

A most basic problem with these models is that they assume classic sensory encoding empiricism. Inputs, in such models, must be somehow transduced into representational sensations in order to support the inferences that are supposedly based on them. No one has been able to provide a model of such transduction of factual input into representation in several millennia of trying, and there are in-principle grounds for concluding that this is impossible. Those are briefly outlined in part I of this paper (see also Bickhard, 2009a and multiple other references).

Furthermore, even if sensory transduction of inputs into sensations is accepted, no one has been able to account for how higher level representations, such as of chair or triangle or the number '3' or the concept of justice, etc., could possibly be constructed out of such input sensations. The predictive brain approach, in fact, seems weaker in this regard than classical sensory empiricism: classical models could postulate various kinds of aggregations and organizations of sensory encodings, while the Bayesian brain approaches are limited to parameters of probability distributions over lower level spaces of parameters of probability distributions over … over patterns and flows of sensory inputs.[34]

The predictive brain approaches and the interactive model have an interesting convergence with regard to the general emphasis on anticipation or prediction, and especially for the particular case of Sokolov habituation. For the predictive brain models, the brain attempts to predict inputs, and matches the predictions against the inputs via something like a subtraction process, so that any discrepancies yield a non-zero "error" signal.

For the interactive model, however, local brain processes "attempt" to anticipate their own near future processing (via microgenetic set-up for such processing). If the only relevant activity — process — of a local domain is that of *registering inputs*, then anticipation of local processing converges extensionally with *prediction of inputs* to that processing. The interactive model, however, is ***not*** focused on predicting inputs: the central functional normativity is that of internal, local anticipations of internal local flows of activity, of internal local flows of process (Bickhard, 2001, in press; Bickhard & Terveen, 1995).

The apparently subtle difference between predicting inputs and anticipating local processes, however, generates major divergences in other cases. With regard to classical conditioning with respect to a shock grid, for example, the interactive model proposes that there are no subtractive processes possible for pain inputs (habituation, to a first approximation, is not possible), thus generating destabilization of the microgenesis processes that failed to anticipate, and, thus, that the only way to successfully anticipate such internal processes is to avoid the shock. Within the predictive brain framework, in contrast, the rat on the shock grid should, upon hearing the tone that signals shock, simply predict pain inputs — successfully — and stay on the grid. Friston could postulate some sort of highest level expectation for avoiding pain, an innate "hyperprior" perhaps, but this encounters problematic exceptions, such as for *seeking* pain inputs, e.g.,

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[34] Note that the spaces over which these parameters 'parameterize' — spaces of functional forms for prediction — must themselves be already available (Friston, Daunizeau, Kiebel, 2009 on switching between functional forms)— presumably innate. The highest level innate priors are the highest level instance of this point.

from hot peppers. Accounting for such exceptions and exceptions to exceptions, etc., yields an epicyclic elaboration of ad hoc and evolutionarily absurd “expectations”.

Similarly, if successful prediction is the only criterion, why wouldn’t a person simply head for a dark room and stay there? Prediction of input is easy if there are no inputs (Clark, 2013). Again, Friston can claim that there is a high level expectation to avoid darkness, and that thus produces action such as turning on a light (Friston, 2013). But again there are exceptions: sometimes a person *wants* darkness, perhaps to sleep, or hide, or hunt.

Such examples demonstrate that the free energy principle cannot account for utility, or normative phenomena (Roesch, Nasuto & Bishop, 2012) — all such considerations have to be already built-in to the system, by the designer in the case of artificial systems and presumably by evolution in the case of living systems (Friston, Daunizeau, Kiebel, 2009).

The basic problem is already manifest in the “basic premise” quoted above. First, phase boundaries are not necessarily “bad” for an organism; they are intrinsic in internal structure, both of cells and of organisms, and “crossing” or changing such boundaries is intrinsic to learning and development. So “phase-boundaries” does not work as an explication or definition of keeping inputs “within bounds”. Further, “within bounds” does not specify what constitutes relevant bounds. Assuming that staying “within bounds” is equivalent to minimizing surprise, prediction failure, is not supported — once again, there seem to be important exceptions and counterexamples. For example, seeking surprise would seem to be central to novelty seeking, play, exploration, esthetic motivation, and so on — all central to human adaptive behavior. Normativity, whether of representations or actions (or emotions, etc.), is fundamentally missing from these models.

The evolutionary-selection account of why organisms would tend to minimize surprise renders “minimizing surprise” a consequence of evolutionary history, not an intrinsic property of living beings. This is different from, for example, enactivist models in which autopoietic construction of the system’s own components is claimed to be inherent to life, not just a result of evolution (Maturana & Varela, 1980; Varela, 1997;

Weber & Varela, 2002). And it is in *strong* contrast to the interactivist model which focuses on the point that maintaining essential thermodynamic relationships with the environment (self maintenance) is *in fact* ontologically inherent to living beings — a necessary and essential inherence — not just a contingent point about their evolutionary history (Bickhard, 2009a).

The proposal that the hierarchical form of processing — in which each layer attempts to predict the "errors" generated by the predictions of the lower layer, and sends its own "errors" to the layer above — constitutes the basic functional architecture of the brain seems to have a partial fit to the visual system (and perhaps to other sensory parts of the brain) in that it can be modeled as 'layers' of cortex that reciprocally project between adjacent layers. Many details of this perspective are unclear, including whether or not the reciprocal projections carry the kinds of "prediction" and "error" signals postulated,[35] but when consideration turns to more general considerations, the model does not fit at all.

Among other problems, such a hierarchical model does not account for:

- Multiple-node (non-hierarchical) loops, such as from prefrontal to basal ganglia to thalamus to prefrontal;
- General widespread neuromodulator projections, such as of dopamine (Marder & Thirumalai , 2002; Marder, 2012);
- The functionality of silent neurons;
- The functionality of astrocytes;
- And has no non-ad hoc account for such phenomena as the ubiquitous oscillatory-modulatory activity of the brain, the vast ranges of physical and temporal scale involved in various of these processes, and so on.

In addition to the basic conceptual framework problems, thus, the model has serious flaws as a general model of brain functional architecture.

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[35] Note that such reciprocal projections would be ideal for engaging in oscillatory processes that could modulate connected such oscillatory processes.

The predictive brain approaches propose that the brain is engaged in *global* prediction of sensory *inputs*, including the inducing of such inputs via action. The interactivist model proposes that each *local* region of the brain is engaged in its own anticipative microgenetic adjustments which tend to stabilize if microgenesis successfully anticipates *local* flow of processing. For the predictive brain, it is the organism-level inputs and derivatives from them that are supposedly representational. For the interactivist model, it is the *anticipating process itself* that is representational, *not the inputs*. These differences and their consequences are crucial.

1.3

Hierarchical Time Scales

In addition to the emphasis on prediction or anticipation, there is another terminological convergence between the Bayesian brain model and the interactivist model that is worth commenting on: time scale differentials. In the Bayesian brain models, higher levels track changes in the environment that are supposed to change more slowly than lower levels. Lower levels, for example, might anticipate sensory inputs while higher levels anticipatively track objects that “cause” those sensory inputs — the objects change more slowly than the sensory flows that they “cause”.

In the interactivist model, spatially larger processes, such as astrocyte processes and volume transmitter diffusions, are dynamically slower than smaller, faster processes, such as classical synapses or gap junctions.

Thus the neural-glial level dynamics in the interactivist model are slower at larger spatial scales, while the neural-glial dynamics in the Bayesian brain model might well be at the same time scales at all ‘predictive’ levels, but what they track, and, therefore, some “tracking” aspect or property of that dynamics will be slower than at lower levels. The time scale differences for the Bayesian brain models are a reflection of presumed time scale hierarchical differences in the environment: sequences of sequences change more slowly than sequences per se (Kiebel, Danunizeau, Friston, 2008). For the interactivist model, time scale differences are inherent in the nature of the neural-glial dynamics, regardless of what they might or might not be tracking or at what ‘environmental level’ they might be tracking. In general, the interactivist model is not built on information semantic notions such as tracking, though *non*-semantic information relationships may certainly exist and be useful in some cases.

So, as with "anticipation", the two models make use of similar notions, but to refer to fundamentally different kinds of dynamics.

2

Information? Of Course!

I have argued against semantic information models throughout this paper, including those of the predictive brain approaches. Lest this be understood as arguing against the functional importance of information per se, I would like to mention some considerations supporting that importance.

The crucial point is that information is a technical term meaning, roughly, being correlated with, and information in this sense is essential for an organism to be appropriately sensitive to conditions in the environment in its interactions with that environment. If there were no processes in the brain that were correlated with properties of the environment, the organism's interactions would have no ability to take the environment into account. But there is no necessity for such correlated processes (or correlations among processes) to be representational.[36]

In this sense, information is a *control theoretic* notion, and a fundamentally important one, not a *semantic* notion (Bickhard & Richie, 1983). Information in the technical correlational sense is involved in all of the modulatory influences in the CNS: each local process sends signals to related domains that are correlated with — that are in a control theoretic informational relationship with — the local processes that generate those signals. The entire CNS, then, can be viewed from a *correlational* information 'processing' perspective, but the *only* such informational relationships that are

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[36] Regarding the possibility of correlational information constituting representation in itself, consider: information is a *factual* relationship, not a semantic relationship. It either exists or it does not; there is no way for it to exist but be false. This is a basic Brentano point, one that has been and still is pervasively ignored. For discussion of some recent ingenious but ultimately failed attempts to address it, see Bickhard (1993, 2009a).

representational are those that modulate (‘control’) microgenetic *anticipatory* set-up processes. That is, it is ‘information’ that control-theoretically anticipates the future of endogenous processes that is representational (Bickhard, 2000a).

Furthermore, *extraction* of higher order (partial) correlations can be important because those can be the correlations that an organism should be responsive to. In that sense, information *processing* is crucial. But it is the *generation* of *future oriented anticipatory information* — which does not necessarily occur via extraction — that generates and evokes truth valued process, and, thus, representation.

So, the issue is not whether information and information processing exist — of course they do. The issue is not whether information and information processing are important — of course they are. The issue is what kind, if any, of information generates or constitutes representation. And the answer is that it is future oriented anticipatory information that influences further processes — information that can modulate, regulate, or control further processes — that has truth value and thus constitutes representation.

Information, thus, is crucial to (successful) anticipation, but it is only the anticipation that can be representational.

One consequence of this point for brain functionality is that information is a property of ongoing modulatory influence on further processing. Information is not a representational state that needs to be created or retrieved — it is a property of real time ongoing influence of some processes on other processes. The brain, thus, does not function in terms of creating stable representational conditions and then (inferentially) responding to them. CNS processes are always in transit, always influencing other processes, always being influenced by other processes. In this sense, it is the dynamic transients that are of importance, not any stable attractors (Rabinovich, Huerta & Laurent, 2008; Rabinovich, Afraimovich, Bick & Varona, 2012).

Conclusion

The sensory encoding framework for “predictive brain” models ensures that they cannot successfully model (cognitive or) brain activity. Multiple derivative and subsidiary problems have been presented, and it is argued that the interactive model resolves or simply avoids these issues. Predictive brain models constitute one of the most sophisticated contemporary encoding approaches to cognition and brain models; its failure constitutes yet one more demonstration that such frameworks should be abandoned.

According to the interactivist model, representation and cognition emerge in *anticipations* of further interactive activity. Timing is crucial to such activity, thus oscillation is the central form of process; functional influences occur as various forms of modulation, both within the nervous system and between the nervous system and its body and external 'environments'. The brain does not function in terms of the processing of information-semantic inputs; it is everywhere always endogenously active. Its basic functional activity consists in multifarious forms of interaction and modulation among oscillatory processes and microgenesis processes.

The fundamental form of brain dynamics, thus, is that of endogenously active oscillatory processes that have modulatory influences on each other. One crucial form of modulation is that of slower, larger scale, processes on smaller, faster processes, inducing a microgenesis of dynamic spaces, such as attractor landscapes. These processes occur at multiple spatial and temporal scales, such as those of gap junctions, synapses, volume transmitters, multiple kinds of astrocyte influences, and so on. Large scale, thus slower, processes parameterize smaller scale, faster, processes: they microgenetically set-up dynamic spaces — e.g., attractor landscapes — for those faster processes. Learning is involved in the evolutionary-epistemological construction of abilities to microgenetically induce new dynamic spaces.

These processes, in turn, are modulated by oscillatory interactions among wide-spread macro-organizations in the brain. Importantly, some of these macro-oscillatory-processes modulate microgenetic processes in other CNS areas, thus *interacting with* the (setting up of the) dynamic spaces of other processes. Also, some microgenetic processes can more directly influence *other* microgenetic processes, e.g., in terms of the dynamic stability or instability of one process influencing other microgenesis processes. In various ways, such interactions among macro-oscillatory-processes and microgenetic processes are involved in learning, emotions, and conscious thought.

Processes occurring throughout the brain tend to recruit among themselves into locally and globally interactively successful forms of interactive process, where ‘success’ is constituted by successful microgenetic anticipation of interactive process. If such recruitment is globally successful, the brain attains functional coherence of its internal interactions. These processes are all modulated by interactions with the environment, so functional coherence entails successful environmental interactions: the body and external environment are, in various modes, interactive environment for the CNS similar to the sense in which some parts of the brain are ‘environment’ for other parts of the brain.

Mind emerges in such overall dynamic processes. Some aspects of mental processes — e.g., emotions and reflective consciousness — have emerged in macro-evolution in differing architectural organizations that elaborate and add to earlier evolutionary developments. A central theme in this macro-evolution is the exploitation of increasingly powerful modes of making use of, and interactively modulating, the processes of microgenesis. Functionally, this constitutes a macro-evolution of increasingly powerful modes of learning and learning to learn. In turn, human capacities in these respects have made possible the further evolutionary and historistic emergence of full person-based linguistic sociality (Bickhard, 2007b, 2009a, 2013, in preparation-a).

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