Bruce Nevin

Independent researcher
bruce.nevin@gmail.com.

Freeing linguistics from computationalism

Generative linguistics developed collaboratively with Cognitive linguistics, organized around an algorithmic conception of grammar and the now commonplace computer metaphor of cognitive process. Harris's formal methods and results are incomprehensible in those terms. Integrating his theory of language and information with the third grand theory of psychology, Perceptual Control Theory, provides a way forward for Sapir's (and Harris's) interest in the common basis of language, culture, and personality.

Key words: Formal linguistics, control theory, semantics, embodied cognition, language acquisition

Zellig Harris's discoveries about language and information spring from his radical re-conception of the foundations of a science of language, grounding the methodology of linguistics in the mathematics of set theory and linear algebra. By his own account,[1] the transformational character of language was evident at the outset of his career. He also saw from the beginning the need for unusual care in using language to talk about language, and the limitations that the nature of language imposes upon the methodology of a science of language. Thereafter, the methodology led and he followed, yielding a long series of scientific reports spanning more than 50 years. "What was remarkable was the consistency of the methods and how each stage resulted from solving the problems of the preceding stage or observing further regularities."[2]

The field is far from exhausted. Responsibility to the data of language without superposition of a priori formalisms will continue to yield further discoveries to those who are willing to do the work. It will also be possible in future to work out Sapir's (and Harris's) deep and abiding interest in correlations between the results of formal linguistics and studies of personality and culture as these other fields also mature and outgrow their reliance upon inappropriate a priori models. The second part of this paper indicates how this might be done.

We begin with a review of the radical differences between Harris's insights and the leading ideas of the school of Generative linguistics originated by Noam Chomsky. This is important because the former cannot be understood in terms of the latter, which have come to dominate the field (though that dominance is now weakening).

How radical these differences are, and how pervasive, has been difficult to realize because of the persistent illusion that in their respective usage of words like "transformation" and even "language" they were talking about the same things. Their assumptions, methods, theories, and modes of

1 (Harris, 1990, 2000). According to Leigh Lisker (p.c.), he was already teaching transformations and discourse analysis when he joined his class in 1939. This work, including e.g. Lowie's Hidatsa and Emeneau's Koto, was not published until much later.
2 Naomi Sager (p.c.). See also her introduction in (Sager & Nhàn, 2002).

presentation are incommensurate. For Chomsky, language begins as a formalism from which the data of speaking may be projected. For Harris, a formalization is no more than a convenience for computational purposes, and "It is important to recognize that language is a system of units and their relations, because that often serves as our criterion of what material is language and what is not" (Harris, 1940:223). Harris's formal linguistics discloses the form of language and the correlation of form with information, but the system of reductions in Operator Grammar has never been formalized.[3] Because of this incommensurability, and perhaps for other reasons, the influence of Harris's results has so far been limited, not as a reflection of their scientific merit, but rather through other aspects of science as a social phenomenon.

A basic principle for Harris is that there is no a priori metalanguage, external to language, with which to characterize language. He did not use those terms at the beginning. Bloomfield, Sapir, and Boas had rejected the metalinguistic assumptions of traditional grammarians, who relied on historical models and the conventions of Greek and Latin grammar, and who 'explained' syntax, language change, and other language phenomena as no more than the outward expression of inward mentation. Harris was more explicit and more careful in bringing out the reasons for this rejection of 'mentalism' (as then defined), and he carried it farther. In his review of Gray (Harris, 1940) and in his review of Trubetzkoy (Harris, 1941), he shows why it is essential to avoid reifying a priori explanatory principles, for

> correlations between the occurrence of one form and that of other forms yield the whole of linguistic structure. The fact that these correlations may be grouped into certain patterned regularities is of great interest for psychology; but to the pattern itself need not be attributed a metaphysical reality in linguistics. [...] The danger of using such undefined and intuitive criteria as pattern, symbol, and logical a prioris, is that linguistics is precisely the one empirical field which may enable us to derive definitions of these intuitive fundamental relationships out of correlations of observable phenomena. (Harris, 1940:228)

Of like effect, and sometimes actually indistinguishable from a priori presupposition, is the reification of ungrounded generalizations, and "the need for withholding general opinions which are not concluded from sufficient evidence" (Harris, 1942:240).[4] The continued pertinence of these cautions will be evident below.

After all such a priori presuppositions and imaginings have been stripped away, we are left with the fundamental data of language—language users' judgements of contrast and repetition (Harris, 1951[1946]:25-26)—and the distributional facts—what can occur next to what. Any other considerations rely upon, or originate in, the very structure of language which we aim to describe. Of course in practice external resources inform the intuitions and hunches that guide us in wrestling with the data of a language, but our conclusions, however reached, must be reconciled with and justified by distributional criteria.

> These procedures are not a plan for obtaining data or for field work. [...] These procedures also do not constitute a necessary laboratory schedule in the sense that each procedure should be completed before the next is entered upon. […] The chief usefulness of the procedures … is … as a reminder in the course of the original research, and as a form for checking or

3 It is a difficult problem (Stephen B. Johnson, p.c.). Something like Gross's Lexicon-Grammar may be possible.

4 This was in a critique of Hoijer's contribution to the Sapir memorial volume.

presenting the results, where it may be desirable to make sure that all the information called for in these procedures has been validly obtained. (Harris, 1951[1946]:1–2)

Distributional analysis is an investigation of the constraints upon the free combinability of elements, and it adjusts their definitions so that the elements (members of sets so defined) are as freely combinable as possible. This has the effect of moving the constraints into the definitions. Thus, if two elements are in complementary distribution, they are redefined as alternant forms of one element—the same phoneme, or the the same suppletive morpheme. Harris referred to this phase of work as descriptive linguistics. The same principles in what he called 'extended morphophonemics' later yielded transformations, Operator Grammar, and sublanguage grammar.

Harris was very clear about the distinction between the structure of language and alternative modes of representing its structure. This follows from the avoidance of reification. A clear example is seen in the comparison of grammar styles called ‘structural restatements (Harris, 1947a,b) and in the much later statement introducing (Harris, 1965). The different types of syntactic analysis are tools of analysis which disclose different aspects of language structure as a reflex of their respective criteria. Bloomfieldian immediate constituent (IC) analysis depends upon informant judgements of how a whole breaks into parts, yielding a hierarchy of phrase-classes. The method of (Harris, 1946) approaches constituent structure from the other end, as successive expansions of words; Sager’s computer implementation as string grammar a decade or more later was restated as string analysis (Harris, 1962) and Joshi's adjunction grammars. Transformational analysis shows how the ‘expansions’ are reductions of sentences.

It was still relatively early in the development of abstract algebra when Harris began applying its principles to the sets of elements defined in descriptive linguistics. This is the origin of the terms *transformation*, *kernel*, *inverse*, *trace*, etc. In abstract algebra *transformation* is one term for a structure-preserving function that maps from subset to subset. He did not begin publishing this work on algebraic mappings from subset to subset within the set of sentences until after (Harris, 1951[1946]).

When Noam Chomsky attended Harris's classes, he sat on the periphery, contributing little.[5] Harris encouraged him to take courses in mathematics and logic. He took every course that the logician Richard Martin offered. Another important influence was Nelson Goodman, who later joined with Harris in sponsoring Chomsky to a graduate fellowship at Harvard. From these came a fascination with the syntax and semantics of formal systems in mathematical logic, and perhaps a conviction that behind appearances are simpler realities of an abstract nature. It may be relevant that Goodman’s signature work in merology (and meronomy) rejects set theory and in principle is consistent with immediate constituent analysis grounded in intuitive apprehensions of part-whole relations.

Chomsky’s divergence from Harris’s work grew from these influences. String rewriting systems introduced by Axel Thue in 1914 and further developed and refined by Emil Post and others in the 1940s were instrumental in specifying the syntax of logical systems and in the quest for logical foundations of mathematics. Chomsky applied these tools of the syntax of logical systems to formalize Bloomfieldian IC analysis.[6] Whereas Bloomfield’s methodology analytically records a native speaker’s intuition of how a sentence (or a sentence constituent) naturally comprises two or three parts

5 Naomi Sager (p.c.).

6 Had he formalized the methods of (Harris, 1946), he'd have had X-bar theory from the outset.

(constituents), Chomsky's rewrite rules synthetically define abstract phrase-classes which are expected (or hoped) to correspond to the products of IC analysis. Thus for the first time a tool of analysis—or, rather, the representation resulting from such analysis—was formalized by a formal grammar, which came to be called phrase-structure grammar (PSG).

Rudolph Carnap had developed the syntax of logic in terms of *rules of formation* (which specify simple propositions) and *rules of transformation*. Chomsky first applied this notion in his undergraduate honors thesis, later his 1951 Master's thesis, on the morphophonemics of Modern Hebrew (published with substantial revision in 1979), where for him 'transformation' meant simply a morphophonemic rule of the type in *Menomini Morphophonemics* (Bloomfield, 1939), described (with reference to Bloomfield's examples among others) in (Harris, 1951[1946]). Chomsky's innovation was to formalize this sort of rules after the manner of the string rewriting systems of Thue and Post.

A second important piece of context for all of this is the early development of computer science at the University of Pennsylvania. In 1946, the year Chomsky came to Harris as an undergraduate, ENIAC was announced at Penn as the first "giant electronic brain". The application of mathematical logic to the programming of computers was a very hot topic. The programmable computer was irresistibly attractive to theorists in a wide range of fields as a metaphor for the functioning of the human brain. It is the tacitly governing metaphor in Cognitive psychology to this day, where it is assumed that the brain is an information-processing device that receives inputs, performs logical operations on symbolic representations, and generates commands that produce behavior.[7]

In this atmosphere, it was inevitable that Chomsky would reinterpret the (Harris, 1951[1946]) checklists for methodological integrity as an algorithm for discovering the grammar of a language. In the 1975 Preface to *The logical structure of linguistic theory* (*LSLT*) and elsewhere Chomsky describes his attempts to formalize Harris's methods as discovery procedures, ignoring Harris's plain statement that they are "not a plan …[or] a necessary laboratory schedule" (quoted above). "Generative grammar is, more than it is anything else, a plea for the case that an insightful theory of language can be based on algorithmic explanation" (Goldsmith, 2004: 1). In my experience, a great deal of the appeal of Generative linguistics to students in the 1960s was in the flashiness of clever argumentation in preference to the hard and often tedious work of linguistic analysis, derided as 'taxonomic linguistics'.This demand for automation of linguistic analysis continues today, under the rubric of Universal Grammar.

In his doctoral dissertation—a concluding chapter excerpted from the long manuscript which became *LSLT*—Chomsky took from Harris the sentence-forms of transformational analysis and reinterpreted them as Carnapian rules of transformation operating upon the abstract phrase-markers produced by PSG. A sentence-form is a set of sentences represented by a sequence of form-class markers. Chomsky reinterpreted this as the sequence of terminal-symbols resulting from the operation of PSG rules. This is an exact parallel to the relation of abstraction that holds between PSG and IC analysis, with the same caveats. With PSG rules in the role of Carnap's *rules of formation* generating sentence-forms, Chomsky defined a new kind of operations that deform the pre-terminal structures generated by PSG rules, and called these tree-deforming operations *transformational rules*, analogous to Carnap's *rules of transformation*.

7 Under sway of the computer metaphor of mind, 'mentalism' has been redefined, making possible the absurd categorization of Harris as a logical positivist, even as a behaviorist.

It is rarely appreciated how radically different this conception is from Harris's transformations. Many years later Chomsky wrote "In *LSLT*, transformations are understood in a very different sense; it probably would have been preferable to select a different terminology instead of adapting Harris's in this rather different context" (Chomsky, 1975: 43). But PSG is not merely a different context for the same concept. Equivocation over the term 'transformation' has been an ongoing source of confusion. It is possible that the homonymy of the logical/Carnapian term and the algebraic/Harrisian term genuinely confused the youthful Chomsky, so that he realized the difficulty only years later in hindsight. One wonders if matters might have worked out differently had Harris chosen to borrow some other term from algebra, such as *morphism*, or even *map*, rather than *transformation*, with its fateful homonymity with Carnap's *rule of transformation*.

As mentioned above, Harris saw the importance of distinguishing between the character of language and the particular way that a tool of analysis represents those properties of language that it best discloses. It is equally important to distinguish such a representation from a formalization of it. It appears that Chomsky blurred or denied both distinctions. For him, the abstract formalism is the reality of language, reflected imperfectly in the data of speech and writing.

Chomsky has repeatedly written that no one paid any attention to what he was doing as a student or commented on what he wrote, except for Henry Hoenigswald. In the Preface to *LSLT*, however, he acknowledges "While working on LSLT I discussed all aspects of this material frequently and in great detail with Zellig Harris, whose influence is obvious throughout" (Chomsky, 1975: 4). This is confirmed by those who knew both during the 1940s and 1950s. It is little known that their student-teacher relationship was the continuation of a protective mentorship or big brother relationship beginning when Chomsky was perhaps eight years old, part of a long connection of the Harris and Chomsky families, including their political interests.[8] Chomsky's disavowal of Harris's influence (except in the Preface of *LSLT*) perhaps reflects a felt need to individuate from this family mesh.

In the early part of his career away from Penn, Chomsky was perceived as continuing and elaborating Harris's work, and Harris continued to seek commonality in the spirit of structural restatements. Those readers who were not up to working through the detailed demonstration presented by (Harris, 1957) assumed that the much simpler presentation in (Chomsky, 1957) was talking about the same thing.

To summarize, Harris identified constraints on combinability of elements, and worked to define elements with the least possible such constraints. This has the effect of moving constraints into the definitions of elements. The constraints that can be removed are notational artifacts; those that remain are those that constitute the structure of language. Every proposal must be tested for consistency within an entire broad-coverage account. Descriptive analysis, transformational analysis, discourse analysis, and sublanguage are all the same kind of work with different scope and scale. An algebraic representation enhances inspectability and comparison, but it has the status of abbreviations, a scientific notation for stating generalizations. It has no transcendent reality of its own.

Chomsky manipulated the rules of formal grammars and their abstract productions. These are by definition self-consistent, so there is no incentive to demonstrate broad coverage. Instead, the method is to look for examples and counterexamples to justify tweaks to rules and meta-rules (constraints on rules). Anything that has not been formalized, he calls 'vague'. Harrisian discourse analysis makes

8 Bruria Kaufmann, p.c., Naomi Sager, p.c., William Evan, p.c.

little sense—Chomsky (p.c.) thought Harris's purpose in doing it was to refute someone's political views. Sublanguage and linguistic information are incomprehensible.

External political and economic factors that have enabled the ascendency of TGG have been documented at length elsewhere (e.g. Hymes & Fought, 1981, Murray, 1998)—the availability of military funding for work that might support machine translation and computer-mediated command-and-control, the eagerness of academic deans to build departmental structures that would tap those funding sources, the revolutionary rhetoric resonating with the uprisings of the 1960s, the aggressive marketing of TGG as an all-or-nothing package, and so forth.

As Harris pointed out in many places, the symbols and expressions of a mathematical or logical symbol system are merely abbreviations which in the normal practice of mathematicians and logicians are 'read out' as sentences of language. From PSG and TGG in the 1950s to bare phrase structure and Minimalism now, Chomsky's formalisms amount to an a priori metalanguage, said to be pre-existent in the brain of every human. Here, then, is the most direct contradiction between Harris and Chomsky. For Harris, there can be no a priori metalanguage; for Chomsky, there must be. Harris's achievement was to demonstrate, with more and more complete and detailed coverage in more and more languages, that the intrinsic metalanguage capacities that are inherent in language are not only necessary, they are sufficient to account for grammar and linguistic information. The dogmas of Universal Grammar persist because it is thought to be necessary. Harris demonstrated that it is not necessary, and Generative linguists have never demonstrated it to be sufficient—that is, there is still no broad-coverage Generative grammar of any language.

We now turn to the relation of language to cognition. Sapir had taught "that language, culture, and personality spring all from the same source" (Harris, 1942:245), and Harris likewise had a deep interest in this—he knew Freud's work, and was in correspondence with Piaget and with Erik Erikson, among others—but this aspect of his thinking is little evident outside his work on politics and the direction of social change, because it was clear to him that the work on language was not yet ready for anyone to seek correlations with psychology.[9] Nor was psychology ready. Bloomfield's awkward and fruitless attempts to connect structural linguistics prematurely, first with the introspective structuralism of Wundt, and then with behaviorism, stood as a cautionary example.

Chomsky had no such qualms, because in his new environment at Harvard and then at MIT his talk of rules and components of grammar for symbolic processing dovetailed in exciting ways with Cognitive Psychology. Both fields arose from and depend upon the computer metaphor of brain function. If the brain is a programmable information-processing device analogous to a digital computer, then research into computer simulations of human learning become relevant, and it seems reasonable to gauge learnability from measures of computational complexity. 'Language acquisition' (a tendentious replacement for 'learning') is understood as part of the process of programming the computer. Given certain simplifying assumptions that were thought to be analogous to Galileo's frictionless inclined plane, it was concluded that it is impossible for children to learn a language empirically from the uses of language that they experience environmentally, so grammar must be innate. In the same way, a simplistic engineering model based on wing surface and body weight predicts that insects cannot fly (Peterson, 2004). Simplistic assumptions that follow from a commitment to an a priori programmatic metalanguage made the creed of Universal Grammar inevitable.

9 N. Sager, p.c.

As the computational metaphor for cognition gained wide acceptance, the symbolic rule systems of Generative grammar were taken to be obvious examples of the operations of the brain. "The standard view of classical cognitive science stated that cognition consists in the manipulation of language-like structures according to formal rules" (Mirolli & Parisi 2009:1). But the promise of opening a window into Mind has not been realized. The computational metaphor is controverted by several kinds of experimental evidence, and symbolic computationalism is no longer accepted among the majority of neuroscientists. It persists as a background assumption of cognitive psychology and of Generative linguistics because of the conceptual inertia which has been demonstrated in many fields due to social-psychological influences such as each participant's natural reliance upon 'mainstream principles' to gain employment and to build and sustain reputation and funding. For these and other reasons, certain readers may find it difficult to consider on its merits the alternative dynamic and connectionist model of embodied cognitive process that is sketched below in the second part of this paper, just as 'mainstream' linguists have difficulty understanding Harris's work on its merits.

Computationalists proposed that specialized modules of the brain are responsible for domain-specific modules of cognition, employing language-like syntactic rules for internal manipulation of explicit symbolic structures (mental models), and that learning of the models and rules in each identified area of cognition (e.g., language, intentionality, number) is accomplished by a domain-specific symbolic sub-system for learning or 'acquisition'. This has been criticized as 'neo-phrenology' (e.g. Uttal, 2003). Connectionist and dynamical systems such as the theory to be discussed presently assume only relatively low-level general-purpose neurological structures, and a small set of very general learning mechanisms in which the weighting of connections between neurons accomplishes Hebbian learning from environmental stimuli. Demonstrations that connectionist systems can accomplish high-level processes such as logical reasoning have settled the matter in favor of connectionism among the majority of neuroscientists. Models of embodied cognition emphasize the mutual influence of organism and environment.

In the 1950s and 1960s, the 'Cognitive Revolution' (Gardner, 1985) made much of superseding the stimulus-response theory of Behaviorism. Computationalism in Cognitive psychology assumes that the brain receives sensory inputs from the environment and constructs symbolic representations, called cognitive maps (some of which may be an innate inheritance). Current inputs are said to be correlated with these cognitive maps, 'information processing' takes place, and the brain issues commands to muscles resulting in behavior. This is merely an elaboration of the stimulus-response (S-R) theories of behaviorism. Symbolic representations and 'information processing' are interposed between the S and the R, but it is still held that stimuli in the environment cause behavior. A linear arrow of causation links S to R, however much intermediary 'cognitive process' is attributed to that arrow. The IV-DV methodology of Cognitive Psychology has also changed very little in its fundamentals from that of the stimulus-response theories (Marken, 2009, 2014). Part of the attractiveness of these theories for funding agencies is their long-standing promise to enable prediction and control of behavior. However, they produce only statistical measures, with a low threshold for significance and a lack of precision for individual behavior that would be an embarrassment in the physical sciences.

To escape these limitations, the crucial conceptual shift is from linear causation to circular causation in a closed loop. James, Dewey, and others were on the right track around the turn of the 20th century when they spoke of behavior as the attainment of a fixed goal by variable means, but their ideas were dismissed in the rise of behaviorism. How could present actions be determined by a goal, a future state that does not yet exist? The obvious answer—that we 'have in mind' what we want and act so as to bring it about—could not be given a mathematical and experimental basis until in 1927 an engineer at Bell Laboratories, Harold Black, worked out the mathematics of negative-feedback control systems (Kline, 1993). This gave rise to engineering control systems in which the reference values or setpoints for behavioral output are set by an external operator. The thermostat and the cruise-control system are simple examples. The reference value is compared to a sensed value that is input from the environment, and the difference between them (a variable called the 'error signal') determines behavioral outputs that maintain the sensed input at or near the reference value in a loop of circular causation. The error signal from a thermostat varies the heat delivered by a furnace, affecting the sensed ambient temperature; the error signal in a cruise-control system varies the power delivered by a car's engine, affecting the speed reported at the speedometer.

The science that studies negative-feedback control of perceptual input by means of behavioral actions is called Perceptual Control Theory (PCT). This alternative to the computational metaphor, "the third grand theory in psychology" alongside behaviorism and Cognitive psychology (Mansell & Marken, 2015), arose in the 1950s in association with cybernetics, and has developed in parallel to Cognitive psychology. The earliest major publications are Powers et al. 1960 and Powers 1973[2005]. For a recent overview with further references, see (Mansell & Marken, 2015). (Powers, 1973) describes a number of neural structures as part of the perceptual control hierarchy. For recent investigations into the neural implementation of the perceptual control hierarchy, see e.g. (Yin 2014), (Kim et al., 2014).

The presuppositions of stimulus-response psychologies pervade our cultural expectations. The efficacy of rewards and punishments is unquestioned, surprise is expressed at studies showing that workers are not strongly motivated by money nearly as much as by self-determination and meaningful integration into larger purposes that matter to them, and it is a commonplace to say that one person 'made' another person feel or do something. Perhaps this is why the following conceptual shift is a stumbling block for so many readers. It concerns an essential contrast between the feedback loop of circular causation and the supposed linear causation of behavior by stimuli that is posited by behaviorist and Cognitive psychology. I will state the contrast several times in different ways. Behavioral responses are not controlled by stimuli; indeed, behavioral responses are not controlled at all. It is the sensed input that is controlled. The output is not controlled, it is varied as needed so as to counter the influence that unpredictable factors in the environment have on the sensed input (such as the effect of an opened window on temperature, or the effect of a hill upon the speed of the car). Behavior is not controlled, it is varied so as to control the identified sensory input. As the title of (Powers, 1973) expresses it, behavior is the control of perception. You are urged to put this to experimental test for yourself, using interactive demonstrations that are provided in the cited literature.

There is an important contrast between living control systems and engineering control systems such as a thermostat. This is sometimes another conceptual stumbling block. In the many control loops within a living organism, including the well-known 'homeostatic' biochemical systems, the reference value or 'setpoint' variable is not set by an outside agent, it is set from within the organism in a system of cascade control, where a loop at a higher level sets references for plural inputs from lower levels. Each level constructs a different order of perceptions in the perceptual hierarchy.

This does not imply an infinite regress, no more than there is an infinite regress of metalanguages in language. The ultimate source of reference signals is understood to be the intrinsic reference values essential for survival, such as blood glucose and core body temperature.[10] When intrinsic error persists (e.g. when an experimental animal is maintained at 85% of its normal body weight as the 'establishing condition' for experimental work), a random exploration of alternative behaviors commences. At a cellular level, it can involve neurons making and breaking branches and synaptic connections. When error is reduced, the random reorganization process slows or ceases, and the then current reference values are established in memory. This is understood to be the means by which the levels of the perceptual hierarchy emerge in infancy (Plooij & van de Rijt-Plooij, 1990) and are refined throughout life. Exploitation of this plasticity is the basis of what psychologists call the 'conditioning' or 'shaping' of behavior. The kernel of truth in our dogmas about rewards and punishments is that coercive interference with an organism's ability to control important variables can influence its internal processes of reorganizing connections and reference values. However that influence is not precisely predictable. Instead of providing a theory of behavior, such experiments show how learning and adaptation may be influenced by artificially constraining the circumstances of the learner. I leave the working out of implications about the freedom and dignity of living things, vs. naive determinism, as an exercise for the reader.

Experimental demonstrations of the validity and strengths of PCT, and review/refutation of counter-arguments from Cognitive psychology, Gibsonian Ecological psychology, and so forth, are beyond the scope of this brief paper; the reader is referred to the abundant literature, some of which is reprinted in (Powers, 1989, 1992) and (Marken, 1992, 2002, 2014). Our more limited purpose in this brief paper is to indicate the particular compatibility of PCT with Harris's theory of language and information, and the prospects for modeling the control of language perceptions in an integrated way with control of those non-language perceptions that constitute the subjective aspects of meaning. For the unification of sociology, social psychology, anthropology, and other fields of study in the framework of PCT, see the contributions to (Mansell & Powers, forthcoming).

Figure 1 is a block diagram (standard in PCT) of a simple negative-feedback control loop at the boundary between an organism and its environment. Here, [EV] (for "environmental variable") represents an aspect of the environment, as perceived by the given organism. The perceived state of [EV] is influenced by two factors, one or more unpredictable disturbances *d* and the behavioral outputs (actions) produced by the output function [O]. At the boundary between the organism and the environment, represented by the dotted line, [O] refers to effectors, and [I], the input function, refers to a sensory input organ. The input function [I] constructs a perceptual signal *p*, a copy of which branches to the comparator [C], where it synapses with the reference signal *r*. The perceptual signal *p* is an inhibitory afferent (inbound) signal, and the reference signal *r* is an excitatory efferent (outbound) signal. When they synapse together at [C], the difference between them is the error signal *e*, an efferent signal that is amplified in [O] and transformed to action affecting the environment.

10 It is well known that neural connections are both electrical and chemical (Valenstein 2005), and neurological and biochemical systems are closely interactive with each other, and indeed not separate from each other.

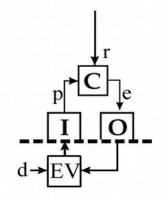

Figure 1. A simple control loop diagram.

The brain employs continuous analog computing processes, not serial steps of calculation and representation. A continuous change in *d* immediately causes a continuous change in *p* and in *e*, which is immediately opposed by a continuous change in the behavioral effort produced by [O]. (Whether or not the disturbance *d* is perceived is irrelevant; it rarely is.) “An indication of the error is used to cause the very output that opposes the error” (Powers 1980: 226). Neurons do not perform numerical calculations, they merely increase or decrease their rates of firing continuously as a function of the rates of firing of axons of other neurons synapsing with them. The myth that transport lags prevent control has been debunked long ago.

Figure 2 is a block diagram of a fragment of the perceptual control hierarchy as it is modeled in PCT. This model of the neural architecture is described more fully in the references cited above and in (Nevin, forthcoming). At each level are many control loops like that shown in Figure 1. Obviously, sensors receiving environmental input and effectors influencing the environmental variable [EV] are found only at the lowest level, where Intensity perceptions are constructed. For example, the hair cells of the cochlea generate neural signals at the Intensity level representing acoustic energy at particular frequencies, and combinations of several bands of frequencies, the formants, are represented by signals that synapse together to construct the perception of a particular vowel quality at the Sensation level.

Figure 2 shows how a perceptual signal *p* is carried up past the comparator at which it is controlled, branching to synapse with other perceptual input signals at one or more superordinate perceptual input functions [I] that construct higher-level perceptions. However, not all perceptual signals may be traced to input generated by sensory organs. Higher-order perceptual signals may be generated internally, without environmental input. At relatively low levels, the vivid detail of the experience is called hallucination or the like; at higher levels, imagined perceptions are controlled in processes that we call thinking, planning, and the like. To generate an imagined perception, the reference input branches across to synapse with the perceptual input ascending from the same location. There is abundant evidence that all perception includes imagined components, e.g. in the McGurk effect.[11] For more on how imagined perceptions originate and are controlled see e.g. (Powers, 1973), (Nevin, forthcoming).

The perceptual input functions for Configuration, Transition, and Relationship perceptions have been identified by the neuroscience researcher Alvaro Pascual-Leone as neural 'operators' for shapes, movement, and spatial relationships (Doidge, 2007:211-212). He has found that they process inputs from all sensory modalities, e.g. perceiving the width of hand both tactilely and visually, depending on input. This is another basis for imagination, and the inherent synesthesia provides a basis for analogy and metaphor without any additional perceptual functions or processing.

11 McGurk & MacDonald (1976). Several good demonstrations may be found online..

The details of nomenclature are unimportant for present purposes, and may indeed change as neurological investigations continue. More important is the many-one relationship between levels. A perceptual input function [I] receives many lower-order perceptual signals and constructs from them a higher-order perceptual signal. At the comparator [C] a reference signal *r* enters from one or more output functions at the level above, and the difference between *p* and *r* is sent as an error signal *e* branching to invoke reference signals *r* for the efferent systems below from which the input perceptual signals originate. Each reference signal *r* specifies a rate of firing for the perceptual signal *p* (the desired amount of that perception) that the given lower system is requested to send up to the higher-level perceptual input function. This simple architecture has been demonstrated experimentally to account for perceptual and behavioral phenomena of great complexity and subtlety, without requiring complex calculations such as inverse kinematics. Demonstration of this is beyond the scope of this brief paper but amply provided in the cited references.

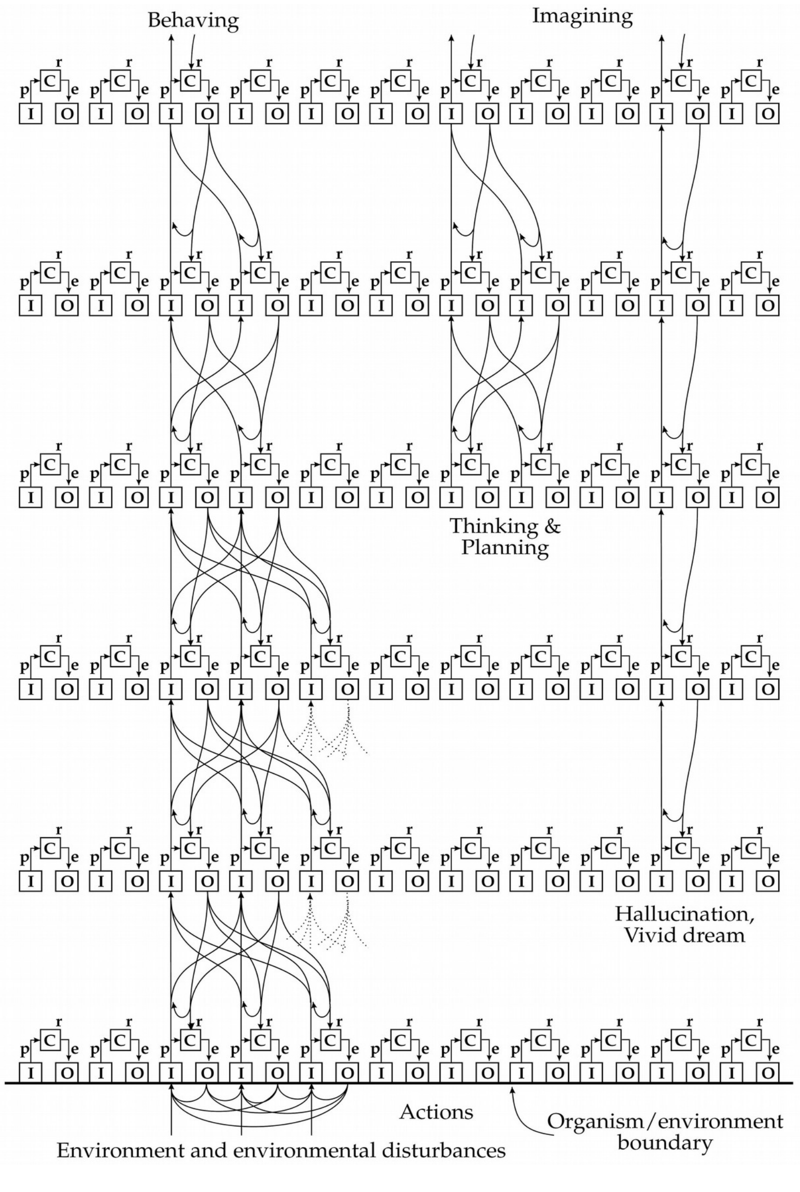

Figure 2. A fragment of the perceptual control hierarchy. (Only a few input or output lines are shown connecting levels.)

The appearance of functional areas or modules in the brain is a reflection of how the perceptual hierarchy is implemented by co-located neural structures (see e.g. Yin, 2014). What is thought of as symbolic cognitive maps of the environment is likewise a reflection of the physical organization (the interconnections) of perceptual input functions in the brain. The particular elementary control loops whose input functions at different levels of the hierarchy are activated because of input from the periphery, by associative links, and by the generation of imagined perceptual signals, constitute in effect a real-time map of the environment. The same activated systems are controlling their input perceptual signals by means of their output signals, which are transformed down through the hierarchy to continuously and appropriately variable efforts at the periphery. See the referenced literature for experimental demonstrations and extremely precise generative models of specific behaviors, such as e.g. how a baseball player catches a fly ball (Marken, 2001, 2005).

The fundamental methodological step in PCT is the test to identify what perceptual variable(s) the subject is controlling. To do this from the subject's point of view rather than the observer's is not simple. (See Runkel, 2003:77-79 for a detailed specification of this procedure.) Harris's linguistics is concerned throughout with the controlled perceptions of language users. The pair test for phonemic contrast, the various substitution tests that determine the distributional structure of language, and the acceptability-gradings that provide the criterion for transformations, are all tests that identify the perceptual variables that are controlled by users of a given language. Thus, anyone who has been doing Harrisian linguistics has been applying the methodology of PCT to language. Practitioners of Generative linguistics are not (see e.g. the critique by Clark & Lappin, 2011), insofar as they are concerned with the observer's perceptions of a priori categories and abstractions.

In the final chapters of his books on language and information, where he talks about what is required to learn language, and about the probable stages of its origination, Harris summarizes the controlled perceptions that constitute language.[12] These are

1. Phonemic distinctions.
2. Words and morphemes, with their main meanings.
3. Word dependencies (the argument requirement of each word).
4. The selection of each word (the dependencies that have greater than average likelihood).
5. The canonical or preferred linearization (word order) and its alternatives.
6. The main reductions (variant shapes of words), their domain (a particular word or all words in a position) and the conditions for applying them.

We will now consider the stages of child development leading to control of language. PCT research has shown that the levels of the perceptual hierarchy develop in the child's growing brain at predictable intervals. As a new level of the hierarchy begins learning how to control its perceptual inputs by reorganizing the connections and reference values that it sends to lower levels, the child experiences cognitive and behavioral consequences that are referred to as 'predictable regression periods' (Plooij & Van de Rijt-Plooij, 1990, Van de Rijt-Plooij & Plooij, 1992, 1993, Plooij, 2003). The stages of a child's learning of language depend upon mastery of control at these successive levels of cognitive capacity. These stages are shown in the first columns of Table 1.

The innate reorganization process tries out different connections and different signal weights at random, both in the branching of error signals that synapse to evoke reference signals at lower levels, and in the perceptual signals branching upward from lower levels to the input functions that construct perceptual signals at the new top level. Newborns go through an inarticulate "phonation" stage for about 8 weeks while the vocal tract lengthens enough for mature articulation to be possible. This is

12 Harris (1991.404–405). Also, with slight differences, in Harris (1988.111–113).

followed by what is called a “gooing” stage for another 11 weeks or so, then for about 7 weeks during the so-called “expansion” stage there is heard a growing ability to produce clear vocalizations with the diaphragm and larynx and to restrict the vocal tract, producing interruptions in the flow of vocalization that sound more and more like consonants.

These stages (shown in the first columns of Table 1) are increasingly sophisticated manifestations of the trial-and-error reorganization process in action. During this extended period of about 26 weeks, children play experimentally with all the ways that they can produce sounds, manipulating all the organs that affect the flow and vibration of air between the larynx and the apertures of the nose and mouth. During this same period, the they also wave about their arms, legs, fingers, and toes, exploring their effects, reorganizing internally, and gradually developing control systems with which to move them purposefully. PCT predicts that child language researchers should be able to distinguish some differences in the articulations and sounds that they perceive the child producing in the earlier and later parts of the phonation stage and ‘gooing’ stage, and that these differences will reflect growing control at each successive new order of perception by means of their control of previously established levels of perception.

Table 1. Emergence of perceptual levels aligned with stages of language development

weeks	Perceptual order	Language stage
	1. Intensities	Phonation
5	2. Sensations	Phonation
8	3. Configurations	‘Gooing’
12	4. Transitions	‘Gooing’
19	5. Events	Expansion
26	6. Relationships	Canonical babbling
37	7. Categories	…
46	8. Sequences	...
55	9. Programs	Words
64	10. Principles	
75	11. Systems	

Syllables are perceptions on the Event level. An Event is a brief, well-practiced sequence of Configuration and Transition perceptions. The consonants in a syllable interrupt the flow of vocalization in a coordinated way. Syllables become more clearly recognizable to adults as they become controlled from the Relationship level in relationships of phonemic contrast. This is why canonical babbling begins just as the Event level comes under control by a newly-emergent Relationship level. The canonical babbling phase is three or four times as long as the other recognized phases of child language development. Across sequences of syllables, the child plays with control of the pitch and amplitude configurations of intonation contours and the temporal configurations of speech rhythms. Adults hear babbling that sounds more and more like conversational assertions, exclamations, and questions.

PCT predicts that during the 30 weeks or so of babbling, the child develops perceptual input functions for recognition of a growing passive vocabulary of words. This is why, when the Sequence level is fully established, and begins to come under control of the emerging Program level, adults observe an 'explosion' of active vocabulary at approximately 12 months. The child does not suddenly learn the words. The input functions are there, and the means to control them at lower levels (as phonemically contrasting syllables), but the Program level perceptions that employ them purposefully for social effect have to develop before the child begins to speak them productively.

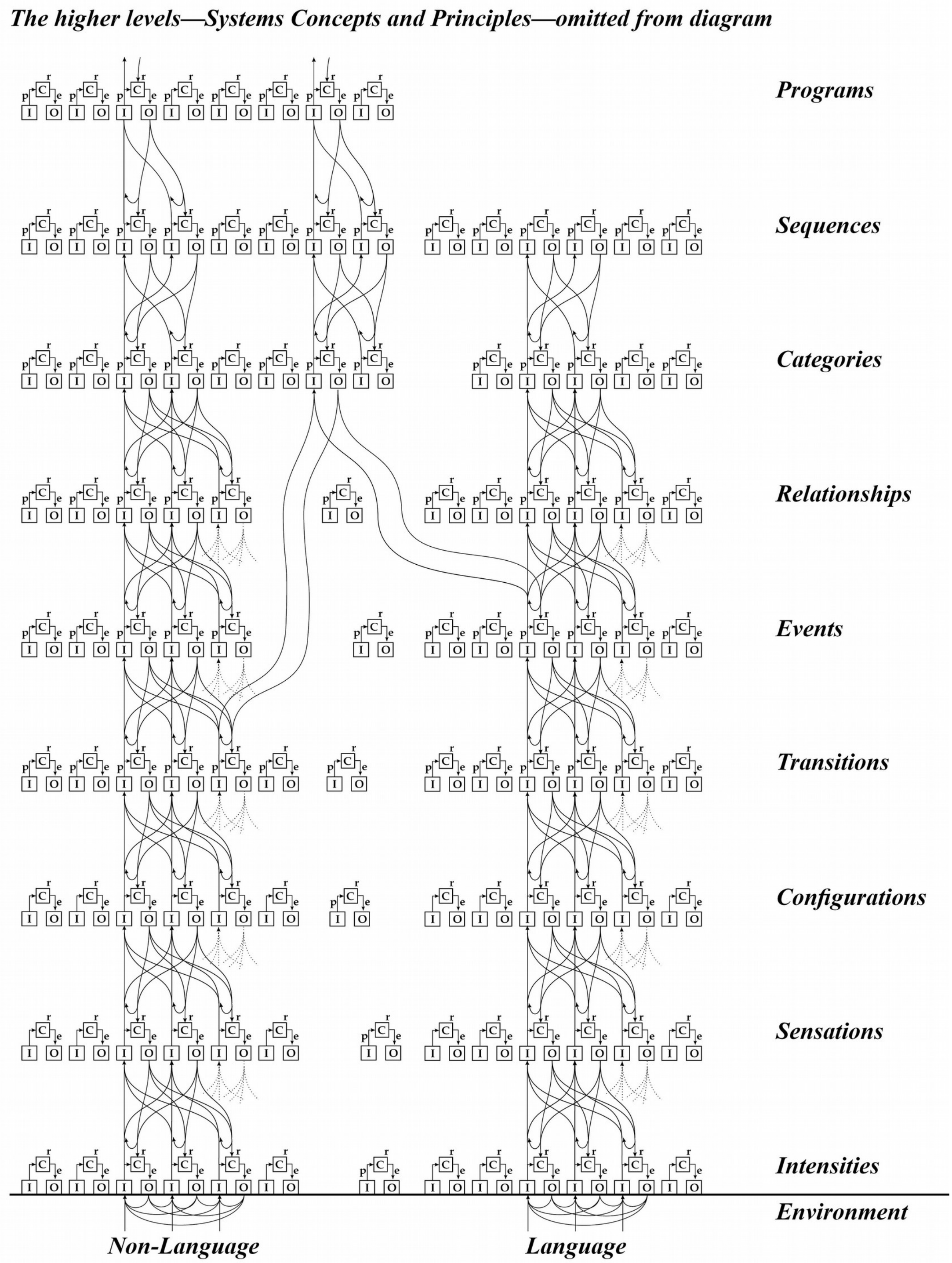

Figure 3. A fragment of the lowest nine levels of the perceptual control hierarchy, with language perceptions indicated on the right and non-language perceptions on the left.

Obviously, children's learning to recognize and produce words is inseparable from their learning word dependencies, their reductions, and the correlation of words with their appropriate contexts of use. Gleitman summarizes research demonstrating "a perceptual learning process sensitive to interacting distributional regularities at many levels of analysis" (Gleitman, 2002:213) and reports how surprised she and her colleague felt when they "discovered that the first verb in a blind child's vocabulary was liable to be *look* or *see*, and that these words—learned from the normal usage of sighted parents—were used sensibly to describe haptic exploration and apprehension" (Gleitman, 2002:215). As we know, this open-ended learning process continues for years.

One of Harris's great achievements is the isolation of objective linguistic information, which manifests as distributional constraints on combinability of words (Harris, 1988, 1991). An important area in which further work can be done, building on Harris's theory of language and information, is in a PCT model of how subjective meanings are associated with the objective information in language. The objective linguistic information is given its clearest representation in the analysis of a technical sublanguage, as in (Harris et al., 1989), but it is present in all forms of language, though often obscured by ambiguity and other degeneracy due to reductions.

Language users associate subjective meanings with the objective information in an utterance. Some subjective meanings are culturally standardized within a given communicative network (typically a community or subcommunity, even e.g. a family), and others are idiosyncratic and personal. Harris talks about cultural standardization of meanings in his reviews of Sapir's work (Harris, 1942, 1951), but not about subjective meanings other than that they exist and are too difficult to control to be useful for the scientific study of language because we have no means for specifying them other than language itself, or a symbol system derived from language and 'read out' in language.

Figure 3 indicates how PCT may clarify the process by which language users associate subjective meanings with the objective information in an utterance. The elements of language are controlled perceptions of the same kinds and in the same perceptual hierarchy as all other perceptions, albeit controlled in language-specific combinations by means of language-specific perceptual input functions and behavioral output functions. In the schematic diagram of Figure 3, the perceptions that constitute language are shown on the right, and non-language perceptions (as in Figure 2) on the left.

One obvious means of linking language and non-language perceptions is ordinary associative memory. This is effected by physical neurological connections between the perceptual input functions for language perceptions and the perceptual input functions for associated nonverbal perceptions. A second means of association is the control of like perceptions synesthetically across sensory modalities by the 'operators' discovered by Pascual-Leone. A third means is illustrated in Figure 3. At the Category level, perceptual inputs from both sides (language and non-language) are combined in a single perceptual input function. At the Event level, a word perception (a short, well-practiced sequence of syllables)[13] is an acoustic/articulatory shape devoid of semantic content. At the Sequence and Relationship levels, constructions, and relations of equivalence between them (making the reductions), constitute linguistic information which is associated with the non-language perceptions. It is not necessary to put all of this in a formal grammar and lexicon; but with PCT it may be possible to model how users of language do this with the control systems in their brains.

13 This is not recursive. It is recognized as a word by one input function and as syllables by the input functions for the syllables.

Rather than reporting work that has been done, this paper indicates a direction of work for the future, freeing linguistics from a conceptual trap that has confused the field for half a century. We began with a survey of how Harris's empirical linguistics contrasts with Generative linguistics, which is often considered a part of Cognitive psychology; in particular how Harris's methods and results are incommensurate with symbolic computationalism, the organizing metaphor in the latter two fields. In the second part of this paper we saw how the methodology of behaviorism and its fundamental assumption that stimuli cause behavior are retained unchanged by Cognitive psychology, and we contrasted these with "the third grand theory in psychology." Perceptual Control Theory (PCT) provides a solidly tested, mathematically specified methodology and theory that models individual behavior with very high accuracy, rather than mere statistical generalizations. Because of space constraints in this brief paper, the reader is invited to exercise the demonstrations and proofs of this claim that are abundantly provided in the cited references. We indicated some ways in which Harris's empirical linguistics integrates well with PCT. For the integration of other fields with PCT the reader is referred to (Mansell & Powers, forthcoming).

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