

The emergent process of thinking as reflected in language processing¹

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Introduction

It has been common practice to explore the process of thinking in terms of our most familiar publicly available aid to thought: language. Much of contemporary cognitive theory takes its lead from a detailed analysis of language. But in evolutionary terms language is an unprecedented, most recent, most divergent, most highly differentiated form of social communication and its role in organizing cognition is likely also just a recent overlay on much more ancient and basic mental processes. Indeed, I will argue below that modeling cognition on the analysis of language artifacts like written sentences, may actually have inverted the process logic of both thought and linguistic communication.

The assumption that the minimal lexical units of language are primary and that its composite structures—phrases and sentences—are derived from combining these more basic units seems too obvious to question. Most sentences are novel products, while all words and grammatical markers have ancient origins. How could sentences ever be prior to the words that compose them, either historically or mentally? In fact, as is our common experience, it is not a sentence *per se* that is prior, but rather what might be described as the imagistic impressionistic frame of the sentence.

The classic compositional analysis of sentence generation is based on a formal or engineering analogy. In such artificial systems, a set of design instructions (or assembly constraints, or both) and a set of component parts precede all operations. Complex structures are accurately modeled by combining components according to these

¹ A few paragraphs included in this paper were presented previously in Deacon (2005), though they have been significantly re-edited to reflect the difference in context.

rules. So it seems natural to assume that the neural production of sentences should also proceed this way.

And yet there is a troubling parallel in biological thought. Although we often describe the structures and functions of bodies as though they are marvels of engineering, they achieve this appearance by means almost diametrically opposed to engineering design. In biology parts never precede wholes, but rather differentiate out of less differentiated whole units (e.g. blastulas and embryos) or evolve from simpler whole organisms. Language too is a spontaneously evolved phenomenon produced by a biological organ, and biology is not engineering. Moreover, language processing is ultimately carried out with the same brain structures that other primates use for non-linguistic functions. Could we be analytically inverting the logic of language processing, and by implication cognition in general, by thinking in engineering terms?

Brain development parallels

Consider a parallel with brain development itself. It has become increasingly clear that the vast majority of the »design information« expressed as brain structure is not encoded in genes. Mouse brains, which are roughly the size of the last digit of your little finger, develop using roughly the same number of corresponding genes as does the human brain, which is roughly the size of a pineapple. With each neuron interconnected with roughly a thousand others in both kinds of brains, the information embodied in these two structures differs by many orders of magnitude. So where does the extra information come from to build human brains?

The answer does not come from reapportioning influences of nature versus nurture, but rather from neither. The extra structural information arises spontaneously, not by magic or divine intervention, but by a process that, like evolution, can spontaneously generate adaptive correspondences and novel complex structure and function without external guidance. Indeed, brain development resembles a kind of microevolution in many important respects. And both evolution and embryology take advantage of a variety of spontaneous ordering tendencies as well.

The way that open dynamical systems fall into orderly patterns without extrinsic imposition of these regularities has come to be

called self-organization, and the dynamical structures that arise from such processes (as well as from evolutionary processes) are generally described as emergent (for an overview see Deacon 2012). Examples of autonomous pattern-generation can be seen in the formation of hexagonal convection cells in a heated liquid (Bénard cells), the individually idiosyncratic yet hexagonally symmetrical growth of snow crystals, and the interwoven spirals of seeds, leaves, and petals that spontaneously organize to exemplify the Fibonacci number series (which is not explicitly encoded in the plant's genes). These regularities of structure and function are not prefigured in any antecedent instructional process but come into existence dynamically as the repeated interactions of components gradually reinforce some structural biases and damp others. Self-organized regularization can lend itself to selection dynamics as different patterns of interaction are pitted against one another in a larger «ecology». An interplay between self-organization and selection processes is responsible for much of the emergent structure and adaptive complexity of brains.

For example, in the process of brain development, patterns of connection are initially generated by the self-organizing interactions of axonal growth processes extending between regionally organized distinct cell populations. These distinctive cell groups also arose from antecedent self-organizing and competing cell proliferation and interaction processes. Converging axons then compete with one another in an «ecology» of signal-processing demands. The resulting selection process culls many and preserves other cells and connections that are more synergistic in activity patterns. In this way, much like phylogenetic evolution, the developing nervous system can augment the biasing influences of the genes by using this as a base from which to «explore» adaptive correspondences between different neuronal populations, between regionally different signaling patterns, and between organism and environment. This contextually sensitive sculpting of cell populations and connections results in the spontaneous emergence of complex functional synergies as the developing brain adapts to the body it finds itself in.

This should not be misunderstood to mean that brains of humans and brains of chimpanzees, for example, mostly differ with respect to these plastic connections. Human brains resemble other human brains, not chimp brains, because of the influence of genetic differences which set slightly different initial conditions (mostly with respect to quantity of neurons produced in each region) for this con-

nectional development. Subsequent self-organization and selection processes augment the subtle biases contributed by these genetically established differences affecting cell-cell interactions to produce large-scale systemic change. This exemplifies a logic that is roughly analogous to some physical self-organizing processes, like snow crystal growth (for example). Individual snow crystals share remarkable family resemblances despite diverse conditions of origin, because of (not in spite of) the regularizing affect of self-organization. Though stochastic factors may make the fine details unpredictable, general patterns are reliably produced even though this emergent structure is not predetermined.

Similarly, selection processes tend to produce convergence toward common forms (e.g. streamlining in diverse aquatic species) despite diverse origins and substrates. This is an important point, which is often misrepresented by overzealous critics of genetic determinism. Emergent structures are often highly predictable and can converge on universal features, even from quite different initial conditions. This is of course relevant to language regularities, as well.

When brain development is viewed through the prism of self-organization and selection processes, little remains of the engineering logic that is so familiar, and yet the result can still be precisely organized. Brain development demonstrates that just because a biological structure is highly predictable, complex, and systemic in organization we need not appeal to algorithmic or instruction logic to explain this fact. Moreover, the extensive role played by self-organizing dynamics in brain development should make us highly suspicious of engineering analogies used to explain brain functions like language production.

Language as a differentiation process²

Languages and human language abilities have evolved spontaneously. Like other naturally evolved complex phenomena we should expect to find that they exhibit the hallmarks of this undirected process re-

² My thinking about this has long been influenced by an early paper by Jason Brown (Brown 1979) and his so-called microgenetic analysis of brain function. This theory has its roots in Gestalt theories of brain function. However, while the approach discussed here incorporates aspects of the embryological analogy implicit in microgen-

flected in an emergent architecture. Language has an emergent architecture to the extent that its structure is a product of spontaneous bottom-up self-organizing interactions, not top-down imposition of structure or constraint by any pre-existing template. This requires conceiving of basic linguistic units as differentiated end-products of a cognitive process rather than as fundamental atoms of a constructive process in which they are »merged« to form progressively larger functional units.

To reconceive language processing in emergent terms we first need to analytically de-differentiate the many levels of a speech act, but this introduces a conceptual difficulty. We cannot start with the familiar components of expressed language—e.g. words or morphemes—but must instead derive these from something far less concrete. Finding adequate ways to describe such an undifferentiated starting condition has troubled psychology since its inception. We must ask »What is the form of a thought before it is put into words?« We find it difficult if not impossible to gain introspective insight into the nature of a word before it is formed, or the idea that a sentence conveys before it is encoded into words. Remarkably, for all the difficulty we have describing this, it is probably fair to say that a good deal, if not most, of our mental life is lived in this not-quite-articulated not-quite-formulated state. Sometimes this is described in terms of »mental images« not quite formed or desires and intentions to achieve some imagined goal only vaguely formulated.

This stage of cognition that serves as the nearly unconscious and automatic ground of language use is also the anticipatory/preparatory stage of perceptual assessments and implemented behaviors. When serving as the ground for linguistic expression it is quickly and effortlessly resolved into words and sentences. As in the case of differentiating other forms of action, we are usually entirely focused on aiming for and achieving expressive goals, not on selecting function words or following grammatical rules. So long as these results are achieved without any serious hitch (e.g. because of word-finding difficulties) the antecedent generative processes go unnoticed.

But if sentence structure is produced analogous to the way embryos develop, not as machines are built, then words and sentences

esis theory it does not assume either its anatomical or phylogenetic assumptions. This parallelism and divergence was initially described in Deacon (1989), published in a collection that also included a paper by Brown.

must also begin as some less differentiated cognitive structures. Following this analogy it suggests that we should consider language processing as though words and phrases differentiate from more inclusive generic precursors. But what are the undifferentiated cognitive precursors to complex sentential structures with their multiple component parts? These precursors are not linguistic units, but rather more general cognitive, semiotic, and pragmatic structures. From this perspective the apparently most elementary phonetic and morphological features of language are, in contrast to standard linguistic analyses, late-stage developments in the progressive differentiation of these larger semiotic neurological »embryos« of a speech-act.

So in this approach to reconstructing the process of language production we must begin with the most difficult step first: identifying these most abstract levels of what can be called the »infralinguistic« hierarchy. The questions »What is a concept before it is expressed in words and phrases?« and »What is a proposition or request before it is phrased as a sentence?« must be given serious attention as linguistic issues.

Let's begin by considering a simple declarative sentence produced with the intention of describing some state of affairs. It may have a social context, which directs and constrains the kind of information that will best fit, such as being produced in response to a request or expectation. This will play a role in promoting one's change in arousal to speak and in eliciting certain memories or shifts of attention to relevant events. The social-pragmatic context includes a shift to a specific mode of communicating as well—e.g. providing or seeking information—and may consequently involve activating habits associated with this social role. This first stage is thus a social and pragmatic orientation stage that creates both a specific communicative frame and an arousal to act within it. Even merely interpreting someone else's speech requires establishing such a communicative framing of activity along with attention focused on certain expected general content. It is what amounts to the act before it is initiated, the content before it is developed or fully interpreted, the perceptual experience that is anticipated. It is a focused readiness and expectation with respect to social interaction.

Within this framing of social-communicative arousal what might be described as the »mood« of the speech or interpretive-act is differentiated. This forms the minimally differentiated space of options from which further differentiation of content and expression

can proceed. But the neural trace that constitutes this extrinsic framing does not get »passed on« to some subsequent brain structure for processing (as might be imagined for a component assembly process). Rather this »mood« needs to be maintained in parallel throughout the sentence generation or interpretation processes, and is updated only if there is a shift in communicative intent or a challenge to expectations. Maintaining this continuity requires a distinct neural substrate specialized for maintaining social orientation and arousal, and for monitoring conditions that would require a shift from this state. In contrast, the differentiation of this communicative orientation into distinct linguistic details must take place in other linked (yoked?) neural substrates.

»Languaging« in the brain

So neurologically we should not expect to find that the areas of the brain associated with the undifferentiated phases of language behavior are specifically associated with speech production or comprehension *per se*. The arousal process almost certainly involves limbic structures and adjacent peri-limbic cortical regions, as well as deeper brain structures associated with social arousal. Cortically, this probably includes the anterior cingulate cortex, which mediates the arousal and monitoring process, and other midline »background« attentional and motivational systems. These earliest phases are also comparatively slow-changing, maintaining a constant orientation. This stability may need to persist long enough for many sentences to be differentiated within a single generalized communicative mood. Later phases will therefore correspond with the generation of many temporally shorter and more fleeting aspects of speech production or analysis.

Damage affecting the brain regions associated with this arousal and monitoring of communication produces deficits that are seldom described in terms of aphasia, since word-choice, grammar, and phonetic decisions are unaffected. But more global disturbances of language are typical. Most notably, damage to midline frontal regions, including anterior cingulate cortex and supplementary motor area (especially bilaterally) is known to produce akinetic mutism. This has often been described as an inability to generate sufficient arousal-to-act though it can suddenly and transiently abate under high

arousal conditions. *In vivo* imagery has shown that differentially elevated anterior cingulate activity is also associated with many language generation tasks, even when motor speech functions are controlled for (e.g. see Deacon 1997).

It is notable that midline frontal regions are also the only cerebral cortical regions from which primate vocalizations have been elicited by stimulation, and are also associated with laughter in humans. In both cases there is evidence that the role of these dorsal midline cortical areas is inhibitory and that the vocalizations are produced with release of their inhibitory control.

Although speech cannot be elicited by cortical stimulation in humans (only blocked or modified), there have been reports of expletives being elicited by stimulation of limbic structures in human patients and such automatic arousal-correlated word production is often all that is spared in cases of severe global aphasia with massive damage to left peri-sylvian areas.

Within this mood frame the first specific orientation and expectations of the semiotic process are next generated within adjacent cortical areas. These include the intended goal of the communication and the selection of major categorical orientations relevant to this context. This is a phase of neural processing in which specific sensori-motor orientations relevant to the communication become more specified and need to be sustained in the face of competing and interfering alternatives.

These processes appear to involve sub-regions of prefrontal, parietal, and middle temporal cortex. These areas of cortex are mostly polymodal, judging from their primate homologues, and in classic (misleading) terminology were described as »association cortex«. Consequently, damage to parietal and middle temporal areas tends to result in difficulties of maintaining attentional focus and distinguishing distinct objects of interest, respectively, especially when multiple modalities of discrimination are involved. Damage to lateral prefrontal areas disturbs the ability to manage multiple competing sensori-motor attentional options, irrespective of salience, recency, or immediate reward contingencies. Prefrontal functions are sometimes referred to as »working memory« because they involve the ability to hold many simultaneous competing predispositions in mind at once so that they can be assessed with respect to one another. *In vivo* imagery studies consistently show differential activation of the left ventral prefrontal region (anterior to what is more commonly defined as Broca's area)

during word association and memory tasks that involve rapidly mediated decisions (see examples in Deacon 1997).

Language as semiosis

With respect to language differentiation processes I think this can be understood as the phase in which predication differentiates out of a more general mood of communicative arousal. In many ways, the structure of predication has much in common with specific sensorimotor orientation. The logical structure of predication, formally symbolized by a function F operating on one or more variables, in the form $F(x)$, or $F(x, y)$, etc., can be interpreted in semiotic terms as a symbolic relationship F indexed to (pointing to) some locus or loci (x, y) in the world, which may include loci within the physical communication process. In computational terms these comprise an operation and one or more 'slots' for pointing to the 'addresses' for the data to be operated on. In terms of semantic theory, F is a predicate (e.g. verb) and x and y are arguments to which it applies (e.g. subject and object). In neurology we may see an analogy to the trace of a sensory or behavioral association and an attentional orientation toward some locus or loci to which it currently applies (either external or internal to the organism).

Despite this parallel, this structure is not, however, due to intrinsic neurological organization, but rather to semiotic constraints that are relevant to both cognition and communication with symbols. By 'symbol' I am not referring to the sort of complex sign vehicles that constitute, for example, artistic, sacred, or mythical processes, but merely the sort of referential relationship that is exemplified by the words of a language. The relevant issue is that even this most basic form of symbolic reference is mediated by a system of symbol-symbol relationships. In this respect symbols effectively refer to other symbols. This is well illustrated by the organization of a dictionary or thesaurus. This is why the utterance of a lone noun or verb almost never constitutes a completed act of communication, but merely invokes associated symbols as possibly relevant. Standing alone it is a fragment, lacking a necessary functional component that if present could point outside the symbolic web.

But notice that when coupled with a pointing finger or uttered in a context where a specific object or state of affairs is obviously salient

to the message recipient, this missing role can be filled. The coupling must be immediate, however, since the very basis of indexicality is connectedness in space, time, or expectation with what is indicated. What this tells us is that the missing linguistic unit, now supplied by the pointing act, would have played an indexical role. Because of this system-internal web of relationships each symbolic function requires an associated indexical operation (as a bound index) in order to point outside this system to objects of reference.

This suggests that a complete symbolic communication, so to speak, consists of at least one semiotic unit playing a symbolic role and another playing an indexical role. In terms of the $F(x, y)$ formalism, F is the symbolic operation and x and y serve as its bound indices. Even though these variables can be filled with other symbolic operations, these too must be individually indexed or reference fails. And indeed, this indexical function requires an immediate proximate coupling between the unit playing the symbolic role and the unit(s) playing the indexical role(s). If this coupling is broken or ambiguous reference will likely fail.

Are these constraints difficult to learn? Actually, they are probably acquired long before language in infancy. Uniquely in human development there is a period during the first year and a half of life where the infant communicates with its caretakers largely by indexical means, and in particular by pointing. The success or failure to achieve a desired result by enlisting one's caretaker's actions is dependent on disambiguating indexical communication. So by the time the infant begins to do this with words combined with gestures and eventually with words alone, there has already been extensive experience with the demands of this process. The semiotic infrastructure on which linguistic communication will be built is already in place. The transition is not discontinuous from non-linguistic to linguistic, but rather a case of further differentiating communication tools already well developed. The infant already »knows« the logic of these »rules« of indexicality before learning how to implement them with strings of words, not because they are innate knowledge but because they are implicit in the experience of communicating in general.

To the extent that prefrontal, parietal, and middle temporal systems play critical roles in maintaining and selecting among specific orientation and action options, they are also relevant to parallel operations on the virtual objects of symbolic reference as well. For example, the traces of object-attribute associations are likely generated

in posterior (temporal- parietal-occipital and polymodal cortex), while the traces of orientational dispositions with respect to them—and thus also the neural correlates of indexical operations—are likely generated and maintained in lateral prefrontal cortical areas.

A classic descriptor of a global deficit common to patients with damage to one or more of these prefrontal and parietal cortex is the »loss of abstract attitude« (see discussion in Lecours et al. 1983). Though difficult to characterize, it generally refers to the overly literal way these patients approach language and behavior in general. This can be understood as an impairment of the ability to inhibit prepotent orientation to concrete sensori-motor associations compared to those that are more indirect and symbolically mediated.

Also in classic aphasia terminology the so-called transcortical aphasias offer relevant correlates of damage involving these still early stages of language differentiation. These leave perception, repetition, and production of speech intact but diminish control of these higher order content orientations. Damage to parietal and middle temporal regions can produce confusions of associative analysis (transcortical sensory aphasia, and semantic aphasia) in which spurious interpretive substitutions may arise despite minimal nonsense paraphasia (non-word substitutions). For example, there may be word substitutions that reflect wildly divergent and incompatible categories, though they represent real words of the language and may even be appropriately inflected. Damage to lateral prefrontal areas; this can involve a weakened control of speech by predication with respect to merely reactionary or echolalic speech (transcortical motor aphasia).³

Historically, these aphasic syndromes have come under critical scrutiny and have been considered by some to be of questionable validity as discrete syndromes or specific language disorders. This ambiguity reflects the semiotically more general character of this early phase of processing before word choice, syntax, and phonological realization are relevant. In this sense these kinds of deficits are often described in terms of ideational difficulties rather than linguistic impairments. Persistent transcortical motor aphasia also appears to require damage to underlying white matter and basal ganglia structures, but as we will see, this is a feature that appears common to all frontal language deficits. This is often considered an argument

³ For a classic review of the history of aphasiology, see the comprehensive review by Roch Lecours et al. 1983.

against identifying frontal cortical structures with language processing per se, but this is an over-reaction. The relatively greater importance of deep forebrain nuclei to frontal systems almost certainly reflects the far greater elaboration of cortical-basal-ganglia-thalamic-cortical circuits in frontal as compared to posterior cortex, and not a reduced importance of anterior cortical areas to language processing.

This predication-orientation phase of differentiation establishes the frame in which the first distinctively linguistic differentiation functions emerge, and for which there is general agreement that correlated impairments constitute true aphasia. These involve superior temporal regions, including Wernicke's region, and the ventral frontal and prefrontal regions including Broca's region.⁴ In this phase of language differentiation the distinctions between frontal and posterior functions become more divergent and their functional interdependence decreases. This is in part a function of the decreased time domain for these functions to be performed, which limits the possibilities for complex interactions. Functional integration and coordination have however already been established by earlier phases that are more globally coupled.

The temporal regions adjacent to Heschl's gyrus (the site of the primary cortical auditory map) that comprise Wernicke's region are extensively interconnected with middle temporal and inferior parietal polymodal areas. The predication-orientation established in these polymodal systems (which also activates parallel differentiation of more specific sensory imagery in modality specific areas to which they are also connected) superimposes corresponding constraints and biases on these more auditory specialized regions. This facilitates the activation of relevant classes of phonological traces for words (in anticipation of producing them or of the high probability of hearing them). Many cycles of word elicitation may occur within the frame of a single predication-orientation. This frame must also impose agreement constraints on the subsequent elicitation of words. Damage to cortical areas at this level of processing effectively interrupts this constraining and facilitation of word-sound expectation by predication relationships. Thus Wernicke's aphasia typically are not confused about their intentions to communicate and may understand much of the intention of others trying to communicate with them,

⁴ I prefer the designation »region« to the more common »area« in order to avoid the implication of anatomical boundedness and functional homogeneity.

but they tend to make both production and comprehension errors at or just below the word-formation level. While content words (carrying much of the load of predication) are inaccurately differentiated in these patients, resulting in frequent nonsense words and word substitutions that are »in-category« but wrong in detail (e.g. »chair« for »bed«), function words (e.g. »why« »that« »but« »it«) tend to be retained and used fluently in appropriately structured phrase and sentence frames despite the paraphasias (e.g. word and sound substitutions). We can describe this as a failure to differentiate the primary linguistic tokens despite maintenance of both the predicate frame and the indexical supports.

Before analyzing these temporal functions further, consider the complementary role of frontal cortical systems associated with Broca's region. The functions of this layer of processing take place within the predication-orientation frame established by prefrontal and polymodal posterior systems. The prefrontal contribution (as distinct from the parietal-temporal contribution) to establishing this predication frame is primarily with regard to the orientation or indexical component of this frame; i.e. the orienting with respect to different conditions and objects of attention.

In general this aspect of the predication frame can be described as a schema for conditionally shifting orientation and redirecting attention. This is a fundamental feature of most complex learned behaviors in general. The subsequent phase of processing, characteristic of the cortical regions associated with Broca's region, involves the differentiation of the elicitation and sequencing schemas regulating word production. This is accomplished by using the orienting constraints of the indexical frame to regulate predispositions activated by phonological cues from posterior processes and high frequency word-association habits keyed by prior word production. But this is one stage less differentiated than the motor production of the content words themselves, and can probably best be envisioned as generating the ordered slots into which these words will be inserted. But the indexical orientations of the previous level differentiate into at least one form of overt motor output at this level: the production of function words, pronouns, and articles that serve as the markers for these syntactic slots and phrase transitions. These syntactic markers are the overt trace of an orienting and pointing schema that has differentiated in parallel with the posterior differentiation of words and their phonology.

These classic language areas thus represent the first level in which there is differentiation of linguistic units per se, but this interface should not be construed to be discontinuous from earlier stages. The various »component« linguistic units derive their referential power and combinatorial constraints from these many levels of pre-linguistic processes within which they are nested. These lexical units may appear to self-organize as though they possessed intrinsic structure, but this apparent structure is rather a reflection of the fact that they are merely surface markers for the end stage of a cognitive differentiation process. Well before these specific lexical units are crystallized into aural-vocal traces, their combinatorial options have been constrained by prior differentiation processes involving larger less differentiated semiotic frames.

Broca's aphasia is typically identified with labored production of words and non-fluent speech, despite relatively spared vocabulary and comprehension. The non-fluency is also in part due to the absence of function words and grammatical markers. Although difficult production may indicate adjacent motor area damage, it may also simply be the result of the absence of sufficient cuing by syntactic markers whose function is to mark and point to the space where symbolic operations are required.

The subsequent, most differentiated levels of language processing — phonological analysis and vocal articulation of sentences — constitute a surface map on which linguistic tokens mark the terminal differentiation of these many prior levels of the differentiation processes occurring in parallel in anterior and posterior cortical regions. In well-organized speech, the concatenated linguistic tokens that result provide sufficient cues concerning this hidden differentiation process to allow listeners to independently recapitulate these processes. So although the interpretation of a spoken or read sentence appears to require that a reverse process of merging and combining words via syntax into meaningful strings must take place, this is misleading. In the course of normal communication, sentence interpretation is embedded in a rich matrix of interpretive expectations. So there are already present extensive expectations and predictions concerning new information that is yet to be provided. These partially pre-differentiated sentence frames that pre-bias and potentiate later-stage processes can thus be rapidly differentiated with minimal effort.

Counter-current information processing

So how does this interaction between phases of sentence differentiation produce anything? What exactly is provided by the adjacent linked cortical areas, each to the other reciprocally, in this interaction? Or to put this in anatomical terms, since adjacent cortical areas in these nested processing hierarchies share reciprocal connections, what sorts of signals are being sent in each direction? Here again it is important to remember that this is a temporally nested set of differentiation processes, not a string of steps. So that terms like »early« or »late« stage do not refer to any linear temporal sequence, but rather stages that must be established with a certain differential priority. Each less differentiated frame must persist long enough for all later differentiation stages to complete. So a major feature must be that while cortex of an earlier stage is providing rather stable information to a later stage, in the reverse direction rather more rapidly changing more differentiated information is being provided.

The reciprocal connections linking adjacent cortical areas are not symmetrical in the laminar patterning of neuronal cell bodies and connections.⁵ This asymmetry reflects the differences in the type of information being exchanged in each direction. This pattern of cortico-cortical connections is depicted in simplified and somewhat idealized drawings in Figure 1. Interestingly this pattern is roughly paralleled in both frontal and posterior cortical areas, despite the fact that motor areas are located in frontal cortex and sensory areas are located posterior cortex.

In the direction of increasing differentiation (from peri-limbic toward more peripherally specialized areas) pyramidal cells in deep layers (layer v) tend to project their axons into the most superficial layer (layer i) of the next area in the sequence and to some extent also to layer vi. The patterning of their termination in the target cortex tends to fan out laterally to contact the apical dendrites of many pyramidal neurons. This termination pattern is similar to that of thalamo-cortical inputs from midline limbic related thalamic nuclei and intralaminar nuclei. These thalamic nuclei projections tend to terminate in patterns that span multiple adjacent distinct cortical areas.

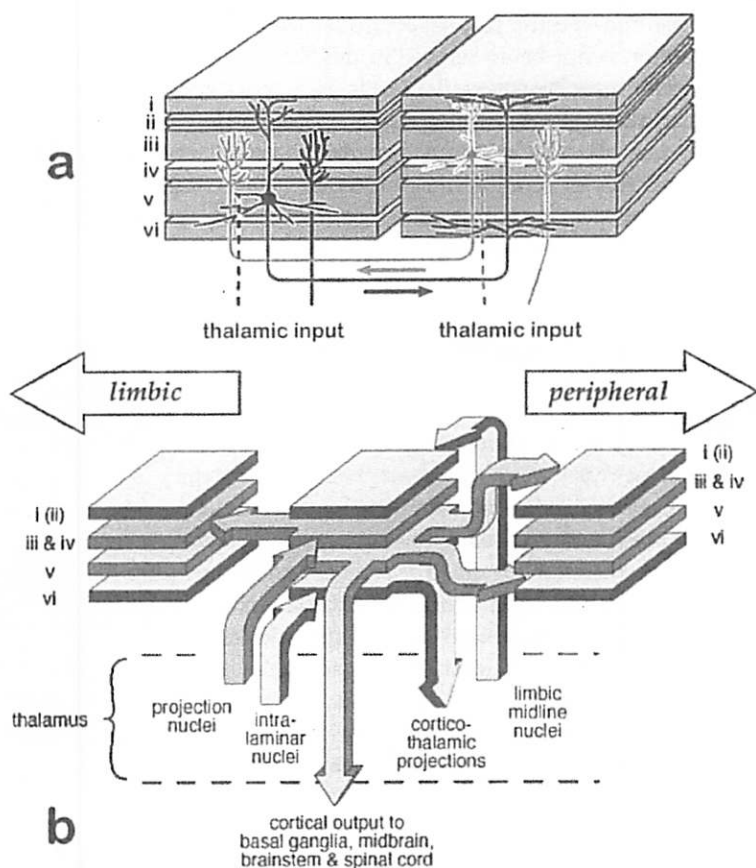
⁵ An initial report describing the cortico-cortical laminar connectivity patterns for areas of monkey cortex that are homologous with human Broca's and Wernicke's regions was presented in Deacon (1992) and more general discussion of these patterns in other cortical areas is provided in Deacon (1989).

This non-specific pattern suggests that topographically specific information is not being relayed in this direction. So that in the differentiation process successive levels each must generate their content intrinsically, not »adding on« to complex details relayed from previous levels. The prior level of development merely constrains and biases this differentiation process in the succeeding level, probably with respect to temporally organized but spatially distributed activity simultaneously influencing background thresholds of whole suites of neurons in the target area. Pyramidal neurons from layer v are also the principal output neurons from cortex, projecting to subcortical sites, such as basal ganglia, midbrain, cerebellum, or spinal cord, depending on the cortical region of origin. So the information being supplied to further differentiate activity in the succeeding level is effectively a reflection of the fully differentiated output of the source area.

In the reverse direction (originating from more peripherally specialized areas and projecting to more generalized cortical areas) the connection patterns are quite different. The output pyramidal neurons are located in layer iii and project their axons to the more generalized cortical area of an earlier differentiation stage in columnar patterns primarily terminating in layers iv and iii. This termination pattern is also characteristic of thalamo-cortical projections from so-called principal projection nuclei of the thalamus, which relay specific information from peripheral subcortical systems. Layer iii pyramidal neurons do not tend to target subcortical sites.

The columnar termination pattern is also topographic (largely maintaining map-like correspondence between areas). This suggests that these connections are providing specific information about the spatio-temporal details of the activity of the source area. And since it corresponds in organization with principal thalamic nuclear inputs it likely maintains this organization from area to area.

This reciprocal stage-by-stage pattern of connections links limbic-arousal systems at one extreme to peripherally specialized areas at the other. This pattern is exhibited in both anterior and posterior cortical regions within each separate sensory or motor modality. Elsewhere (Deacon, 1989) I have argued that this pattern is reminiscent of counter-current diffusion processes found in other physiological systems. These include most notably fish gills and kidneys, among innumerable other systems where extremely efficient diffusion is required. This is because actively moving fluids in opposite directions

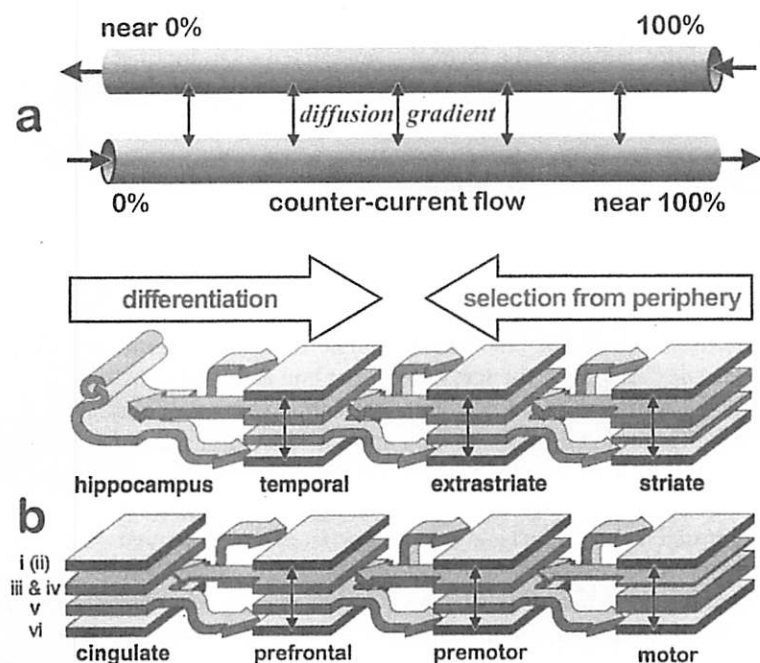


on either side of a selectively permeable interface can drive the diffusion of heat or chemical solute far past equilibrium. In the case of fish gills, for example, oxygenated water flows front to back while deoxygenated blood flows back to front. In this way deoxygenated blood picks up oxygen as it moves forward, continually meeting water, with slightly more oxygenated areas at each increment. The result is that the concentration of oxygen in blood can be pushed close to its concentration in water as it enters the gills (see Figure 2).

The analogue for cerebral cortex is that opposite ends of these pathways are receiving inputs of information with inverse properties. Cortical areas adjacent to limbic structures are receiving information

about generalized arousal states and physiological states. These receive information in the form of a small fixed set of input states about relatively undifferentiated drives and general physiological conditions. This information is lacking in topographic detail and is slow to change from state to state. In contrast, cortical areas that are specialized to receive more or less direct sensory information from peripheral sensors are constantly receiving highly differentiated signals about difficult to predict external conditions. This information is often topographically complex and rapidly changing. Similarly, with respect to the differentiation of complex behaviors, quite generalized intentions to act in response to simple drive states contributed by anterior peri-limbic cortices entering at one end of the stream is contrasted with information about just completed specific movements and differentiated motor coordination information relayed from the cerebellum. One way to think of their relationship is that information developing along a limbic-to-specialized pathway is progressively differentiated by interacting with information being relayed along the inverse-parallel specialized-to-limbic pathway. Indeed, precisely this stepwise interchange of attributes at each stage is what is required to differentiate vague mnemonic and intentional processes to the point where they produce the attentional focus and behavioral response patterns that are optimally fit to current conditions. In other words, this interaction is the necessary means by which vague internal states come to be matched in detail with the demands of a highly variable and complex external world in real time.

Unlike many naturally evolved fluid counter-current processes the cerebral cortical variant is a step-wise, not continuous, process. Analogous step-wise counter-current systems have been developed, however, in such engineering applications as desalination and extreme cooling systems (e.g. nuclear reactors and ultra low temperature applications). In the nervous system this might help explain some of the confusing effects of cortical damage, since damage to some intermediate stage will interrupt the access of motivational processes to peripheral details and peripheral details will poorly update motivational systems. This does not mean that no information is provided from these sources, since every cortical area receives thalamic input relaying both peripheral and limbic sources. But these are themselves differentially pre-processed to an appropriate level of detail by subcortical systems. For example, although the peripherally specialized »primary« visual cortex receives information from the



thalamus (LGN) which relays information from retinal ganglion cells, visual areas further along the sequence toward limbic areas receive signals that are relayed through the thalamus (pulvinar) from superior colliculus and pretectal midbrain structures that relatively indirectly convey pre-processed retinal information. So interrupting this counter-current process essentially affects a distinct level of differentiation and adaptation.

A counter-current process analysis may also provide new insights for understanding other counterintuitive neurological processes and dysfunctions. Recall that both sensory and motor counter-current connections are organized in the same way. So one might ask: »How is sensory processing like motor processing and vice versa?« Clearly, both sensory attentional focus and behavioral precision depend on differentiation. One way to think of the differentiation process in terms of sensory experience is to consider perception as a sort of peripherally constrained hallucination process. Recall that the same neurons that give rise to the limbic-to-peripheral pathway are also the final output neurons of each cortical area. We can thus spec-

ulate that sensory experience is the result of peripheral information »sculpting« this internally (limbic) originated source of »self« information. This way of understanding perception may thus provide insight about both the nature of normal hallucination in dreams—where there is an absence of peripheral input to sculpt the effects of subcortical excitations of intrinsic patterns—and dysfunctional hallucination, as in schizophrenia—where limbic originating signals may be hyperactive and irregular, thus overwhelming the peripherally originating information.

Counter-current dynamical organization also provides the basis for rapid change on the fly. In counter-current fluid exchange systems, for example, a change in the parameters of either input (e.g. oxygen content in either blood or water entering fish gills) is spontaneously compensated for without any oversight because of differentials all along the pathway. Neurologically this helps to explain what appears to be the real-time facility of our adaptation to rapidly changing highly variable peripheral inputs. Counter-current organization allows all levels of differentiation to adapt in parallel. But this doesn't mean that the adaptive work-load is always equivalently distributed in this array. Although we often tend to portray perceptions and actions only in terms of fully differentiated states, in fact, this tends to ignore what is probably the greater fraction of mental activity. Moreover, almost certainly what we are conscious of at any moment in time may involve a different level of this differentiation process. This is likely determined by the amount of neurological work being done at whatever level of this process is impacted with the greatest mismatch between the information converging at that point from these two streams. This predicts that fMRI should be able to track such changes of the locus of elevated neurological work to resolve such mismatches (= focus of consciousness) as it occurs in areas at corresponding levels of differentiation.

Implications and conclusions

In summary, I have sketched a conception of cortical functions in general and language functions in particular that suggest that they can only be understood in process terms. In this view, these functions are conceived as neurologically emergent consequences of dynamical interaction processes where final organization is a product of the

complex synergy that develops between multiple systems and nested levels of progressive differentiation. Moreover, language processing is described in a framework that shows it to develop in a way that is entirely homologous to sensory and motor processing in general. By explaining cortical processing in counter-current terms we also provide a way to conceptualize how the language differentiation process is accomplished. In this view, language comprehension and production begins in a relatively undifferentiated state that is not distinct from sensori-motor processes, neither in its neurological locus nor in the neural dynamical process itself. At these first few relatively undifferentiated stages, language cognition is coextensive with other sensori-motor processes. Indeed, this helps explain why the phenomenology of sentence comprehension and production is typically imagistic (in a multimodal sense) and not of the form of words or lexical categories. These linguistic phenomena are late stage correlates of the differentiation process.

Each stage of differentiation involves correlated processing in corresponding levels of anterior (intention-action) and posterior (attention-sensory) cortical systems. These parallel differentiation processes are maintained in synchrony by reciprocal connections linking parallel levels of frontal and posterior systems in the early differentiation stages. Each relatively less differentiated stage of processing establishes constraints and biases that are the ground from which the succeeding stages of differentiation begin, and within which they are »enveloped« and develop. Subsequent phases involve both more specific and more rapidly differentiating and shifting processes, so that often a number of higher-order developments will occur under the relatively more persistent state of differentiation of the prior phase. This produces a multilevel nesting of more specific phases of differentiation within less differentiated frames, embedding shorter within longer time domains of operation. The processing of the exceedingly rapid phonological transitions of speech perception and the production of the rapid and subtle motor transitions of speech articulation are thus highly constrained by this nesting in a way that minimizes both the diversity of alternatives that must be anticipated with respect to the demands of maintaining large scale functional integration. Interestingly, the anterior and posterior cortical areas involved in the final few stages of differentiation are not connected with one another, and so tend to operate autonomously, constrained to roughly simultaneous development by the linked previous stages of develop-

ment. These latter processes are also relatively rapid and automatically completed.

So how does this translate into terms that linguistics might understand? Most current linguistic paradigms analyze grammar and syntax at one level—the level of terminally differentiated linguistic structures—and derive rules and principles for handling all possible relations among these units. The consequence of this approach is that complex instructional architecture and massive processing capacity must be postulated to handle all the presumptive operations. This has further fueled the expectation that a language »processor« must be present in the brain and that only special language mutations of the genome could have made this possible. From a neural differentiation perspective, however, language production and comprehension is envisioned to develop through nested levels of operations in which only the final stages involve the familiar words and syntax of linguistic analysis. The early stage levels are not explicitly represented as distinct linguistic units and largely involve neural systems that are strongly homologous in function to their nonhuman primate counterparts. Only the very last levels of functional differentiation correspond to linguistic compositional features. This treats the composite structure of a phrase or sentence as a post hoc re-presentation of the entire differentiation hierarchy, not a recapitulation of it. The kind of question we must ask of our linguistic theory, then, is something like »What kind of semiotic unit—not linguistic unit—is a sentence or phrase?« This is a question of referential function and communicative pragmatics more generally. It suggests that a more sophisticated embedding of linguistic theory in semiotic theory is necessary in order for progress to be made in bridging the gap between linguistics and neurological processes.

In many respects, this analysis provides an understanding of language and thought that is more consistent with phenomenal experience than that provided by formal linguistic analysis. Indeed, linguists often remark that the processes underlying the application of the rules of grammar and syntax comprise a vast unconscious automatic and inaccessible algorithmic mechanism, since we don't experience ourselves applying rules to our utterances or judging grammaticality by noticing rule violation. But understanding language as a variation on the emergent dynamics of mental processes in general, in which quite global and familiar semiotic constraints must be re-

spected, obviates the need to explain why we don't experience it as rule-governed construction and analysis.

Unfortunately, the study of language is not made easier by shifting to an emergence paradigm. Indeed, it begs new questions, demands new methodologies, and requires a far more interdisciplinary approach than before. Moreover, this is not yet a theory, but merely a first speculative suggestion of another way of tackling this mystery. It is lacking in the linguistic details and the descriptive power that is offered by even the simplest formal generative approaches. But the comparison is not fair. Formal theories have a post hoc tautological character—reverse-engineered by millions of person-hours scouring linguistic data. Their derivational logic is thus inevitably more elegant, their predictions are more accurate, and their domain of application is more comprehensive, so long as neural processing and evolvability considerations are not at issue. But ultimately these »organic« considerations must trump predictive adequacy and formal elegance.

The formal design metaphor has diverted scientific attention and research resources from the implications of these biological considerations for a half a century, but refocusing attention on these factors does not mean turning our backs on formal linguistics, only abandoning the search for its literal counterparts in genes and the neural processes that generate language communication.

Paradoxically, the successes of formal generative linguistic theories may have impeded progress toward understanding language neurology and language evolution, even while they have provided such remarkably sophisticated tools for the description of language structures. This is because the apparently remarkable adequacy of formal models to account for the complexities of language structure have contributed to an unwarranted assumption that language can be studied as though its structure was designed by a kind of instruction logic, as are other formal systems. Yet despite compelling evidence that language has a formal-structure consistent with top-down rule-governed systems, its status as an evolved biological phenomenon raises serious questions about the plausibility of extrapolating from this descriptive analysis to a theory of language processing. I imagine that future linguists will look back upon this period in the history of the science and wonder why we didn't see the obvious utility in reserving engineering logic for the study of machines, formal logic for the study of computation, and organic logic for the study of brains and language.

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