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Emotion: The Self-regulatory Sense

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ABSTRACT

While emotion is a central component of human health and well-being, traditional approaches to understanding its biological function have been wanting. A dynamic systems model, however, broadly redefines and recasts emotion as a primary sensory system—perhaps the first sensory system to have emerged, serving the ancient autopoietic function of "self-regulation." Drawing upon molecular biology and revelations from the field of epigenetics, the model suggests that human emotional perceptions provide an ongoing stream of "self-relevant" sensory information concerning optimally adaptive states between the organism and its immediate environment, along with coupled behavioral corrections that honor a universal self-regulatory logic, one still encoded within cellular signaling and immune functions. Exemplified by the fundamental molecular circuitry of sensorimotor control in the *E coli* bacterium, the model suggests that the hedonic (affective) categories emerge directly from positive and negative feedback processes, their good/bad binary appraisals relating to dual self-regulatory behavioral regimes—evolutionary purposes, through which organisms actively participate in natural selection, and through which humans can interpret optimal or deficit states of balanced being and becoming. The self-regulatory sensory paradigm transcends anthropomorphism, unites divergent theoretical perspectives and isolated bodies of literature, while challenging time-honored assumptions. While suppressive regulatory strategies abound, it suggests that emotions are better understood as regulating us, providing a service crucial to all semantic language, learning systems, evaluative decision-making, and fundamental to optimal physical, mental, and social health.

EMOTION: THE SELF-REGULATORY SENSE

The wisdom of Jeremy Bentham has oft been quoted: "Man has been placed under the governance of two sovereign masters: pleasure and pain."[1]

Despite this insight, philosophers and psychologists remain haunted by the question: *What is the biological function of emotion?* It has been difficult to disentangle emotion from biological drives and physiological responses,[2] from motivational appetites and defenses,[3] from cognitive appraisals[4,5] or moral intuitions[6]; to make sense of the cultural similarities and differences,[7] or to reconcile divergent theories[8,9]; so difficult, that theorizing about emotion as a functional whole has largely been abandoned. As one critic put it: "My central conclusion is that the general concept of emotion is unlikely to be a useful concept in psychological theory."[10]

The purpose here is to suggest the opposite: That the problem with the traditional approach is that it has been overly *specific*, narrow, and anthropomorphic. Indeed, emotion theory remains reminiscent of the Sufi tale of the elephant and the blind men,[11] with each theorist grasping a portion, but unable to see the phenomenon in its entirety. Yet rather than integration and synthesis, the trend continues of "dissecting the elephant"[12] into ever-smaller fragments devoid of coherent biological function. As a result, emotional feelings and behaviors are written off as outdated animal vestiges, "ill-suited to modern exigencies,"[13] to be suppressively regulated by one's conscious rational mind, if not pharmaceutical intervention.

But with recent revelations from a variety of disciplines, a formerly hidden—yet astoundingly elegant—functional elephant looms large. The current proposal is that the function of emotion is the very sort of "governance" that Bentham suggested, that of *self-regulation*. But in this usage, "self-regulation" refers primarily to the biologically bottom-up autopilot variety of regulatory control processes, and implies that subordination to our hedonic masters is actually a very good thing. It will be argued that our limited ability to suppressively regulate our emotions is because *they are actually regulating us*, and from a much deeper, wiser, evolutionary evaluative authority.

To sketch this ancient function, we must pan much further back in our phylogenetic history, and delve deeper into the biophysical regulatory processes of living systems, tracing the emergent trajectory of the emotional system from its simplest mechanistic roots to its present state of elaborate multi-tiered complexity.

To linguistically accommodate the entire functional elephant, we must broadly redefine the category of "emotion" to include "affect" and innate "hedonic" approach/avoid behavior, locating its function in the arena of *regulatory signaling* and *motor control* mechanisms. We must specifically focus the inquiry upon *feedback loops*, recursive, cyclic and reciprocally deterministic, stimulus-response relationships; those that give rise to the earliest forms of "computation"—*information processing*—in nature; those that inform what will be termed "self-regulated" behavioral agency in organisms as simple as a single-celled bacterium, and those still evident in the cell-signaling cascades that convey identity-relevant information across all levels of organization within complex multicellular organisms—including humans.

Indeed, many theorists have pointed out the primary "relevance detection,"[14] "relevance signaling,"[15] and "informational,"[16-18] functions of emotion, as well as those of resource mobilization and conservation,[19] and the organization and facilitation of adaptive behavioral responses.[20,21] Likewise, many have noted the categorizational,[22] motivational[23,24] goal relevant nature[15] and primacy[25] of affect. In fact, the idea of biophysical feedback itself has a rich history in emotion theory[2,26-37] in which Carver and Scheier[38,39] specifically noted feedback as a self-regulatory "control process" underlying affect. Recent revelations, however, about bottom-up "self-organization"[40,41] and interactive epigenetic mechanisms[42] in evolution, can finally root these insights in solid biophysical ground, as well as offer significant clarifications and enhancements.

Indeed, building upon these contributions, I propose that emotion can only be envisioned as a unified functional whole when reconceived as an entire *sensory system*—a primary somatosensory system that guides *biologically adaptive self-regulation*. Not a newly evolved or sixth sense[43] but perhaps the *first* sensory system to have emerged on the evolutionary stage, born of the simple molecular stimulus-response networks that regulate metabolic and genetic activity and crude sensorimotor behavioral control in single-celled organisms. Such primal self-regulatory "sensations" are functionally homologous to, and still manifest within, *cell-signaling mechanisms* in multicellular organisms that integrate and maintain "the self" at all levels of complexity—rooted as deeply as those that control the navigation and differentiation of pluripotent stem cells into their various tissue environments during embryonic self-development. In other words, while they may have emerged as sensorimotor regulators in the earliest life forms, the same principle mechanisms still constitute the signaling and communication systems, the *self-organizing language*—the *self-regulatory music*, if you will—of the human body.

In whatever form of "subjective experience" these original sensations may have yielded, in functional terms they would deliver *primal perceptions* of *time*, *space* and *self*—an inaugural glimmer of a body-self moving within its not-self surroundings, at some point constituting the "feeling of being"[44] or "how it feels to be alive."[45] Hence, in far more complex bodies in motion (mammals, other primates, and humans), each emotional feeling perception still reflects "a wave of bodily disturbance," or the "bodily affections,"[2] or "the feeling of what is happening."[46,47]

Key to our discussion, however, is that from their emergence forward, these informational sensations have contained "*felt evaluations*,"[48,49] the *symbolic binary opposites that we experience as pleasure and pain, the feel good/feel bad hedonic valence of emotion.* These "positive and negative" binary opposites offer real-time computational representations of the ongoing dynamic orchestration of whole-body coherence, with harmonically resonant and dissonant reverberations ringing forth when environmental perturbations require self-regulatory responses. The current proposal is that the binary hedonic logic within these felt evaluations offers nothing less than a *biological value system*, informing us of universally optimal and deficit states of balanced being and becoming—a *natural value system* rooted in the biophysical requirements for life itself.

At a more concrete level of analysis, the positive and negative hedonic categories equate with "eustress" and "distress" signals respectively[50] and locate the emotional sense as an intimate affiliate of the *immune system* (recently declared a sensory system itself).[51] Adding, however, that its core physiological "*self*" or "*not-self*" distinction is tethered deeper still in genetic and epigenetic regulatory mechanisms, the bottom-up biological processes that ultimately inform the fundamentally "self-relevant"[34] or "motivationally relevant"[52] nature of affective stimulus, and underscore the notorious bidirectional connection between emotion and physical health.[53-59] As such, these core self-regulatory feedback processes in humans also undergird the requirement for "regulatory fit"[60] within and between goals, or concordance within the "psychological immune system"[61] and other self-balancing processes such as "cognitive dissonance"[62] although, as will be argued, *emotional* dissonance may be more biophysically accurate.

The self-regulatory functional elephant will also acknowledge emotion as the unsung hero in conditioned learning,[63,64] in subliminal "priming"[65] and embodied[66] implicit[67] or unconscious cognition,[68] implicit bias[69,70] as well as nonconscious, "auto pilot" self-regulation[71]; in cognitive identity formation,[72,73] self-perception,[74] self-concept,[75] self-serving biases,[76] and self-enhancement motives[77]: in needs for and feelings about self-determinism,[78] self-efficacy,[79] self-esteem,[80,81] self-expansion[82] and urges toward self-actualization[83]; all of which are elegantly integrated within emotional sensory perceptions and their coupled behavioral responses.

In short, the goal here is to sketch a new image for the box of the puzzle of emotion, one where emotion takes its rightful place as a **sense**; one depicting common *feeling tones* on par with colors, tastes, scents and sounds. One in which feeling perceptions, ranging from rudimentary *pleasure* and *pain*, through basic *joy* and *sadness*, to complex *pride*, *shame*, *admiration* and *envy*, serve as *sensory signals* offering an elegant palate of evaluative information about our adaptive fitness in the immediate environment. Indeed, the proposal is not only that emotion should be reframed as a sensory system, but that emotion should also be acknowledged as the biological *grandfather of all the senses*, and that its hedonic self-regulatory logic remains encoded within all other senses—a simple logic, yet one so crucial as to have been conserved throughout our entire evolutionary history. Acknowledging how our presently elaborate, cognitively enriched, emotional perceptions still bubble up from their ancient self-regulatory wellspring, offers quite profound implications for the medical com-

munity, as well as the social sciences in general. Indeed, it allows the scientific construct of emotion to come full circle, rejoining with the so-called naïve realism of immediate human experience, yet offering direct inroads to embodied knowledge, bountiful emotional intelligence, social intuition, and even moral reasoning.

But however elegant, these *subjective* manifestations cannot be separated from their *objective* counterpart, for each emotional sensory perception includes both an *informational* component and a coupled *behavioral response*. Indeed, in this new view, emotion is ground zero for all sensorimotor stimulus-response relationships, with the *hedonic approach and avoid behavioral pattern*—a pattern observable from the single celled ameba to the complex human[84]—serving as the primary empirical justification and departure point for our new story. A crucial point is that this crude sentience is contingent upon, and would *follow from*, the deterministic behaviors themselves, or as Marienberg put it: "the becoming aware of the capacity to act *while acting*."[85] In short, identifying the biological function of emotion requires taking Skinnerian behaviorism to all new reductionist levels—an inquiry into how approach and avoid behaviors emerge from the chemistry of living systems. Yet, when equipped with the lens of feedback control theory, the journey affords a primordial peek into the "black box," offering a clear and detailed functional explanation of how innate ("unconditioned") stimuli evoke "affect" itself—something decidedly lacking in emotion theory.[9]

This brief introduction begins with a redefinition of emotion within this broadened context, turning next to its biophysical substrates and underlying feedback dynamics, and identifying the source of what will be termed "the self-regulatory code." The hedonic behavior of the Escherichia coli (*E coli*) bacterium is offered next as an example of the ancient mechanisms (both function and form), followed by a description of the modern neural, perceptual, and behavioral manifestations of the emotional sense; and ending with a brief discussion of the implications for human health. Indeed, to formally acknowledge emotion as a primal sensory system invites critical reevaluation of many deeply engrained linguistic conventions, beliefs, and practices.

EMOTION: A BROADENED DEFINITION

To begin, I broadly redefine "emotion" within the context of digital *stimulus-response behavioral phenomena*, including any biochemical processes and physical mechanisms, laws and forces that determine their cause and effect relationship. By digital, I mean any sort of distinctly *binary values*, symmetrically isomorphic or oppositional qualities, structures, bistable states or transformative actions that exist in nature that can be harnessed as meaningfully symbolic cues further up the evolutionary ladder. In other words, such binary values (ie, positive/negative electrical charges, north/south magnetic poles, left/right symmetries, cis/trans isomers, bistable attractors, etc) can serve as digital information "bits" for computational processing. In fact, an *if-then* stimulus-response logic is there for the taking in the orderly behavior of electrons, behavior that ultimately drives all higher scale chemical reactions—from the bonding and anti-bonding behaviors of molecules, through the transitional and equilibrium states of metabolic networks, to the signaling cascades and on/off regulatory switching of genetic processes. In short, the sensory informational components of emotion can only be appreciated against the backdrop of the in-forming, trans-forming, stimulus-response dynamics of matter in motion.

These binary opposites, deterministic behavioral laws, and self-organizing dynamics underlie the "regulation" part of the self-regulatory function of emotion, as they deliver bottom-up "order for free."[41] As we will see, they also deliver an elegant stimulus-response choice-making logic—whether or not any sentient life form has yet emerged to exploit it. The "self" part of the self-regulatory function, and the emergence of what is defined herein as emotion proper, is rooted in iterative, self-reflexive, *feedback loops*. Indeed, feedback provides the crucial evolutionary link between the deterministic, self-organizing "happening" behavior of non-living matter and the self-regulatory agency—goal driven "doing" behavior—of living systems. As such, feedback also provides the conceptual linchpin between the physically impartial "positive" and "negative" binaries in nature and the warm-fuzzy/cold-prickly evaluative categories of personal experience.

What Is Feedback?

Feedback, in terms of general function, refers to *communication and control mechanisms* prevalent in both mechanical and organic systems—those that report upon (inform) and alter (transform) the relationship between a given system and its immediate environment.[86] Feedback is cyclic, as it occurs in circular stimulus-response *loops* where the output of a system is fed back into *itself*, serving as a stimulus for a subsequent round of output responses (See Figure 1, two systems with and without feedback). In this primary mechanical context, however, the term "self" is synonymous with the *system* in question, whether it be an atom, a molecule, a cell, an organ system, or an organism interacting with its local "not-self" environment. Equating "system" with "self," of course, does not yet imply sentience or consciousness, but is simply a *relative location in space*, as well as a *subjective center in time* serving as both source and sink for energy and information exchange, and therefore, ground zero for both stimulus and response. Nonetheless, as Figure 1 suggests, feedback processes conceptually juxtapose time, space, and self in unadulterated ways, offering a simple yet elegant springboard for our discussion of emotion as a primal self-regulatory sense.

But the feedback mechanism is also central to the aforementioned "regulatory" side of the self-regulatory emotional elephant—as well as the emergence of sen-

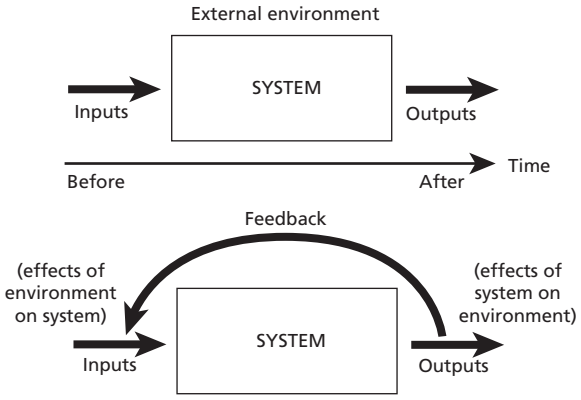

Figure 1 Feedback. (Adapted from de Rosnay, 1979.)

tience itself. For feedback loops are the basic building blocks of *cybernetic* systems,[87-89] also known as "complex adaptive systems,"[90] "dissipative structures,"[91] and self-making "autopoietic" systems[92]—which include all life forms. As the original "science of control and communication,"[89] cybernetics united regulatory control theory with physical information theory, investigating how materially embedded systems can make observers and actors possible—how mechanically in-forming and trans-forming processes give rise to subjective information and behavioral control in living systems. In fact, in terms of thermodynamics, feedback is associated with both *entropy* (chaotic disorder) and the "*negentropic*"[93] *ordering principles* that underlie the physical definition of information itself. (As Nobel laureate Manfred Eigen suggested: "If you ask where does information come from and what its meaning is, the answer is: information generates itself in feedback loops."[94])

In short, feedback is quite literally a key computational in-forming and trans-forming engine in nature, with feedback regulation subserving all biological signaling systems,[95,96] underlies biorhythms and biological clocks[97] and molecular and neural circuitry,[98] is essential to all genetic, epigenetic,[99] immune.[100-102] and even sensory mechanisms,[103] as well as goal-directedness and behavioral control.[104]

The functional architecture of these ordering and disordering principles—from electromagnetic polar shape shifting transitions to favored-state energetic balances—was elegantly depicted by the founder of both cybernetics and general systems theory Ross Ashby, in his original "homeostat,"[105] an electronic device that provided a concrete example of adaptive control. It was a crude learning or "thinking" machine, one that combined both analog and digital information processing in order to maintain stability in the face of widely varied and highly challenging environmental perturbations[106] —an informational architecture central to our discussion. In fact, the auto-induced, cyclic, self-reflexive nature of feedback, and its ubiquitous role in self-organizing and self-regulatory processes places it center stage for both "self" and "regulation" pieces of the self-regulatory function. I will demonstrate herein how the hedonic valence of emotion—with its definitively "self-relevant"[34] stimulus signals—emerges directly from *positive and negative feedback loops*. Indeed, they come in *two types*, providing the binary opposites for digital "choice-making" in what I call the *self-regulatory code*, still evident in the sensorimotor architecture of living systems, much as Ashby had envisioned.

For now, emotion as a self-regulatory sense emerges because feedback "happens" across the great chain of being, the "noise"[107] of its simple computational dynamics having been harnessed by self-replicating systems, and conserved, honed, and elaborated upon by natural selection. As such, the feedback paradigm can shed light upon the hedonic behavior of simple organisms that emerged on the evolutionary stage long before nerve nets or brains, allowing questions of primitive sentience to be separated from the complex neural processes that are correlated with human consciousness. In fact, it is only within this broadened, less neurocentric depiction that the many facets of the entire emotional sensory system can come to light.

Indeed, this new view allows us to zoom in, conceptually revisiting the earliest emergent sensory mechanisms for detailed clarity in the form and function of self-regulatory feedback. At this micro level, the feedback (and feed-forward) circuitry offers conceptual precision to descriptive terms for information flow in space and time (ie, inside, outside, before, after, backward, forward, bottom-up, top-down), precision that can help physicians and social scientists transcend the Cartesian ("dual process") mind-body muddle. This new approach allows us to zoom out to the macro level of analysis, offering a bird's eye vantage from which a complete spectrum of informative emotional feeling tones comes into view, a continuum of meaningful sensory signals ranging from the hardwired and universal, to the learned, socio-cultural and particular, finely tuned to the specific life experience of each unique individual.

In fact, since its initial emergence, the emotional sense has undergone tremendous elaboration by natural selection. Its present structure is an elegant *tri-level informational hierarchy*—from *affect* to *basic* to *complex* feelings—reflecting the generally "triune" structure of the brain,[108] yet with each still playing its own uniquely valuable self-regulatory role. But perhaps most importantly, it shows how affect provides the core "hedonic"[109] evaluative message, the fundamental "bad-for-me" or "good-for-me" appraisals that we experience as immediate psychological pain or pleasure. Indeed, identifying emotion as our primal self-regulatory sense, restores our innate tether to biologically determined optimal—perhaps non-negotiable—states of life-giving balance.

In sum, the emotional sense is born of biophysical regulatory feedback signals that come courtesy of lawful stimulus-response behavior, signals that still undergird our hedonic emotional perceptions and their coupled approach or avoid behavioral responses. These

affective polar opposites are the highly conserved felt evaluations—saying "no" to this and "yes" to that—those that appear across the various levels of analysis, recognizable in affective "eustress and distress" signals[50]; informing us of the immediate environmental "benefits and harms,"[46] or symbolic "challenges and threats,"[110] and giving rise to our general *positive* and *negative* categories of emotion. I will, in a moment, suggest an even more fundamental self-regulatory dichotomy that undergirds them all, one showing how the amazing emotional sense offers universal self-regulatory perceptions for all humans which—when properly understood—also offer a personally tailored *guidance system* to each individual. For now, "emotion" is defined to include these core hedonic self-regulatory signals as well as the primary or *basic* emotions[111] (joy, sadness, disgust, anger and fear); and the *complex*[112] feelings (also known as "unnatural" [113]; "secondary" [114]; "social" or "moral" emotions.[115,116] This complex class, the most recent to have emerged on the evolutionary stage, is the most cognitively laden and temporally expansive, and includes such familiar feelings as trust, mistrust, pride, shame, gratitude, contempt, envy, admiration, love, and hate. Indeed, as depicted in the Venn diagram of Figure 2, this expanded, all-inclusive, multitiered, definition of the emotional system also reflects the stair-step evolution of each new level of self-regulatory information as it emerged over our sweeping biological history—the most ancient remaining functionally foundational and present within each, more recent, additional enhancement.

Whether or not the above discussion coheres for health professionals or social scientists who may not stray far from our respective disciplines, please bear with me, for the self-regulatory logic that emerges from the ubiquitous biophysical feedback process speaks for itself. Indeed, once this missing piece of the emotional puzzle—its self-regulatory sensory function—is identified, many other disjointed bodies of empirical evidence fall into place.

BEHAVIOR, FEEDBACK, AND THE EMERGENCE OF SELF-REGULATORY CODE

In this new view, such ubiquitous bottom-up phenomena as embodied cognitions, priming effects, subconscious attitudes, unconscious motives, conditioned memories, and instinctive autopilot behaviors are a direct result of the self-regulatory processes we perceive via the emotional sense. In fact, it is only in the context of these primary *bottom-up* aspects of emotion that the more recently evolved *top-down* add-ons begin to make self-regulatory sense.

It is conceivable, however, that I am indulging in naïve realism or am equally guilty of anthropomorphism—pushing the human experience of pleasure and pain back upon less complex species. To avert this critique, I'd like to temporarily decouple the stimulus-response relationship, asking readers to simply bracket the subjective aspects of emotion (depicted in Figure 2)

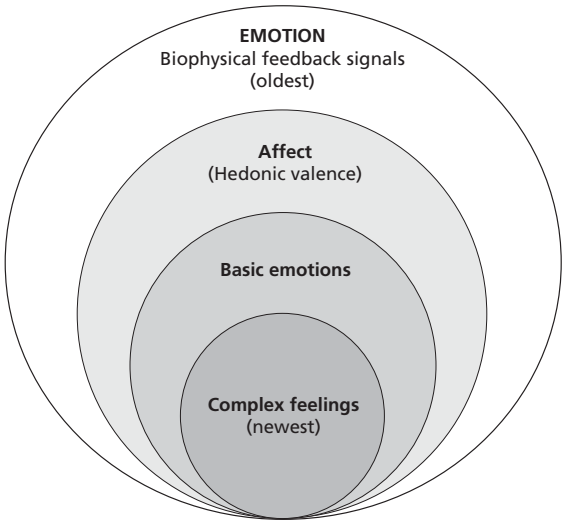

Figure 2 The expanded categorical definition of emotion.

and maintain a strictly behaviorist perspective. In fact, while the sensory information has undergone tremendous elaboration over time, the basic *motor* approach/avoid behavioral responses remain the same—and they embody the self-regulatory logos on offer. Thus, in the spirit of empiricism, we will confine the next portion of the discussion to the objective *approach or avoid* behavioral pattern and let the actions speak for themselves.

To continue, as previously suggested, the secret to cracking the self-regulatory code is *feedback*. This is because feedback is first and foremost a regulatory *control* process—in-forming while trans-forming, ordering, and organizing behavior. In fact, "integral feedback control" is a basic engineering strategy in complex man-made systems such as a jet airplane, with feedback loops found at every level, from transistors and circuits to instruments and actuators, to the autopilot mechanism for the entire vehicle itself.[117]

Although Ashby's homeostat was largely forgotten, this autopilot nature of behavioral control is perhaps what later inspired engineering psychologists to link human behavior with negative or "regulatory" feedback control. Regulatory feedback is associated with *homeostasis*—keeping things at their proper set points in order to keep the airplane or the creature shipshape and on its proper course. Indeed, by the 1970's, on the heels of the behaviorist heyday, feedback control theory a "quantitative science of purposive systems"[118] was resurrected with the palliative promise of restoring *internal goal states* to psychological theory. In organic systems, however, we've seen that homeostatic goal states rely upon natural physical constants, reaction thresholds, and optimal equilibrium balance points—chemically or energetically "favorable" states, in accordance with the laws of thermodynamics. This may be why the classic example of homeostatic feedback control then became the *thermostat.*[119] The thermostatic regulator functions through a three step process: It *compares* the actual state of the system to some preset optimum, *signals* when a

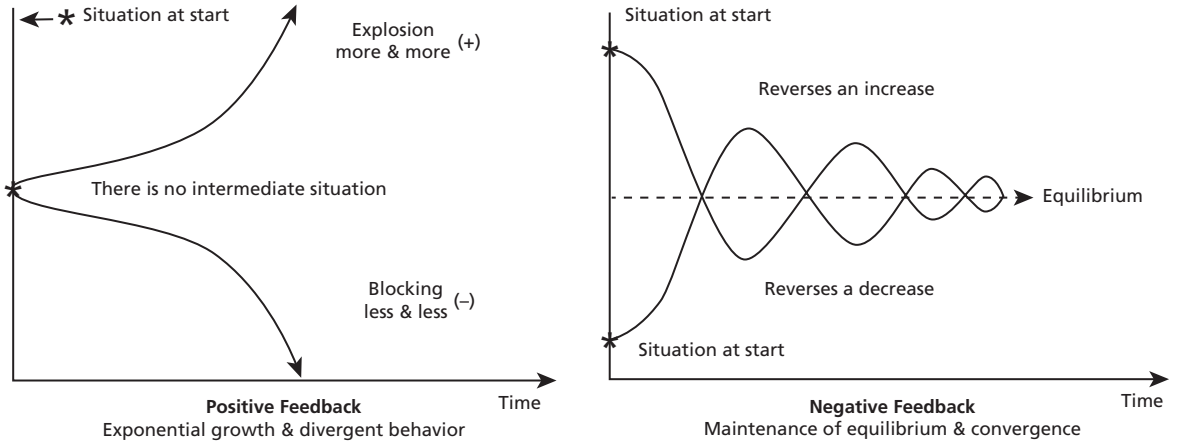

Figure 3 The two types of feedback. (Adapted from de Rosnay, 1979.)

mismatch is detected, and *self-corrects* back toward the optimal state (it "effects"[89] an observable behavioral response). In a home heater, for example, the *actual* room temperature is compared to the desired *preset* temperature, and when the house gets too hot or too cold, the thermostat rebalances the system by kicking the heat on or off. While problematic (outside its original quantitative context), this thermostatic model offers an excellent inroad into our detailed examination of the simplest sensory systems, as the three steps (comparison, signaling, and self-correction) are crucial components of the self-regulatory feedback cycle. For key to our discussion, is that feedback comes in two types. In fact, the binary code—as well as the thermostatic arrangement itself—emerges from an elegant coupling of these two types of feedback, a stimulus response relationship that creates the necessary bridge between the determined (happening) behavior of matter and the partially free—but logically self-regulatory—(doing) behavior of animate agents. This coupling also delivers the functions that the early cyberneticists had hoped could: "at last explain how 'mental' causes could enter into 'physical' effects."[118] Indeed, the coupling of both types of feedback is the missing piece required to illuminate the self-regulatory logos, and vault the gulf to human behavior with that logic intact.

Positive and Negative Feedback

The first type of feedback is called *positive* feedback. In a positive feedback loop the iterative cycles build upon one another, such that with each new cycle the change to the system proceeds *in the same direction* as that of the former cycle (Figure 3.) Positive feedback is associated with chaotic change, leading to *divergent* behavior, "an indefinite expansion or explosion (a running away toward infinity) or total blocking of activities (a running away toward zero)."[86] Functionally, positive feedback is *amplifying*, associated with rapid, exponential, growth (or decay) and upward or downward spirals of runaway change. Examples include: chain reactions, autocatalysis, signal transduction cascades, economic inflation or deflation, and population explosion or depletion. Please note that there is no evaluative (good or bad) connotation to "positive," the term speaking only of the direction of change, with positive connoting qualitative change in the same direction as the previous cycle, whether that direction yields a quantitative increase or a decrease in a given energetic or chemical parameter.

The second type, *negative* feedback does just the opposite, *reversing* the direction of the process relative to the previous iteration (Figure 3). Once again, there is no evaluative judgment, 'negative' simply means reversing the direction of the change, regardless of the nature of that change. But since it is a ubiquitous feature of homeostatic circuits, negative feedback is considered *regulatory*, in that it controls the runaway "chaotic" change born of positive feedback loops. As mentioned, negative feedback relies upon natural laws and statistical mechanics, kicking in when upper or lower thresholds of a given parameter are breached, providing *convergence* to a preferred, chemically or energetically "favorable" state, in accordance with the laws of thermodynamics and quantum mechanics. (Indeed, even the electron has a preferred energetic "ground" state.) But it is equally important to realize that the wild, runaway behavior of positive feedback also flows from those same physical laws and forces—an electron, an ion, a polarized molecule, a membrane, a neuron, or an organism—can also be in an "excited" or temporarily unbalanced dynamic state. It seems that life could neither emerge nor be sustained without both halves of the in-formative trans-formative whole that is feedback.

In short, both positive and negative feedback are ubiquitous in nature, counterparts to one another, working together in the process of self-organization. While positive feedback yields the instability and divergent processes that constantly create, destroy, and recreate new arrangements of matter, negative feedback provides the stabilizing balance, homeostasis, and preservation of form. Indeed, feedback loops are among nature's most fundamental building blocks, "the engine of self-organizing dynamical activity" that "leaves its tracks

and marks as fractal structures"[120]—the non-Euclidian "fractal"[121] geometric shapes underlying all natural and biological structures, including the human brain.

Coupled Feedback Loops and Self-regulation in Early Life

Historically, however, most control models of human behavior relied upon only negative feedback, and have therefore languished. Likewise, it has since become clear that even the simplest behavioral control mechanism in a living system involves many links and *chains of single positive or negative loops*, which changes the entire game. Indeed, when we begin melding the physically deterministic and the subjective functional definitions of "self," the increases and decreases manifested by positive and negative feedback (the changes and their reversals) connote *state changes* within the identity of a living form, changes driven directly by the reciprocally disturbing interactions between the self-system and its immediate (not-self) environment. In evolutionary terms, such a regulatory process would have emerged along with life itself, an outgrowth of "hypercycles" and "autocatalytic" chemical networks,[122] constituting a "thermodynamic work cycle,"[123] the first sort of metabolism. A further requirement for life was the formation of the lipid membrane to bound, contain, and protect a living system (analogous to human skin), yet with structures that allow it to sense and respond to its environment, both of which were essential to the emergence of minimal biological agency[124]—goal seeking behavior. (Also see Sherman and Deacon, for an intriguing theory of a missing link "autocell"[125] that bridges thermodynamics, morphodynamics, and goal-seeking teleodynamics in emergent systems; albeit devoid of the feedback processes discussed here.) In fact, such a system has been suggested to predate even natural selection, described as "context dependent actualization of potential,"[126] or "self-other organization."[127]

At some serendipitous juncture in our evolutionary history however, *self-replicating* molecular arrangements emerged and natural selection was off and running. But, regardless of how this leap occurred, central to our discussion is that *regulatory feedback circuits and their dynamic logic*[128] were *already in place*, serving regulatory functions in the first single celled creatures. "Regulation" in this context involves changes ("covalent modifications") in the properties of a cell under the influence of external and internal signals in order to adjust the cell's internal biochemistry. This process is considered the evolutionary "origin" of sensory processing[129]—and, I argue, is precisely what the cyberneticists were intuiting about feedback control. Indeed, in whatever order they emerged, the trifecta abilities: (1) to sense the physical qualities of one's immediate environment; (2) to respond behaviorally, and (3) to categorize sensory stimulus gives an "operational closure,"[130] *a circular causality*[131]—a general principle of organization within an autopoietic system that defines biological "function" itself.[132]

Feedback Functions of Cellular Receptor Complexes

Nonetheless, while the bulk of this discussion focuses upon the *functional* outcomes of feedback processes, understanding the *structures* that instantiate them is paramount—for biological function follows physical form. These structures are called *protein receptor complexes*, essential components of all cellular membranes in both prokaryotic and eukaryotic cells. Cellular receptors were originally conceived as lock and key stimulus-response facilitators, upon which a chemical agent (ligand) would bind, triggering a specific cellular response. In fact, these unique cell-surface molecules are not only essential to the earliest sensory systems, but remain central to intercellular signaling, interacting with hormones and humoral factors essential to inter-organ communication.[133] However, with powerful new microscopes it has become clear that the simple lock and key model was severely limited, and cellular receptors have proven to be far more structurally and functionally complex (now referred to as "complexes"). Indeed, through their form they instantiate both the positive and the negative feedback loops under discussion and serve as *structural homologues* to Ashby's homeostat. For crucially, these structures are *transmembrane* receptor complexes, physically exposed to both the external and internal environments of a cell. They have both 'heads' outside and 'tails' inside—a general structural feature that facilitates the feedback comparison and the internal effector response.

Moreover, the individual proteins that comprise the complexes are detailed 3-D structures with modular construction and moving parts—shape-shifting dynamics driven by ligand binding that allow for complex *couplings*, *combinations*, and *chains* of individually positive or negative feedback loops. In fact, at present, the repertoire of genes that encode these plasma membrane receptors has been called the "signaling receptome" with receptor families that reflect their evolutionary origins and chart their ever-increasing functional complexity. Indeed, the Seven-Transmembrane (7TM) family of receptors (still present in the human receptome), first emerged in unicellular organisms already composed of seven discrete transmembrane domains that induce conformational changes and diverse functions.[133] As such, receptor complexes at every level on the phylogenetic tree instantiate intricate webworks of coupled feedback loops and circuits with common *functional motifs*.[134,135] These motifs include such functions as: basal *homeostat*, *threshold limiter*, and *adaption* (born of negative loops); and *amplifier*, *accelerator*, *damper*, *delayer*, or *bistable switching* (of positive loops); or *pulse generators* or *oscillators* (of both).

Of particular interest for our new model of emotion, is the positive feedback motif of *bistable*, *digital switches* between alternative phases or states[135-139] the aforementioned covalent modifications.[129] As previously noted, such deterministic binary (either/or) switching is observable at all scales of material organization (ie, chiral symmetry of amino acids that deter-

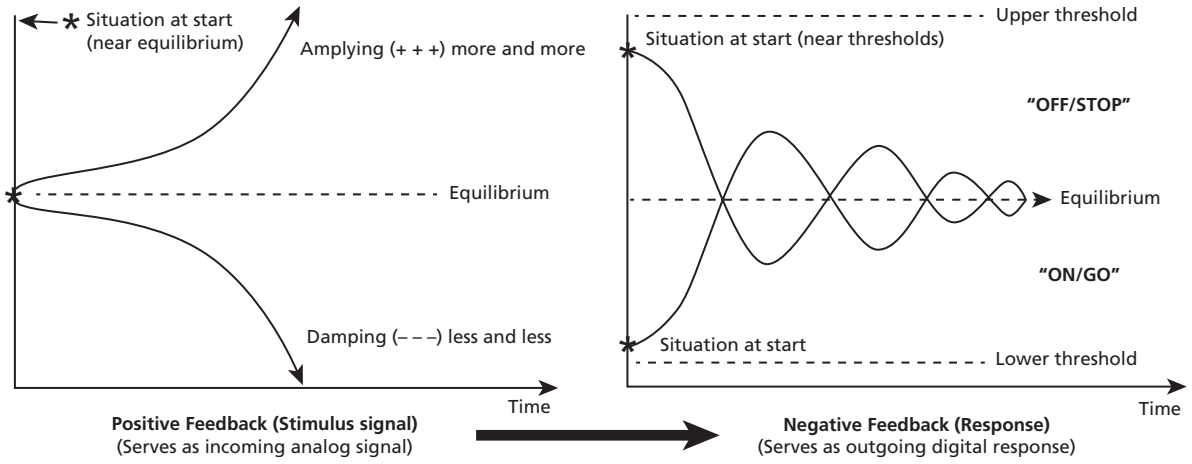

Figure 4 How coupled positive and negative feedback yields stimulus-response behavior. (Adapted from de Rosnay, 1979.)

mine the genetic code; bonding and anti-bonding reactions that govern protein folding; "on/off" switching of genes and all-or-none firings of neurons.) In fact, this dynamic bistable pattern emerges consistently even from randomly connected network nodes yielding systems poised critically on the "edge-of-chaos," dynamically balanced between stability and change.[96] More, the *dynamic transitions between these bistable states* that have been suggested to provide the earliest forms of computation in nature.[140] Indeed, even the simple thermostat requires bistable switching—and several other positive feedback motifs, as did Ashby's original homeostat.

Hence, the present proposal is that the original winning evolutionary scenario—the one that underpins the self-regulatory behavior of life forms—was a *coupling of both types of feedback* such that the *divergent positive feedback stimulus* triggers *convergent, negative feedback regulatory responses* (Figure 4). This general arrangement delivers most (if not all) of the functional feedback motifs in one fell swoop, providing nearly every requirement of the regulatory thermostat.

For example, as depicted at left in Figure 4, the amplification versus damping, and bistable switching motifs of positive feedback offer a graded *analog* signal which indicates the system is changing in significant ways, that some relevant environmental stimulus is either increasing or decreasing. (Others have termed this the "sense signal" which is then compared to an inner "reference signal," triggering the "error signal."[89]) These changes are then indeed *compared* to the desired states and reaction thresholds (basal homeostatic and limiter motifs of negative feedback, shown at right); which triggers a *corrective response* that reverses the trend, bringing the system back into balance (like the home furnace). While perhaps neglected in cybernetic models of human behavior, this coupled feedback configuration has been noted elsewhere and deemed a biological *logic gate* or block that can switch from the "and" to the "or" functions,[141] the logic circuitry of the electrical transistors in computer chips.

With an elegant simplicity, this general feedback arrangement offers both analog and digital information processing, extending its principle of circular closure across multiple levels of organization, to forge a self-similar pattern of relational causality across multiple scales in time and space—fulfilling all Ashby's original hopes for his homeostatic thinking brain. Indeed, like a neural network, it gives rise to *horizontal* cross talk (bi-directional and parallel processing) between local network nodes as well as unidirectional signaling and control relationships across *vertical* levels in fractal hierarchies, fostering synchrony between faster and slower system dynamics, and bridging local and global levels of coherence and control. Most importantly, these reciprocal self-regulatory relationships coordinate life-giving functions in complex organisms, guiding intercellular development[142] and ultimately yielding "perfect adaptation."[143] In fact, the motifs of coupled positive and negative feedback loops include the oscillatory behavior, pulse generators, and on/off firing behavior of neural networks, and the "tunability" of biological rhythms from cell cycles to heartbeats.[144,145] Furthermore, at the macro, systemic, level of analysis, wherein the organism as a whole interacts directly within its external ecological niche, this adaptive tunability constitutes a "constrained form of computational learning"—synonymous with evolution itself,[146] Ashby's learning machine writ large with its simple machine-like algorithms becoming ever more flexibly personalized "ecorithms"[147] guiding evermore complex adaptive responses. Best of all, of course, this elegant feedback coupling sets the stage for the first sorts of hedonic behavior—as well as the first sort of enacted, embodied, *mind*.

Self-regulatory Behavior in Bacteria and the Tit-for-tat Code

Indeed, this new story strikes at the heart of an ongoing philosophical debate as to the nature and origins of mind. Perhaps related to the original Cartesian divide, the debate concerns whether mindful "cogni-

tion" is an exclusive manifestation of a functional brain or whether it is primarily embodied and embedded in an environmental context (ie, references 148-150).[148-150] The emotional sensory model suggests that it is both, but that as the locus of the feedback control function, "branes"—environmentally embedded cellular *membranes*—came before brains in terms of evolution, and their signaling dynamics delivered the first experience of self in space and time. (In other words, it suggests that emotion *preceded* "cognition" proper and that "*sentio ergo sum*"—I *feel* therefore I am—may have been more biophysically accurate.) As such, the sensory feedback model weds the computational, representational, identity and embodiment approaches to the emergence of mind in the singular concept of *primary self-regulatory perception*. That, which I am arguing, gave rise to the inaugural evaluations within the emotional sense.

In fact, the brilliance of the cybernetic model, was that rather than to control behavior per se, it served to "control perception."[89] It was a theory of how a system controls its *somatosensory experience of being*—its hedonic feeling of what is happening.[46] But this seems just a convoluted way of saying that a regulatory control system *delivers (ushers or creates)* perception itself. In short, it yields a crude mind. Indeed, Jaak Panksepp, founding father of "affective neuroscience"[151] posits a *core affective consciousness*, or a "visceral nervous system" that yields "primordial affective mentality"—genuine feelings in all neurally endowed creatures, "similar to seeing a color." Theorists stop short, however, of declaring emotion to be an actual sense, for as emotion pioneer Nico Frijda puts it: "There is still no detailed hypothesis at the functional level of how innate affective stimuli evoke affect."[9] This is where an examination of the simplest sensory systems can clarify and expose the devilish molecular details within which the primal emotional sense remains shrouded.

Take, for example, the chemosensory system of the *Escherichia coli* (*E coli*) bacterium, perhaps the first identifiable sense to emerge, and one whose molecular circuitry is quite well understood. The on/off switching that underlies affect is readily evident in the digital behaviors of coupled protein molecules, those central to genetic regulation as well as sensory perception. (For reviews, see references 129, 152, 153.) As mentioned, the structure of interest is the protein receptor complex on its "brane"—transmembrane structures analogous in humans to external sense organs on our body and skin (noses, ear, eyes, etc.), yet where all the feedback functionality is orchestrated.

Indeed, in the simple *E coli*, there are three levels of binary self-regulatory switching with functional outcomes from *on/off* genetic regulation, through *stop/go* behavior (approach/avoid chemotaxis), to the *yes/no* hedonic evaluative representations under discussion, and as the details will demonstrate, *each of which exemplifies the self-regulatory feedback arrangement depicted in Figure 4*. In fact, though far more complex than our ancient ancestral autocell, the molecular circuitry on the brane of the *E coli* illustrates evolutionary enhancements of the original capacity to *categorize* sensory stimulus, an original requirement for causal, operational, and functional closure. Furthermore, in terms of the brain-only view, these three levels offer exact matches to the three criteria required of a legitimate "internal representation" offered by Haugland[154]: (1) to coordinate its behaviors with environmental features not always "reliably present to the system"; (2) to cope with such cases by having "something else" stand in (in place of a direct environmental signal) and guide behavior in its stead; and (3) that "something else" is part of a more general representational scheme—a code—that allows the standing in to occur systematically and allows for a variety of related representational states.[155] Likewise, these conditions dovetail cleanly onto Powers' control model of human behavior,[89] with the *comparison* between Haugland's conditions 1 and 2 (termed the *sense* signal and the *reference* signal),[154] which when discrepant delivers the *error signal*, with a coupled self-correcting *effector* behavioral response that I am suggesting manifests as the binary hedonic valence of emotion. In short, the coupling of positive and negative feedback gives rise to all three criteria for a functional mind and an elegant sensorimotor behavioral control system—far before brains emerged on the evolutionary stage.

While some may rightly worry that an *E coli* bacterium is hardly analogous to a human being, its simple sensory system provides an elegantly detailed example of the "thermostatic" feedback arrangement in action, allowing us to precisely parse what happens *where* and *when* in *space* and *time* that yields self-regulated hedonic behavior. In other words, in terms of both function and structure, the *E coli* bacterium offers an excellent biological stand-in for the "system" depicted in Figure 1, its membrane physically bounding itself from its not-self environment. The feedback loop is the *embedded* aspect of mind, the transmembrane sensory receptors reporting self-relevant stimulus as the body moves about, with the three steps of feedback control constituting what goes on in the "*black box*" mind proper—a simple loop that yields primal hedonic perception and approach/avoid behavior. Indeed, the suggestion is that this simple circuitry reflects the core "molecular universals" of approach and avoidant behaviors conserved in a wide range of species.[156] It is also likely the source of the generally accepted taxonomy of "primary process affects" in emotion theory: *sensory* affects, *bodily homeostatic* affects, and *brain emotional affects*[151]—those that loosely capture the three tiers of information encoded in human emotional perceptions (previously depicted in Figure 2).

With that said, the general mechanism works like this: A chemical in the external environment binds to a receptor protein complex on the bug's outer membrane, activating a signal transduction cascade inside the cell that leads to both a short term change in the organism's behavior, and a long-term adaptation of the receptor mechanism itself.[157] Each of these changes is driven by the feedback arrangement (depicted in Figure

4), and via their coupling to one another, they typify the circular causality wherein the faster dynamics serve as the bottom-up signals triggering the slower, top-down corrective response. In short, the system utilizes three levels of the thermostatic stimulus-response switching, each facilitated by the feedback coupling.

Specifically, in *E coli*, the short-term behavioral response is the switching between a *counterclockwise* (CCW) or *clockwise* (CW) rotation of a given flagellum—one of the four to eight tail-like protein appendages embedded in the cell wall—that allows swimming *toward* or *away* from beneficial or harmful chemical gradients, temperature changes, or other relevant environmental conditions. (With the CCW motion, all the flagella rope together propelling the organism forward, but a switch in any one flagellum to the CW mode, flails them apart causing an abrupt halt and a "tumble" off in another direction.)

From On/Off to Stop/Go

This basic stop and go behavior is accomplished by a circuit of many positive and negative loops mediating interactions between five receptor proteins (ie, Trg, sensing ribose and galactose; Tar sensing aspartate; Tsr, serine; Tap, peptides; and Aer, which senses O2) and the protein products of six key genes (CheW, CheA, CheY, CheZ, CheR, CheB). These receptor proteins (numbering in the tens of thousands) cooperatively cluster together in the cellular membrane by a process of stochastic self-assembly,[158-160] such that they serve as an "information processing organelle,"[161] likened to a "nose."[162] As mentioned, however, what is instructive about the brane, is that this nose-like sensory organ spans the depth of the membrane "skin" such that its outside heads and inside tails are privy to both internal and external environments simultaneously, which is how the feedback comparisons, signaling and responses are instantiated.

These transmembrane receptor complexes (assisted by adaptor protein CheW and histodine kinase CheA) detect the change in chemical gradients—the environmental stimulus—and regulate behavior accordingly via integral feedback control.[117] As in Figure 4, they constantly *monitor* the environment, *comparing* the relative concentrations at time one with those at time two (your classic negative feedback homeostat motif), with the increase or decrease in bound receptors serving as a positive feedback *signal* informing the cell that a significant deviation from stable set-points (negative feedback limiter) has occurred. (As the core sensory organ, the outside "heads" of the receptor complexes deliver Powers' "sense signals," [89] and subsequent alterations of the inside "tails" serve as Haugeland's first criteria for an internal representation—the direct detectors of relevant environmental stimulus that may not always be present.[154]

For from there, a coupled positive feedback exchange between CheA and phophatase CheZ takes place *inside* the cell, which adds or removes phosphorous (respectively) to and from second messenger CheY, which directly initiates the *regulatory* (negative feedback) *motor response*, the switching between CCW and CW flagellum rotational modes that controls the bugs behavior. (This second messenger protein, serves as Haugeland's second criteria for mindful representation, the "something else"[154] that stands in for the missing stimulus, yet still mediates the stop and go behavior. In the Powers model, this is an internal extension of the sense signal [89] (and perhaps the simplest example of the evermore complex signal transduction cascades observable in more complex organisms, those that include neurotransmitters and hormones in humans.)

From Stop/Go to Yes/No

So far, however, this is only half of the story. For these are the bottom-up fast time, activating, dynamics, wherein the binding and unbinding of receptor proteins triggers the *on/off* phosphorylation or dephosphorylation of CheY, which then drives the immediate *stop/go* switching between behavioral regimes. These are the dynamics (the feedback coupling depicted in Figure 4) that operate on timescales of *milliseconds*, with the amplifying (+) signal triggering a (–) reversal switching to the "OFF" (or, in this case, "Stop") mode. Likewise, a decrease (–) in the phosphorylation signal triggers an increase (+), wherein the reversing (negative feedback) response switches to the "ON" (or "Go") mode (See Figure 4). Do note that these dynamics are regulatory (negative feedback) responses; they are keeping the system within the specific thresholds, preserving the system within its existing parameters. (This is the level where the, homeostatic negative-feedback-only control models still ring true.)

The other half of this regulatory circuit *follows the same feedback pattern*, but unfolds over a longer timescale (minutes), yielding the slower, top-down, deactivating dynamic that gives rise to *adaptation* in the bug's sensory system—a brief, but functional, *"memory."*[129,161] This is a change that increases the range of sensitivity by altering the *sensory mechanism itself*, offering the bacterium a broadened bandwidth of information for subsequent encounters, adding a *feed-forward* step in the cycle.[163]

This is a crucial juncture in our new story. For it is this adaptive response that takes the logic of *on/off* switching and *stop/go* behavior to the *yes/no evaluation* that ultimately underlies the proximate *feel good/feel bad* hedonic valence of emotion. (In fact, this feed-forward step is a necessary piece for any control model that posits anticipatory or purposeful goal states.)

To continue, this slower top-down adaptation process informs the system of the *rate of change* in the original stimulus, and results in an alteration of the *sensory receptor complex itself*. This occurs through *methylation* of specific units of the receptor complex—the inside "tails"—by a reciprocal on-off relationship between the remaining two proteins: CheR (a methyl

transferase that adds a methyl group) to the tail and CheB (a methyl esterase that removes it). This pattern is virtually identical to and directly linked with the faster phosphorylation switching for stop/go behavior (as depicted in Figure 4) and thus provides a record of the specific responses to environmental changes. (Indeed, as phosphorylation of Ch A increases, the methylation activity of CheB correspondingly decreases.)

However, unlike the faster dynamics, this adaptive homeostatic (negative feedback) response occurs *after* existing sensory *thresholds have been breached* (or saturation has occurred), settling the system into a *new normal* rather than simply returning to the original set point. Hence, this modulation-by-methylation allows the system to reset its equilibrium to zero, even while the chemoeffectors are still present, but at a new *higher or lower* equilibrium point—altering receptor sensitivity and adding overall complexity to the system. (This threshold shift can be envisioned by imagining the starting point on Figure 4 to have begun either above or below the existing threshold, rather than within as depicted, where the "On" or "Off" response settles the system into a relatively upward or downward new normal; and will also be depicted in Figure 7.) In terms of function, as one molecular biologist put it, this allows the bug to tune the "volume" of its sensory system up or down[164]; or as Powers put it, how the feedback process "controls perception."[118]

In sum, the reciprocal feedback relationship between the phosphorylation and the methylation signaling pathways yields the causal circular connectivity between multiple levels of organization, with its temporal pattern of *fast activation* and *slow deactivation* delivering the best "noise attenuation,"[165] bringing us full circle to the vertical tunability that synchronizes cells in multi-cellular organisms. Indeed, this methylation-adaptation process is the *key "stimulus-response" relationship in our new story*, as its corrective action kicks in with threshold-breaching, globally significant stimulus—whenever novel, intense, and deeply "self-relevant" changes are underway.

The Tit-for-tat Self-regulatory Code

Best of all, it comes freighted with its own *evaluative logic*. The positive feedback increases or decreases in methylation of the protein receptor complex (the chemical marks on the inside tails) offer an exact reflection of the *stop and go behavior* and its direct correlation with the *harmful or beneficial environmental conditions*. They provide a faithful signal of how previous behavior said "yes" to certain environmental conditions and "no" to others. (They provide Haugeland's third criteria for a mindful internal representation, a more general representational scheme—a code that can reflect a variety of related stimuli.[154]

Indeed, the upward going (positive, +) stimulus represents "goodies" that promote metabolic flow and developmental growth, while the downward (negative, –) decreases, signal "baddies" that could threaten structural stability. Together they offer the bacterium a single—yet binary—*evaluative symbol*, one that represents everything of life-giving importance from the presence of food and toxins, to temperature shifts, changes in oxygen levels or ph balance,[167,168] to the constant energy flux and flows of electromagnetic fields on nanoscales in space and time[169]—which inform the digital approach/avoid behaviors of chemotaxis, thermotaxis, aerotaxis, osmotaxis, and phototaxis, respectively.[161] In fact, given its origins in electromagnetic forces and thermodynamic laws, it offers a general searching and learning strategy dubbed "infotaxis" for balancing the needs to explore and exploit the immediate environment, a way of zeroing in on information that "accumulates as entropy decreases,"[170] not unlike a child's game of Hot Beans ("you are getting warmer, you are getting colder"). In short, the functional effect of this chemical network is that *a formerly neutral on/off switch can be bootstrapped into holding general good/bad—"for me"—evaluative significance.*

Although these elegant feedback control networks are based on simple diffusion and stochastic (statistically random) chemical fluctuations, they set the evolutionary stage for genuine self-regulatory sentience to emerge. Indeed, tremendous selective pressure would be placed upon any mutation allowing the organism to *distinguish between these two binary stimuli and respond in ways that help them along.* In fact, such ability is required in any control model of behavior, as it would constitute both the *comparison* process and *perception of the error signal* itself.

Herein lies the logic of what I call the *tit-for-tat self-regulatory code* within the hedonic valence of emotion. All that was required at this historical juncture was an *additional positive feedback loop*, one that could offer a further *feed-forward* enhancement of the existing signaling pathway, one that allowed a *choice-making switch between the yes/no options*, *before* the negative feedback rebalancing had occurred. In fact, this is the missing link required to bridge the gulf to self-regulatory (goal seeking) behavior in humans, as well as the conceptual heart of genuine "cognitive" perception.

Indeed, a feed-forward control process can act in *anticipation* of stimulus conditions,[171] drawing upon the on-line memory embodied in the ebb and flow of sensory adaptation. This flexible choice-making response would indeed facilitate the optimal sorts of changes that have happened in the past, and could readily be accomplished by a binary switch between the *positive or negative feedback responses* themselves. Centrally, this new story suggests that something like this *must have occurred*, giving rise to the binary computational algorithm inherent within the feedback comparator: a straightforward *if-then logical rule* within the self-regulatory sense. Elegant in its simplicity, the rule states: **If positive (+) then positive (+), if negative (–) then negative (–).** In other words, for a positive stimulus signal (more and more), perform a positive feedback (more and more amplifying)

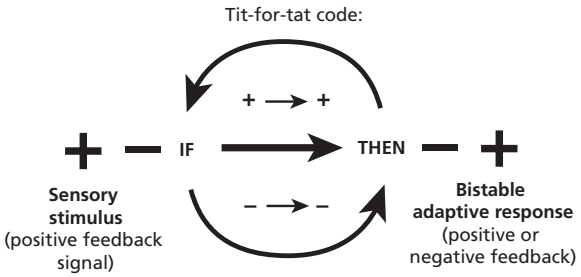

Figure 5 The Tit-For-tat self-regulatory code.

response. For a negative stimulus signal (less and less), perform a negative, stabilizing response that reverses the present trend (Figure 5).

Following this simple tit-for-tat self-regulatory perceptual logic allows the organism to approach, facilitate, and otherwise *increase* the in-forming conditions that are life-promoting, and to avoid, prevent or otherwise *decrease* harmful, entropic changes. Likewise, with the automatic nature of the adaptive process, this simple code provides the classical semantic symbols, the innately reinforcing—rewarding or punishing—"unconditioned" Pavlovian responses that undergird both classical and operant conditioned learning. Indeed, the fundamental hedonic perception provides the elusive "basement language" that philosophers have long sought, reliable knowledge about the external world rooted in primal sensory experience.[172] In short, the self-regulatory code unites the stimulus-response phenomena noted within the behaviorist tradition with the cybernetic control models of human behavior. As depicted in Figure 6, the self-regulatory code elucidates the inner workings of the black box (what goes on between the input stimulus and output response); clarifying the relationship between Powers' "sense," "reference" and "error" signals[89]; and bridging cleanly to Carver and Scheier's origins of affect.[38,39] (Offering, however, the more intuitive self-relevant logic of hedonism, wherein negative feedback is associated with pain and avoidant behavior rather than with pleasure and approach.)

In our little *E coli*, however, it matters not whether any subjective experience of the positive feedback signal is present, for the negative feedback response—the automatic adaptation—has already had an important self-regulatory effect.[129] The adaptation has shifted the system to a *higher* or a *lower* equilibrium point (the new normal), rather than returning it to the formerly favorable state, and in perfect accordance with the harmful or beneficial environmental stimulus. In doing so, it has accomplished either an *optimizing, developmental, adaptation*—saying "yes" to beneficial changes—or a *self-preservationary intervention*, saying "no" to potentially self-destructive harms.

Depicted, for example, in Figure 7, is essentially the "on/off" response process shown previously (in Figure 4), and in Figure 7 is that *same response* but one *following a breach of either threshold* yielding the "yes/no" evaluation. (Herein lies the roots of the hedonic treadmill,[173] wherein sensory adaptations to good stuff become internalized such that new levels of stimulus are required to trigger positive self-relevance.) But regardless of any possible perceptual accouterments, in even the very earliest forms of life, these simple chemical regulatory feedback networks have cracked the philosophical door between determinism and compatible free will, between hardwired logos and softwired telos, ushering behavioral agency with a few degrees of freedom—allowing the organism an active role in the evolutionary process.

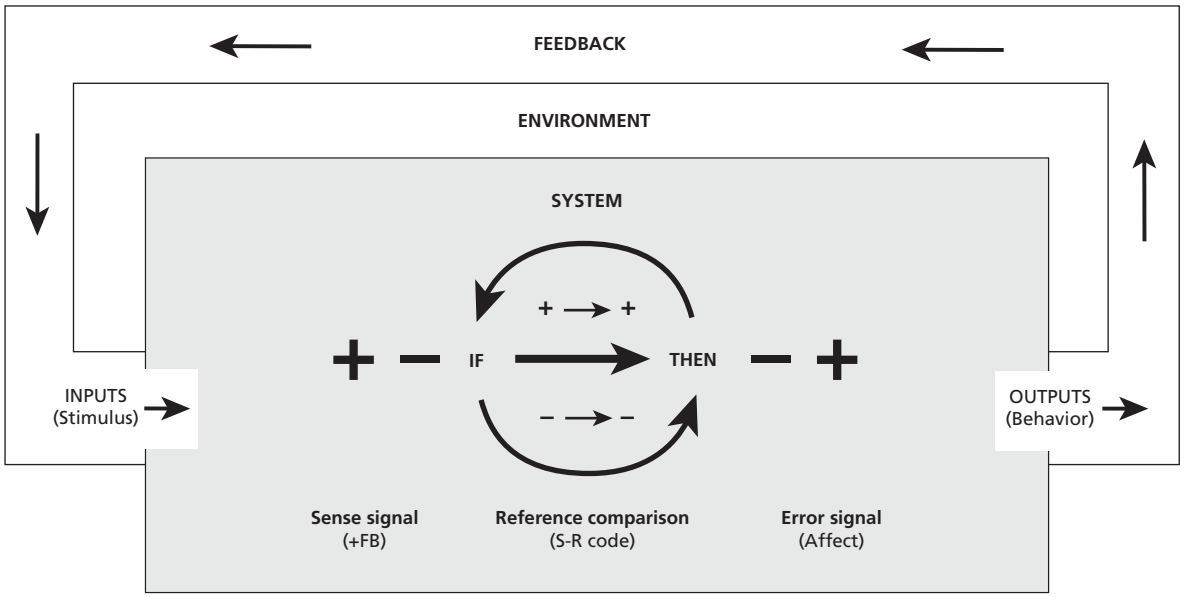

Figure 6 The Self-regulatory code in the black control box.

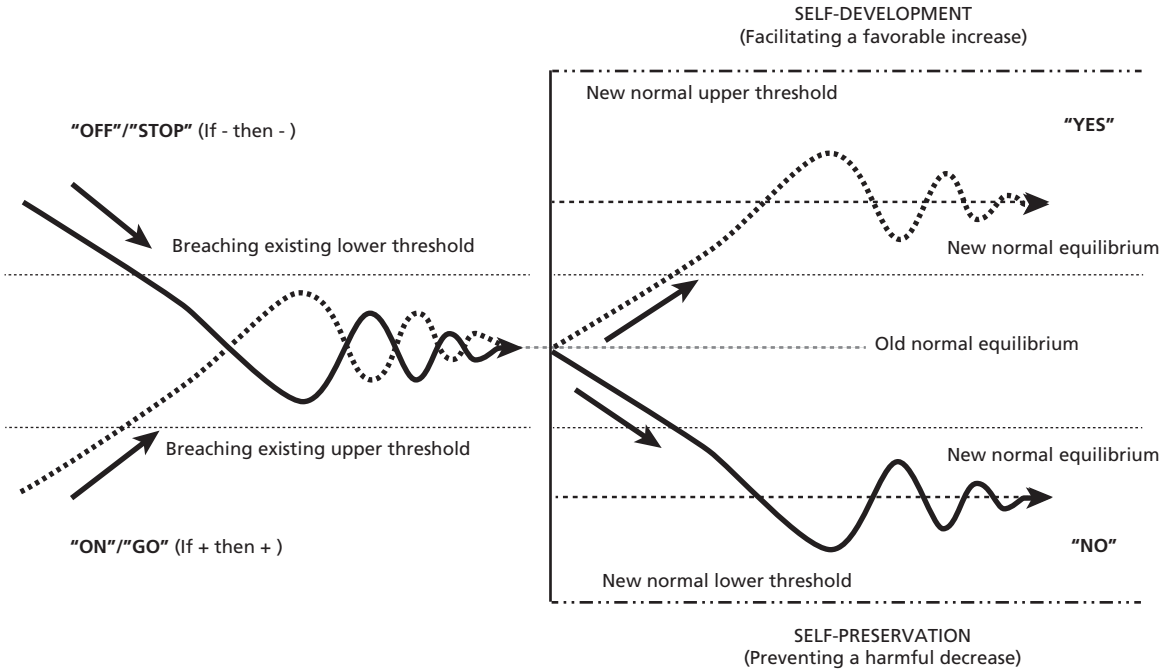

Figure 7 How the Tit-for-tat code serves dual self-regulatory "purposes": self-development and self-preservation.

Individual and Social Aspects of Self

In fact, and perhaps even more philosophically intriguing, this simple self-regulatory system also sets the stage to define *individual* and *social* aspects of the self-system. While the cellular membrane initially demarks self from the not-self environment, this simple yes/no rule can also be pressed into service to identify genetically similar and different bacterial species, in perhaps the earliest forms of cooperative communalism and competitive tribalism. For example, the phenomenon of "quorum sensing" where on/off switching between behavioral modes depends upon the concentration of *other citizens* within a specific bacterial species.[174]

Indeed, in addition to pre-existing environmental stimuli, quorum sensing bacteria produce and release self-identifying *autoinducers*, chemical signal molecules that then rise and fall with the local cell-population density. They are used for *communication*, allowing individuals to synchronize particular behaviors so they can function as multicellular organisms, marshalling cooperative chemical defenses—or virulent attacks—against other species.[175] Likewise, these either/or (me or we, us or them) signals, can be coupled to other sensory stimuli like heat or cold to guide more complex autonomous or communal behavior. For example, an individual E. coli bacterium will normally thermotax toward warm environments where growth conditions are optimal. But should the population become overly dense and therefore resources strained, loner—self-preservationary—mode will kick in and the bug will move toward cooler locations [166] to "chill out" until conditions for growth improve.[164] Likewise, is this dual sense of self-identity in the elegant slime mold *Dictyostelium discoideum*, that can exist either as a single-celled organism or as a colony of social amoebas—a eukaryote with the same cAMP-sensing toolkit as humans, rooted in two varieties of the ancient 7TM receptor.[133]

A central insight from this level of analysis is that a core, physical, sense of *identity* (both personal and social) is already apparent in the lowly bacterium, founded upon simple protein networks and their integral feedback dynamics. Hence, this first form of self-regulatory sentience also cracks the philosophical door to phenomenal *being* (and *becoming*) in time and space as well as *doing* behavior.

Nonetheless, first and foremost, the present proposal is that these ancient self-regulatory mechanisms have been honed by natural selection to yield the chemical—hard-wired (*genetic*)—distinction between self and not-self utilized by the immune system, as well as the chemical language of the paracrine and endocrine systems,[176] and to subserve the neuropeptides involved in neural communication in both enteric[177] and central nervous systems—those deemed the "molecules of emotion."[178] In fact, they provide the informational "language"[179] that allows optimal cellular differentiation and space/time migration of the *right* types of cells to the *right* places at the *right* times throughout embryonic development. But in addition to this physiological legacy, in humans, the ongoing development and empathic expansion of one's mindful, social, and cultural sense of identity[180] is also crucial to an optimal developmental trajectory, and key to decoding the *universal guidance* offered by our emotional sensory perceptions.

Purpose in Evolution?

This brings us to the fundamentally significant binary dichotomy gestured toward previously, that

which lies at the most primordial core of nature's *value system.* This is the prime self-regulatory directive that has been conserved, kept intact throughout our evolutionary history; the one that allows organisms to actively participate in natural selection; and the one that provides the evaluative meaning within the hedonic valance of emotion. As already depicted in Figure 7, the yes/no binary evaluations mediate dual *teleological goal states*—***purposes***, if you will: Those of ***self-development***, the core evaluative appraisal for categorically pleasurable "positive" emotions, and ***self-preservation***, for the painful or "negative" category. These are the binary functional outcomes of the ancient self-regulatory process, those that make hedonic behavior "optimal" or "right" in the deepest, most biologically valid, sense of the word (moral implications notwithstanding).

Although potentially oppositional purposes, it is crucial to note that these are *two right and good*, perhaps *non-negotiable* requirements for life itself inherent within the most primordial regulatory processes. Each is equally appropriate at different times and spaces, and optimal under different environmental circumstances. These are the underlying goals states, the teleological purposes, glimpsed by the early cyberneticists; later described by pioneering systems psychologists as *preparatory* (preserving the original set point) and *participatory* adaptation to the new,[181] and are now described as the dual regulatory "focuses" within complex human self-regulation.[60] These binary purposes are also what complexity scientist's might call self-organizing "attractors" on "fitness landscapes,"[182] those that keep creatures poised between chaotic change and rigid stability; and those that are reflected in the digital "growth or protection" programs of cells.[183,184] Best of all, these dual purposes provide a direct biophysical tether between *subjectively good and bad perceptions* and *objectively right and wrong states of living-giving balance.*

This is how acknowledging bottom-up self-regulatory sensory feedback can fill a sizable gap in evolutionary theory—for these dual purposes are simply mirror reflections of the top-down criteria for natural selection: *adaptation* and *survival.*[185] Yet, until recently, these present moment stimulus-response behavioral adaptations were considered evolutionarily irrelevant, the functional role of the cell membrane largely unnoticed, with causal genetic control credited to the nucleus (the DNA) alone. Upon the mapping of the genome, however, the subsequent revelations about *epigenetic* control processes have forever altered the central dogma by elucidating the crucial role of environmental cues, intrinsic signals, and cellular memory in evolution.[186-188] Revelations of how supposedly "junk DNA" and noncoding RNA are actually providing ongoing regulatory switching[189,190]; with relational if-then rules of engagement that ensure specific gene products are brought into action when and only when appropriate,[191] and mediating the very developmental morphology of an organism[192] as well as its behavior. Revelations of how epigenetic switching yields critical modifications during cellular stress responses,[100,193-196] plays a key role in immune functioning,[197] and serves as modulators of neuronal responses,[198] of neural development and neuroplasticity.[199-202] Revelations of how our old friend the methylation marking process, sets down tracks on the histone cores of DNA, yielding heritable memory systems in non-germline cellular replication[203]; marks that appear to be bidirectional ("poised") bistable switches themselves[204,205] with both bi-directionality and reversibility of DNA methylation crucial to optimal neurodevelopment,[206] discoveries that help explain the mysterious phenotypic variations between monozygotic twins[207] and highlight the importance of individual differences in behavior, cognition, physiology[208]—and emotionality.[209,210] Indeed, the new field of neuroepigenetics is rapidly evolving, finding disordered methylation markings to be associated with autism, schizophrenia, bipolar, and degenerative disorders.[211,212]

In sum, the discovery of epigenetic regulatory mechanisms is expanding and reframing the reactive "selfish gene" scenario,[213] to a more Lamarckian proactive, fluid, and *self-regulating genome*, now recognized to be in constant cyclic interaction with the immediate environment, and adaptively switching specific genes on or off in response to ever-changing ecological circumstances. (Of course, these include *social* environments and the relational components of self-regulation, as evidenced in such emerging fields as "social genomics," [193] "stress genomics,"[194] and "social neuroscience." [214]) Acknowledging these bottom-up dynamics honors the generative, developmental, symbiotic and cooperative underpinnings within and between living systems and partially deflates the purely competitive, random, blind, meaningless, and glacially slow depiction of evolution. Indeed, as Charles Darwin himself once suggested (in a letter to Nathaniel Wallich, 1881), selection might be 'the consequence of a much more general law of nature'[94]—to which I would add: That of the *binary computational laws* of *self-regulatory feedback.*

FROM BRANES TO BRAINS AND THE MODERN FEEDBACK CYCLE

These new micro-biological lenses can liberate social scientists from limited evolutionary narratives that look only to conditions of the ancient ancestral environment to elucidate the genetic components of adaptive behavior. Indeed, the "iterated systems" and "algorithms that govern emotional states" in the here-and-now are anything but "irrelevant."[215] They serve as the very self-regulatory core of adaptation itself. In fact, the original molecular sensory organs of the emotional sense (receptor clusters on cellular membranes) remain hard at work regulating each cell of every specialization within its immediate intracellular environment. While the second messengers—and third, and fourth . . . from phosphates and kinases to neuropeptides and

hormones—have become ever-more complex, their original binary computational processes generate the electrical, chemical, and cellular "rhythms"[216]— the cyclic feedback at every level of scale that delivers self-regulatory "coherence."[217] Examples from the human "receptome"[133] include the *G-protein-coupled receptors* (the largest family of proteins in the human genome[218] that mediate responses to hormones and neurotransmitters as well as facilitate vision, olphaction, and taste[219]; *the IP3 receptor* (Inositol Thriphosphate receptor) a calcium release channel that switches between open and closed conformations, generating calcium oscillations that in turn regulate periodic hormone secretions[220]; the β_2*-adrenergic receptor* that regulates cardiovascular and pulmonary function[221]; the *Syk* family of *kinase*s that turn immunoreceptors on or off, and the *Src kinases* that can "turn up or turn down immune cell signaling responses"[222]; and T cell antigen receptor complexes that tune immune responses to match the level of the threat[223]—in the classic homeostatic arrangement.

Nonetheless, the 'sensory organ' of emotion now has many additional structural components, from the original membrane receptors and networks of molecules to specialized nodes and networks of neurons (sensory, motor, excitatory, inhibitory, interneurons, etc), and the topological architecture of the human brain.

Dendritic Computations via Feedback

Moreover, the feedback arrangement, with its fractal self-similarity, computational logos and three step cycle (compare, signal, self-correct) is also readily apparent in the structure and function of *individual neurons* as well.[224,225] Indeed, the *dendritic spines* of pyramidal nerve cells have been discovered to serve as *computational building blocks* that are fundamental to synaptic plasticity, a discovery with "revolutionary implications for neuroscience."[226] For contrary to Cajal's original notion that action potentials only flow one way (dendrites to soma to axons), it has become clear that they also "backpropagate" in the reverse direction (soma to dendrites). These formerly unacknowledged dendritic computations allow the neuron to sum up synaptic inputs, "compare" that sum against a threshold, and "decide" whether to initiate an action potential, to "operate as a device where analog computations are at some decision point transformed into a digital output signal."[227] We see yet again the ubiquitous binary logos, the pattern of yes/no increases and decreases in synaptic weights to positive and negative exemplars[224] and in the reciprocally local and global computations.

Furthermore, the intriguing fact that dendritic spines are suspiciously homologous in size, structure, and chemosensory function to bacteria—a possible ancient symbiont a la mitochondria—has not gone unnoticed.[228] In fact, dendritic spines appear to be a morphological link between the early cell receptor complexes and specialized excitable cells—neurons; their dynamic structure and shape-shifting behavior echoing and expanding upon the *electrical* properties of branes, not mentioned above. For even the *E coli* has both ligand and voltage gated ion channel receptors, with membrane potential a major component of the driving force for membrane transport and flagellar motion—the energy required to power metabolism and any movement at all. Indeed, voltage spiking has recently been observed in the *E coli*, with on/off "blinking" associated with aerobic respiration and the stress response.[229] Likewise the dynamic growth and shrinkage of the spines themselves follows the same pattern of regulatory increases and decreases (of specialized *glutamate receptors)* associated with long-term potentiation and damping, correlating with synaptic plasticity, the "self-modifying" cognitive processes that give rise to memory, emotion and executive function[230]- core elements of human consciousness. Indeed, spine plasticity itself responds to life experience including fear conditioning[231], and intriguingly - as with the aforementioned epigenetic methylation marks - altered or disordered spine dynamics, morphology or density, are associated with psychiatric diseases and neurological degeneration.[232]

In fact, in the 1990s, neurobiologists discovered additional discrete structures on neural membranes known as "microdomains," little rafts that perform computations and regulate ion-channel dynamics—if not the action potential itself .[233] These microdomains, as further complexifications of the multiple domains on the ancient receptor toolkit, self-assemble in clusters with haunting similarity to the membrane receptor clusters on the E. coli, and play a significant role in the assembly of other receptor proteins as well. Indeed, enriched in cholesterol and sphingomyelin, microdomains can be likened to larger, fancier 'heads' on the topside of the membrane, those that allow the specialized neuron to function as a *series of switches*, beyond the simple circuitry of other cell types. Whether evolutionarily homologous or not, however, the circular causality and self-similar pattern of signaling are unmistakable, with dendrites to neurons, neurons to neural networks, and neural networks to sensory perceptions each making unique contributions to the ongoing interactive computational process.

The Three Functional Loops in the Tri-level Brain

Even without the added discoveries of microdomains and dendritic computation, even the more conservative ("cognitive") neuroscientists have identified both the top-down (efferent) and bottom-up (afferent) neuroanatomical pathways of emotional sensory perception; converging in the limbic sensorimotor cortices, and complete with frontal-lobe hemispheric lateralization of positive and negative affect in approach and avoid behavior, respectively.[234] Even those disputing the natural kind view of emotion,[235] acknowledge that affect is synonymous with somatosensory perception of both external stimulus and internal responses.[236] And perhaps even the most neurocentric explanations of emotional experience can soften in light of the fact that the very development of nerve cells, particu-

larly *interneurons* of the prelimbic cortices—a hallmark of complex brains of every variety—is contingent upon optimal immune signaling in response to distress and early deprivation.[237]

Indeed, since this ancient regulatory pattern is so fundamental, the three main steps in the feedback cycle are reflected in globally complex nested loops of the triune brain, each integrating particular emotion and appraisal processes.[238] These include a "*motivated monitoring loop*" (linking the dorso-lateral prefrontal cortex (DLPFC), the anterior cingulate cortex (ACC), hippocampus (HPC), amygdala (AM), orbitofrontal cortex (OFC) and the brain stem/basal forebrain (BS/BFB); the "*motivated object evaluation loop*" (linking the OFC, AM, and BS/BFB with the sensory cortices); and the "*motivated action loop*" (between the OFC, AM, nucleus accumbens (NAS), ventral pallidum (VP), the ventral tegmental area (VTA) and the thalamus; where, respectively, the ongoing *comparisons*, *signaling* and the *corrective actions* occur.

In fact, if defining an emotional "sensory organ" in terms of neural structures, the *amygdala* is present in all three loops,[239-41] and is instrumental in signaling the novelty [242] and uncertainty[243] of self-relevant[34] environmental stimulus. Likewise, would be the ACC, "the receptive organ of the experience of emotion,"[244] with special clusters of P-type (positive) and N-type (negative) neurons in the primate pregenual (pACC) that are respectively "sensitive to positive and negative motivational states."[245] Together, the AM and pACC serve as exact functional analogs to the on/off (occupied 'heads') and yes/no (methylated 'tails') of the sensory receptor clusters in the *E coli* bacterium. Of course, as we have seen, the self-regulatory sensory network begins in the "branes" of all cells, including the skin cells that still bound and contain the human system—hence the classic Galvanic Skin Response (GSR) measure of emotional arousal as well as the emotive component of social touch.[246]

Likewise, the coupling between positive and negative feedback is evident in the reciprocal, bi-directional, interactions between the right and left hemispheres of the brain,[247] between the brain and heart, and between the sympathetic and parasympathetic branches of the autonomic nervous system. Indeed, the vagal nerve mediates bottom-up emotional sensitivity (high stress "reactivity") as well as top-down emotion regulation (faster recovery), both of which are associated with high vagal tone.[248-250] In fact, the polyvagal theory,[251] picks up the story of the evolution of emotion, setting forth the phylogenic shift in regulatory mechanisms through three global stages that gave rise to the "primary" emotions of our "social nervous system."[252] As mentioned, Jaak Panksepp[151] has mapped "the affective brain" across species, and the bottom up emotional regulatory path characterizes the "default mode network" in humans (medial parietal/posterior cingulate, medial prefrontal, lateral inferior parietal and superior temporal cortices), specific to empathy and "social tasks" versus those that manipulate inanimate objects.[253]

The Modern Human Feedback Cycle

All told, over our evolutionary history, natural selection has expanded the self-regulatory feedback cycle from its original two-step stimulus response loop to a *five step interactive process* between mind and body and world. At present, the cycle contains three cognitive *feed-forward* (top-down) add-ons cobbled upon, yet constantly interacting with the ancient (bottom-up) subconscious autopilot system. Indeed, these sequential steps set forth the temporal order required to elucidate the specific distinctions between the basic and complex categories of emotional perceptions (as set forth in Figure 2, and elaborated shortly). For now, it is crucial to note that this cycle constitutes the mind-body-world interface, and that the linear flow of direct human experience constantly cycles through its five sequential components. It is an ongoing process wherein mind and body each play a unique self-regulatory role, but are elegantly unified, connected and in-formed by the emotional sense at every juncture; a process that yields ongoing trial and error feedback during "self-relevant" moments, *intra*personal feedback that is instrumental in evaluative/embodied cognition, memory formation, adaptive learning and behavioral motivation. More generally, to whatever degree nature has afforded the human being a mind with genuine "free will"; such volitional behavioral control is undergirded and constrained by the body's *foundationally causal* self-regulatory feedback dynamics - reliably delivered by the ever-present emotional sense.

Loosely, the first three steps can be described as conscious intentional *motives*, volitional *actions*, and perceived *outcomes*—all of which inevitably contain perceptual filters, and cognitive biases[254-256] unique to one's individual socio-cultural developmental history (Figure 8). Fortunately, they are kept in check by steps four and five, the original yes/no *evaluative perception* and the approach/avoid *behavioral correction* from whence they emerged. This general five step temporal sequence was aptly captured in James Gross' process model of emotion regulation, with his "antecedent focused" coping capturing the first three feed-forward steps of the modern cycle, and his "response focused"[257] regulation capturing the last two—the original here and now body-in-world sensory-motor feedback loop.

However, I would emphasize the crucial link between steps *three* and *four*, wherein the salient self-relevant *comparison* now takes place—a vital comparison between how the mind *perceives* an unfolding event against the body's *actual* outcome. This might well be accomplished by Lewis'"motivated monitoring loop,"[238] which then triggers the *primordial affective feedback signal* in order to *keep things biophysically real*, hence, my call to rethink the value of suppressive forms of emotion regulation. Indeed, in this new view, our binary feel-good/feel-bad hedonic feelings remain the conscious mind's only valid informational tether to the biophysically optimal/deficit conditions required for life itself, and an innate safeguard against its more

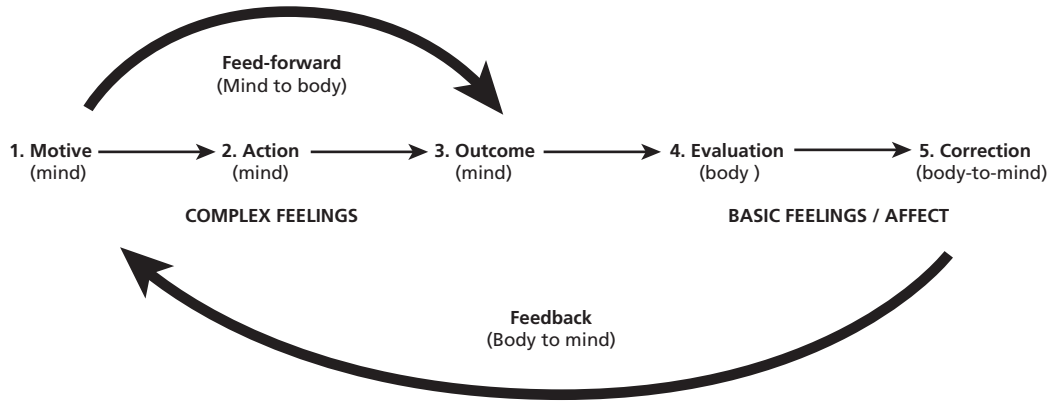

Figure 8 Modern feedback cycle with feed-forward cognitive elaborations and complex feelings.

volitional—yet potentially dishonest[258]—rationalizations and hypocrisies.[259] Instantly, they offer both a reality check and a behavioral fix—concordant with the ancient self-regulatory imperatives. Their elegant stimulus-response mechanics moves us to actively avoid self-destruction and create evolutionary self-development, and their simple tit-for-tat logic constantly reminds us of these dual universal purposes.

Moreover, suppression does not work. Suppressive emotion regulation actually increases the bottom-up activation of the error signal.[260] Likewise, whether or not the informational component of the emotional message is deliberatively and rationally incorporated into the cognitive schemata (building conscious, reasoned motives), the coupled corrective response will simply forge them into the mindscape via Pavlovian conditioning (perhaps through Lewis' "motivated action loop,"[238]) yielding the subconscious variety of motives propounded by Freud—those instinctive libidinous drivers that run roughshod over our higher rational intentions.

The key point is that this five-step cycle depicts a fundamental *temporal* sequence that is prerequisite for the many facets of the self-regulatory emotional elephant to come into view. It conceptually reunites "the self" as a functional whole, bridging the gap left by the Cartesian severance of mind from body and the many illusory divides, judgments and assumptions that would follow. Particularly those that privileged reason over emotion, and conscious and intentional processes over intuitive, embodied cognitions and "naïve" sensory perceptions. Indeed, the sensory feedback model resolves many time honored controversies in emotion theory: Reconciling William James' original insights about the bottom-up causal components with Cannon's top down; Lazarus' subsequent emphasis on cognitive appraisal[295] despite Zajonc's primacy of affect.[25] It unites the dimensional[261] with the discrete models of emotion, and the feedback dynamics offers the bridging rules[262] that reconcile the materialist, behaviorist, identity and functional approaches to subjective emotional experience.[263] It honors Joseph LeDoux's distinction between cognitive computations and affective—*self-relevant*—computations,[34] and his low road/high road dual but interactive emotional processing paths in the brain, those that validate Bernard Weiner's "attributional"[264] linking of motivation and emotion.

Perhaps most importantly, it elucidates how core affect.[12] basic emotions,[265] and complex (socially constructed) feeling perceptions [266] all dovetail together in exquisite functional elegance within the modern day emotional sensory system (as previously depicted in Figure 2).

DECODING HUMAN EMOTIONAL MESSAGES

Key to understanding emotion as a sensory system is that emotional perceptions deliver self-regulatory messages from the self (the body) to the self (the mind) about the well-being whole self. Once we can frame these messages within the context of the ongoing feedback cycle and decipher their specific meaning, the emotional sense offers nothing less than a personal guidance system. Hence, in this section I will set forth more detail about the three levels of information encoded in human emotional perceptions, how they unite the various components of the self, and how they relate to the temporal sequence of the modern-day five step feedback cycle (depicted in Figure 8). Doing so will clarify muddy linguistic conventions with more precise terminology.

Hedonic Valence (Affective Evaluation)

The first level of meaning concerns the term *affect*, which I will henceforth subsume within, after distinguishing from, the *hedonic valence of emotion*. Indeed, in the literature, "affect" concerns only valence and arousal intensity,[261] and omits the motivational behavioral dimension. The key insight of this model, of course, is that the binary valence is *born* of behavioral regulation and rooted in positive and negative feedback processes. In fact, the evaluative message it bears is not only meaningful for optimal self-regulation (maintaining "emotional equilibrium"[267] and "regulatory fit,"[60]) but one fundamental to the process of evolution itself. The valance provides subjectively positive or negative "qualia" as an informational lynchpin between an organism's biophysical well-being and the criteria of natural selec-

tion. In short, valence speaks of natural—universal and nonnegotiable—*biovalue*s that concern the optimal conditions for life itself.

From the perspective of human experience, the bottom-up primary evaluation encoded within affect[268] is the perceptual error signal, directing attention toward self-relevant events and placing them in the context of the dual self-regulatory purposes, with "goodies" signaling opportunities for adaptive self-development and "baddies" for corrective self-preservation. This is the ultimate, long-term evolutionary meaning associated with affect.

Indeed, in terms of epigenetics and immune functioning, core affect relies upon the ancient evaluative yes-no logic of cellular signaling, synthesizing the myriad voices of the cells, organs, and organ systems, into the symphonic "interoceptive"[234] wisdom of the entire organism. This model, however, tethers the identity-relevant hedonic wisdom deeper still in the self/not-self logic of autopoietic self-making, bridging to the self/not-self distinction of the immune system and its salient distress and eustress signals - with the circular closure delivering a bidirectional communication flow. In fact, the top down manifestations of the emotional sense are likely involved in placebo and nocebo effects[269-272] providing a direct inroad to our physical health.

At the more proximate level of meaning, affect still concerns optimal behavioral movement, providing immediate *feedback* about the state of the *body in present time and space*, the original right-here-right-now signaling of good or bad events as they are unfolding, and triggering hedonic approach or avoidance—the tit-for-tat logic of increasing the stimulus, or moving toward the goodies in the immediate environment, and decreasing, or moving away from the local baddies. This original, primal, function of affect is represented by the last two steps of the modern feedback cycle, limited in terms of conscious experience to the somatic[46] and visceral[151] perceptions, "attentional attitudes,"[9] and "gut feelings."[273] These are also the time-urgent "hot nodes" of emotional perception,[274,275] those that signal the dissonance long thought to be "cognitive."[276] Nonetheless, natural selection has conserved the original stimulus-response pairing, and affect is implicit *in every step* of the feedback cycle.

Indeed, whether or not we are aware of any sensations of pleasure and pain, primal affect also delivers the subconscious, automatic, aspects of emotional perception, regulating purposeful approach/avoid behavior even if the mind remains out of the loop. This includes, of course, all conditioned learning, and the nonconscious aspects of motivation and self-regulation: implicit volition,[277] implicit intention,[278] or automated will.[279] Hence, the ubiquity, primacy, immediacy, and classical conditioning power of affect,[280,281] and such mysterious manifestations as the "present bias preferences,"[282] the anchoring and availability heuristics,[254] the projection bias[256]; the confirmatory bias,[283] and a host of other "wild,"[284] "irrational,"[285,286] influences that have long bedeviled the rationalist model of economic decision making.[287,288] Of course, they also reflect the ancient embodied wisdom, and manifest as the automatic, subconscious aspects of decision making that are intuitively advantageous[289]—for they faithfully reflect the ancient self-regulatory code.

Basic Emotions

While this deeper relational and functional significance of pleasure and pain has gone largely unrecognized, evolution has forged the basic emotions (and all complex blends and shades) upon their ever-present self-regulatory base. As such, the "natural kinds" basic or primary[265,291-293] emotions also deliver in-the-moment, bottom-up, *feedback signals* with universal symbolic meanings—yet with an added layer of specificity within their common *appraisal themes*.[5,294] Here an important distinction is made between the efferent, top-down, *cognitive appraisal*[295] and the afferent, bottom-up *affective evaluation*,[268] the former involving more complex prefrontal and linguistic processing; yet emphasizing also that both serve equally important functional roles in the emotional system.

While controversy remains over which emotions are basic,[296] based upon their temporal (feedback) significance, this model suggests *joy*, *sadness*, *disgust*, *fear* and *anger* to be the best contenders for the mantle of universal self-regulatory perceptions. These basic emotions are relatively more hardwired, unfolding over the first 6 months of infant development,[297,298] with their common appraisal themes delivering more specific information[299] about basic life-giving requirements—"hedonic needs"[300]—and how to fulfill them in the immediate environment. The "how to" part is the additional informational component, involving conditioned or conscious cognitive schemata forged through the feedback cycle over time, yet the hedonic requirements and behaviors remain the same.

Indeed, like primary colors, their common appraisal themes carry specific information about innate *physiological* as well as *psychosocial needs*.[79,83] ("Needs" in this context reflect any biologically hardwired urges, drives, values or "specialized modes of organismic operation that match evolutionarily recurrent situations."[215]) For example, basic joy with its "Yes!–Go!–Good-for-me!" message, pulls us to discover and honor these basement needs and reinforces novel strategies for meeting them, driving optimal developmental adaptations and fostering creative cultural and environmental enhancements. Although research on needs is scant, this model suggests the "hierarchical" nature of needs relates directly to *the dual self-regulatory purposes*, with the top priority negative emotions (self-preserving: sadness, disgust, fear, and anger) largely honoring the non-negotiable thermodynamic and metabolic needs—with the autonomous agency, the *freedom* and *empowerment* as well as the physical and social *safety* required to fulfill them.

In fact, it is important to note that four out the five basic emotions are of *negative valence*—the painful dis-

tress signals, and their urgent "No!–Stop!–Bad-for-me" self-preservationary message. Indeed, bad is stronger than good,[43,301] perhaps the reason why evolutionary theory acknowledged only the self-preservationary imperative, and psychology emphasized the dysfunctional aspects of the human condition.[302] But through this new lens, the predominance of basic negative emotion is because nature gifts us with nearly *four times as much* specific, universal, information about how to *correctively preserve the body in the world.*

For instance, the appraisal themes of the four basic negative emotions—*loss* (sadness), *imminent danger* (fear), *contamination* (disgust), and disempowering *obstacles to agency or social violations* (anger)—move us to either change the immediate environmental circumstances or alter our location, to "fight or take flight." To which I would add: ***to make right***—a catchall term I offer to categorize any sort of adaptive, creative problem-solving response to emotional distress, born of the *self-developmental* imperative and the *approach* mode of behavior. Right, in this context, is also healthy.

Instead of suppression or behavioral avoidance, a Right Response (RR) is one that involves an active, adaptive, rebalancing of the ecologically optimal (biophysically favorable) relational state between the organism and the environment. The RR has been captured in the stress literature as problem-focused coping,[303,304] or transformational coping,[305] as perhaps the most adaptive way of reducing the psychophysiological arousal tension.[306] This happens in one of two ways: It can involve an active adaptation of the *immediate external environment*, which is essentially creative action or "work," the way we build social and economic capital[307] and the way we accomplish cultural evolution.

For example, when *sad*, finding or creating replacements for what has just been lost; when *disgusted*, finding more wholesome comestibles or creating hygienic conditions; when *afraid*, finding protective shelter, connectivity and community; or when *angry* removing the obstacles to one's requisite self-regulatory agency, ensuring balanced interactions, and repairing social connections. Indeed, in terms of interpersonal conflict, all acts of nonverbal and linguistic communication are RRs, reducing basic pain with an outside change without running away or resorting to fisticuffs. In fact, "doing good," helping to resolve the distress of others, is in and of itself a buffer against "feeling bad."[308]

In short, basic emotions offer universal meaning in the present moment and under the specific conditions of the immediate environment, information about the health and well-being of the *body*—any body and everybody. As such they are represented by the last two steps of the modern feedback cycle. They remain *feedback* signals, and are only fed-forward to the degree that they combine and blend into the complex emotional perceptions. Nonetheless, they move us to fight, take flight or correctively "right" the *external* environmental stimulus conditions.

Complex Feelings

For, in contrast, as secondary blends and shades of the primary emotions, the *complex* feeling perceptions enfold the remembered past and the imagined or expected future, bearing self-regulatory messages about the *mind.* They are highly personalized, delivering specific guidance tailored to the individual's particular cultural immersions, private life experiences, and unique history. As defined herein, they are to be found exclusively in the *first three steps* of the modern feedback cycle.

Complex feelings include *trust*, *mistrust*, *courage*, *anxiety*, *pride*, *shame*, *gratitude*, *contempt*, *compassion*, *guilt*, *admiration*, *envy*, *hope*, *worry*, *devotion*, *rage*, *love*, *hate*, *curiosity*, *honor*, *faith*, etc., and have a clear developmental trajectory (emerging between ages two and eight,[112] if not fully complete by age three.[298]) They largely serve the *self-developmental imperative*, and are goal-relevant to the "higher" human needs—needs for enduring *social bonds*, for *self-esteem*, for *creativity*, and long term *meaning.* They are the result of many self-constructing[309] repetitions through the feedback cycle, the basic themes having been elaborated upon by language, individual learning experiences, self-identifying concepts, and sociocultural schemata (cognitive structures—knowledge, beliefs, rules, habits, rituals, traditions and in-group norms, obtained from one's foster environment).

With the notable exception of rage (a perfect storm of belief driven blame, positive feedback amplification, and basic anger) the complex emotions are the less time urgent, "cold nodes" of emotion,[274,275] yet still carry the ancient hedonic logos within them. Indeed, as depicted in Figure 8, these complex feeling perceptions are the more long-term *feed-forward* causal components of behavior,[79] reflecting both conscious and habitual motives, judgments, and appraisals that still carry their original emotional valence as "emotion schemas"[290] in attitudes[310,311]; moods,[312,313] and even personality traits.[314] In short, the complex feeling perceptions deliver self-regulatory information about the *mind*, feeding forward an ongoing stream of evaluative commentary about its optimal or dysfunctional holdings, habits, and the uses and abuses of the rational intellect.

Indeed, complex feelings prescribe the second kind of optimal RR, which is affected to the *internal environment*, the personal mindscape, in acts of conscious knowledge acquisition, deliberate learning, personal growth, or mindful self-regulation—offering a personally accountable answer to the distress call (oftentimes despite the external circumstances). This internal variety of RR also includes building and invoking optimal belief structures to reappraise[260,315] or temporarily endure a challenging or uncontrollable situation; or to bear an injustice, setback, or misfortune with relative grace and "resilience."[316] This internal RR is also known as "self-control,"[317] "self-discipline,"[318] or when habitual, "grit,"[319] all of which describe the ability to endure short-term pain in order to cultivate long-term, complex—highly meaningful—pleasure (captured by the body builder's lament "no pain no gain.") While there

are many implications beyond this introductory scope, suffice it to say that the information offered by the complex emotions harbors a vast reservoir of biological—indeed moral—wisdom yet to be tapped by humanity.

SUMMARY: EMOTION AS SELF-REGULATORY FEEDBACK

In sum, the self-regulatory feedback model proposes that there are *three levels of self-regulatory information* encoded within each human feeling perception—information that sub-serves the self-regulatory purposes of all living systems, as well as a suite of universal human needs, and the individually unique ways of meeting them that evolve over time. The model highlights the ongoing, cyclic, trial-and-error nature of learning and human development, with the confluence between the three levels coming into focus with the recognition that primordial affect serves as the "error" signals—both good and bad deviations from homodynamic states of balance. Balance within and between body and world, within and between mind and body, and ultimately within and between individuals comprising social bodies.

With the proposed additions, clarifications, and structural exemplars from cellular sensorimotor mechanisms, this model helps resolve criticisms of the control model of human behavior.[79] Indeed, there has been abundant misunderstanding, misinterpretation, and a series of patterned "blunders"[118] on the road to realizing the early cybernetic vision. This includes linguistic confusion across interdisciplinary literatures concerning the terms "positive" and "negative" feedback,[320] often confounded with *feed-forward* loops or complex *feedback circuits* built from couplings of multiple positive or negative loops. Even the best models[38-39] rely upon only one of the two types of feedback, confound internal and external locations in space, and vault to the complex level of human self-regulation with assumptions that inadvertently *reverse* the logic of the self-regulatory code.[39]

But with both the redemption and validation of regulatory feedback, this model also refines and builds upon the rich tradition of "consistency theories"[321] wherein some stimulus event creates a deviation from a balanced cognitive state and affect plays a role in signaling or restoring that balance. Some examples include congruity theory,[322] cognitive dissonance theory,[62] balance theory,[323] psycho-cybernetics,[324] neuropsychological theory,[325] self-discrepancy theory,[326] homeostatic synaptic signaling,[327] affect-balance mediation,[328] regulatory focus theory,[60] the original "logical calculus" in nervous activity,[329] and even the "equilibrating" nature of development itself.[330] As mentioned, all such models suggest a sort of *psychological immune system*[61,331] that operates unconsciously, wherein intense hedonic states trigger a variety of processes designed to attenuate them. These range from the homeostatic processes that diminish their physiological impact[332,333] to the defensive processes (ie, rationalization, self-serving bias, positive delusions, self-deception, etc.) that diminish their *psychological* impact[13,315,331,334,335] in order to "protect the individual from an overdose of gloom."[61] To which I would add, can spell "doom" when misunderstood and left unanswered—threatening the very physical integrity of the individual.

IMPLICATIONS FOR PUBLIC HEALTH

Indeed, in this new view, common words such as "right" and "wrong" are biologically grounded in the physical requirements of the living organism—recognizing the original yes/no, feel good/feel bad, hedonic evaluation as physiological *eustress* and *distress signals*, and reframing certain elements of morality in the context of public health.

Right states of life-giving balance, right behavior and right-track development in this context, concern optimal biophysical functioning, self-regulatory responses, and mediation between the dual evolutionary purposes: preserving the body and adaptively developing the mind. "Wrong" behavior is that which repeatedly suppresses, denies, or otherwise fails to respond correctively to the emotional sensory information, with ongoing, unanswered, distress signals giving rise to a limited, unhealthy, and perhaps even self-destructive trajectory.

Fortunately, the simple hedonic code yields a singular and universal moral commandment of harm reduction, a blend of the Hippocratic oath and the Kantian categorical imperative: To simply ***reduce*** *the external environmental conditions that elicit basic pains* (the **negative** emotions), *and* ***increase*** *those—in both the local landscape and personal mindscape—that foster the complex pleasures* (the **positive** emotions).

EMOTION AND OPTIMAL DEVELOPMENT

In fact, evidence is mounting that the *positive eustress signals* offer far more than simple good feelings and short-term rewards: They "broaden and build"[336] and "inspire and rewire"[116] the mindscape and social landscape, expanding our empathic boundaries, moving us to bond with others, to "mend, tend, and befriend"[337] and to "shift and persist"[338] during formidable challenges. They even promote vibrant health,[339,340] and longevity.[341,342] They both signal novel developmental opportunities and reflect optimal self-regulation, the "self-control" that predicts health, wealth and even public safety.[343] Indeed, born of the positive feedback dynamic, the positive emotions drive a self-perpetuating "upward spiral,"[344] naturally punctuating an optimal physical, mental, and social developmental trajectory.

For example, in Erickson's stage model of psychosocial development, the first stage is marked by either *trust* versus *mistrust* in the first year of life; the second by "autonomy"[345] (to which I would add: *confidence* in one's self-regulatory agency, *curiosity*, *delight*, *zeal*, and *hope* for life) versus *shame* or *doubt* (*anxiety*, *worry*); and the third stage by "initiative" (*courage* to tackle challenges, *faith* in oneself, *mirth*, *affection* for peers, and *admiration* of inspiring others, *gratitude* for caring support and mentorship,

and *compassion* for suffering) versus *guilt* (to which I would add *boredom*, *envy*, *greed*, *contempt* and *rage*). Successful development of the right-track positive emotions all contribute to an integrated and meaningful sense of identity and a passionate humanitarian conscience by adolescence, as well as loving intimacy, generosity, and compassion in adulthood.[346]

This model suggests, however, that these perceptual milestones also reflect the fundamental epigenetic and immune regulatory processes and the structuring, pruning, tuning of neural circuitry and ongoing dendritic plasticity. It suggests that there may be critical opportunistic windows during the emergence of primary identity and self-regulatory agency, the formation of fundamental complex human capabilities[347] and personalized psychological capacities[348]—timely processes which, if stymied, can yield compromised or detrimental developmental outcomes.[349]

For conversely, the prevalence and preponderance of the *complex negative emotions* implies a more compromised or deficient developmental trajectory, reflecting maladaptive schemata—"wrong" in that they are limiting if not self-destructive. Indeed, when basic sadness, fear, disgust, and anger are not allowed to their job, the causal environmental factors remain the same, and these unanswered distress signals will simply be conditioned into the mindscape, causing long-term imbalances and ongoing, self-perpetuating, distress ("suffering"). Indeed, complex feelings such as mistrust, shame, anxiety, worry, envy, contempt, rage and hate are indications that the prime commandment has been violated, and the eliciting conditions have actually been *increased*, now harbored mentally and feeding forward in negative attitudes, limited beliefs, and narrow identity boundaries that skew perception and that drive habitually avoidant behaviors, and all the predictable intrapersonal dissonance (and interpersonal conflict) that results. These are the targets of therapeutic interventions such as rational-emotive or cognitive behavioral therapy,[350,351] their negative valence nominating them as maladaptive candidates for revision or elimination.

Worse, we have pressed our man-made suffering into service in a warped third-party form of morality—one where we *suppressively regulate one another* by deliberately inflicting emotional pain. For example, as moral psychologist Paul Rozin has noted, ethical codes are routinely enforced by third party expressions of the negative emotions,[352] with *disgust* mediating codes of *divinity* (religious mores), *contempt* enforcing codes of *community* (local sociocultural mores), and *anger* upholding codes of *autonomy* (equal justice, human rights, etc). But this strategy can backfire, for it only succeeds to the degree that it instills *first person* emotions such as shame, embarrassment, guilt, sadness, or fear, harnessing the "flight," submissive, mode of hardwired emotional response.[353] Likewise, it predicts competitive conflicts between the various ethical codes should they prompt first person disgust or anger instead, and its naturally aggressive "fight" mode of self-preservationary avoidance[354]—or elicit such hostile complex emotions as contempt, rage, or hate and "getting even" (the negative feedback rebalancing) via revenge.[355] In fact, punitive authoritarian parenting that relies upon shame and humiliation negates the self, invites anger, promotes rage[356] and self-destructive activity; and can lead directly to violent criminal behavior.[358,359]

EVOLVING SENSITIVITY TO CONTEXT

Furthermore, sociocultural practices and structures that exploit negative emotion in this manner create a compounded, lingering state of biophysical distress,[360] setting the epigenetic stage for compromised immune function, ill health, maladaptive development, and psychiatric disorder.[361,362] Indeed, through epigenetic pathways, stressful events become biologically embedded—they get "under the skin"—during developmental windows crucial to the forging of neural circuitry,[363,364] and are implicated in the DNA damage that accelerates degenerative aging.[365] It is now well documented that environmental factors such as maltreatment, family adversity, marital conflict, maternal depression, and even financial distress are been linked with cognitive deficits and socio-emotional behavioral problems in children.[366-379] The mechanism of such biological embedding has been called "time dependent sensitization,"[380] "neural sensitization,"[381] "sensory hyper-arousal,"[382] "central sensitization,"[383] "central nervous system sensitization,"[384] and "sensitivity to context,"[385] but by any name, they reflect the self-regulatory feedback dynamics—and epigenetic and immune manifestations—of *the emotional sense*.

Additionally, humans continue to evolve, and we may be becoming increasingly sensitive to the biophysical cues that elicit emotional perceptions, implying that epigenetic processes are becoming evermore influential in all aspects of our health and well-being. Or, in other words, that psychosomatic and sociosomatic effects of the mind and the world have an increasingly potent effect on our genetic processes. In fact, one's very stress response can be epigenetically programmed by the environmental exposures of one's immediate ancestors, one's grandparents.[386] Likewise, "increasing evidence suggests that most, if not all, diseases of the central nervous system are associated with either primary or secondary perturbations of the epigenome,"[387] which of course include "psychosomatic" syndromes, affective disorders[388,389] and psychiatric diseases[390]—not to mention the profound developmental deficits from extreme contextual deprivation.[349] Furthermore, disruptions in these chemical signaling systems and their neural circuitry can give rise to the empathy deficits in autism,[382] to psychopathy,[391,392] and the dissociative[393] and identity pathologies in schizophrenia.[394,395] Yet their underlying feedback dynamics can also explain the marginal efficacy, adaptive tolerance, and long-term deficits that can accompany pharmacological therapies.[396-398]

Indeed, we have *blamed the emotional messenger while missing its primal self-regulatory message*. We have chosen

to suppressively regulate our emotions instead of allowing them to inform and regulate us. It should be no surprise then, that most of the mental, behavioral, and identity disorders within the psychiatric guidebook, the Diagnostic and Statistical Manual of Mental Disorders (DSM),[399] are characterized by emotional dysfunction, particularly the ongoing negative emotions. Nor should it be surprising that controversy abounds concerning the changeability, suitability, and efficacy of the DSM criteria, for we surely cannot adequately grasp "disorder" without first understanding the original, self-regulatory, *emotional order*.

Nonetheless, our ever-evolving emotional sensitivity is a good thing. For while increased sensitivity to context in children raised in adverse, stressful, environments is particularly harmful; extra sensitivity in those with enriched and nurturing environments fosters even better developmental outcomes than their less sensitive peers.[385] Likewise, with the development of emotional literacy and emotional intelligence, extra sensitivity means earlier warning, more detailed information, and timely opportunities for swift and effective corrective responses.

CONCLUSION

I have argued that a broadened interdisciplinary perspective, an updated evolutionary theory, and an expanded definition are required to elucidate the biophysical function of human emotion—to envision the entire emotional elephant both within and beyond the wide variety of theoretical viewpoints. Indeed, despite all effort, the bigger picture remains opaque, emotion remains undefinable in psychology,[400] and seeking a unifying function has been deemed unfashionable if not misguided.[401] The result is a continuum of independent and often mutually incompatible theories ranging from the position that emotions are biologically hardwired, to the view that they are largely sociocultural constructions, suggesting that "emotion generation" and "emotion regulation" are "either one or two, depending on your point of view"[402]—a situation that has reduced the science of emotion to a matter of personal opinion.

This new story, however, suggests that emotion generation IS emotion regulation, because it is best understood as a biologically ancient *self-regulatory sensory system*. Yet, despite many theorists noting both the sensory and self-regulatory nature of emotion, there seems little inclination to officially acknowledge emotion as a sense. Nonetheless, abundant empirical evidence is there for the taking that justifies making that declaration: Evidence ranging from the patterned molecular activity that drives hedonic stimulus-response behavior and yields inaugural evaluative perception in the simplest organisms, to the functional connections between cell signaling networks and epigenetic, immune, and neural processes in more complex organisms. Evidence of how these mechanical regulators manifest as multi-tiered feeling perceptions, sensitivity to context phenomena, patterns of development, motivation, decision-making, moral reasoning and emotion regulation in humans. Evidence that compatibly dovetails with, extends, and provides biological foundations for "the laws of emotion"[403]; that melds with evolutionary theory in both its early and contemporary forms, and that is comfortably compatible with nearly every major ideological tenet and empirical finding within psychology. Furthermore, is the significant fact that *synesthesia*, the odd overlapping of sensory modalities, includes an "emotionally mediated" variety.[404] So my friendly challenge is to ask: *Why not?* If it walks, talks, and acts like a duck (or functional elephant in this case), perhaps it is time to publically declare it to be just that: The preponderance of evidence suggests that it is time to rightfully honor emotion as our self-regulatory sense.

For indeed, this new story has come from a broader evolutionary vantage, noting that affective feelings and their coupled behavioral responses are rooted in the most primal forms of identity and sensory-motor control, readily apparent in the molecular structures and self-regulatory circuitry of "branes" (membranes) of the simplest living systems. This is a control circuitry instantiated by protein receptor complexes that govern hedonic approach and avoid behavior, fashioned via a serendipitous coupling of positive (amplifying) and negative (regulating) feedback processes and harnessed—very early on—as symbolic cues for beneficial or harmful environmental conditions. It maps the confluence of the self-regulatory computational dynamics across the more hard-wired genetic and soft-wired epigenetic regulatory landscapes with its dynamic on-off switching, to stop/go appetitive behavioral control, to yes/no hedonic approach/avoid responses in accordance with its simple—yet universal—tit-for-tat self-regulatory code. It suggests that pleasurable and painful categories of feeling relate directly to the criteria for natural selection (self-preservation and adaptive self-development); that subjective perceptions of "goodness" and "positivity" concern optimal balances between the organism and its immediate environment, and that "rightness" equates with optimal biophysical conditions for living systems as well as adaptive, timely, and appropriate responses to immediate environmental challenges.

It maps how the ancient sensory language of emotion now manifests as bi-directional communication pathways, across the generally tri-level structure of the human brain and its dual processing paths,[34,234,405] and in individual neurons, as well as the receptome "branes" of each specialized cell; fostering the parallel computations across the epigenetic, immune, endocrine, respiratory and central nervous systems in the generation of "self-relevant" emotional sensory perceptions. This mapping elucidates how common human feelings now encode three levels of self-regulatory information, elegantly balancing the immediate needs of the body in the context of the world, mediating the growth of mind while prioritizing preservation of the body, and elegantly integrating the individualistic and social aspects of

human identity. This new model is also fully testable, and many of its predictions are already well-established facts across the social as well as physical sciences.

On the other hand, the model is not without its vices. *Accessibility* is of primary concern, due to its departure from traditional assumptions and approaches, if not *antipathy*, given that it upsets several paradigmatic apple carts. Investigations will require a broader scientific lens—an interdisciplinary inquiry and a *synthesis* of biophysical facts, bucking the academic trend toward ever more detailed analysis and career specialization that plagues emotion theory.

It will also necessitate a revised vocabulary for the feeling signals themselves. Indeed, words fail; and even exploring the model's implications will require building a new lexicon, one with terms that more accurately depict the biophysical origins, temporal significance, and elegant complexity of emotional feeling perceptions; one that is functionally tethered to the biophysical underpinnings, and that rightly privileges our hedonic evaluations; one that links appraisal information with universal human needs and is not freighted with mind-body dualism (or the traditional good/evil dichotomy), and one that has been laundered of the pejorative connotations that suppressive emotion regulation presupposes.

The model may also challenge the ecological validity of some standard empirical approaches, ranging from laboratory emotion induction and self-reports (such as PANAS), to statistical analysis (wherein a more Bayesian paradigm would honor the feedback dynamics, the self-relevant nature of emotion, the subjectivity of the investigator, and the observable real-world behavioral patterns.[406-408] In short, the model poses some heady challenges for social scientists.

The virtues of this model, however, suggest surmounting such hurdles to be a worthy pursuit. For, to the author's knowledge, it is the first model to offer a biologically justifiable function of emotion, one that is devoid of neurocentricity, and rooted in the fundamental biophysical facts and principles beyond the conventional interpretation of Darwinian evolution. In fact, while he wondered whether or not emotional facial expressions may be vestigial,[409] Darwin himself recognized the these core self-regulatory dynamics in his three principles of emotion: He noted the bottom up behavioral automaticity and positive feedback in his "principle of direct action," the negative feedback dynamic in his "principle of antithesis," and anticipated the self-developmental Pavlovian conditioning and its feed-forward manifestations in his "principle of serviceable associated habits."[410] He also endorsed Alexander Bain's "fundamental law of pleasure and pain," which states that pleasure is connected with an increase and pain a decrease in vital power (the tit-for-tat self-regulatory code), a law founded upon "the principle of self-conservation, the *self-regulating, self-acting impulse* of the animal system"[411] (emphasis mine). Had Darwin been privy to modern understandings of the chemical networks, computational, and regulatory dynamics involved in genetics, epigenetic inheritance,[42,186] social genomics,[193] and neuroplasticity,[412] it seems likely he would have noted the importance of here-and-now environmental interactions and behavioral responses, and perhaps more pointedly given emotion its functional due. Still, despite his laudable parsimony, Darwin concluded that "the 'language of emotion' is certainly of importance for the welfare of mankind."[410]

Indeed, in addition to unifying many seemingly separate and unrelated bodies of literature, this model affords science a pioneering inroad into the territory of *values*. It allows us to reexamine and transcend the naturalistic fallacy,[413-415] providing a language of embodied bio-values against which to contrast, inform, and assess our standard philosophical assumptions. It invites us to reexamine traditional value judgments and linguistic categories such as good and evil, and virtue and sin; allowing us to shift certain aspects of morality into the realm of public health with "right" and "wrong" states concerning biophysically universal requirements, conditions and optimal balances for all life forms. It offers a hard-science bedrock for the "positive" in "positive emotions"[33] and "positive psychology"[416] as well as the "positive" adaptive functions of the "negative" emotions and insight into why they are so insistent, acknowledging a clear epigenetic and immunological bridge between mental well-being and physical health.

Finally, the model places *purpose* in an evolutionary context, with both positive and negative relating to universal self-regulatory purposes to which the biovalues of all living systems are tethered. To recognize our teleological end-directed purposes is to fill a "gaping hole" in our understanding of our world and our place within it—"the intrinsic value in humankind,"[417] offering a much more optimistic portrait of human nature—if not of nature itself. It suggests that cohesion, cooperation, and adaptive creativity are as deeply rooted in our evolutionary history as random mutation and red-in-tooth-and-claw competition. It suggests that nature is green with grace and embrace, balancing self-preservationary necessities with self-developmental synergy, and that it is our feeling sense that defines us—and defines us as good: ("*Sentio ergo sum bonum!*": "I feel, therefore I am good!")

Still, aside from a better scientific foundation, this isn't really a new story. It has been with us since time untold, for even the ancients—Plato, Aristotle—recognized moral virtue as rooted in the judicious use of pleasure and pain. But reframing emotion as a self-regulatory sense, offers a more judicious appreciation of the biological fact that first and foremost, emotion is actually—and rightly—*regulating us*. Indeed, as Jeremy Bentham suggested, our "sovereign masters" of pleasure and pain "point out what we ought to do as well as determine what we shall do." And that their perceptual persistence is not only devoid of vestigial or original "sin," but may offer our only salvation from it.

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