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# Some Implications of a Behavioral Analysis of Verbal Behavior for Logic and Mathematics

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The evident power and utility of the formal models of logic and mathematics pose a puzzle: Although such models are instances of verbal behavior, they are also essentialistic. But behavioral terms, and indeed all products of selection contingencies, are intrinsically variable and in this respect appear to be incommensurate with essentialism. A distinctive feature of verbal contingencies resolves this puzzle: The control of behavior by the nonverbal environment is often mediated by the verbal behavior of others, and behavior under control of verbal stimuli is blind to the intrinsic variability of the stimulating environment. Thus, words and sentences serve as filters of variability and thereby facilitate essentialistic model building and the formal structures of logic, mathematics, and science. Autoclitic frames, verbal chains interrupted by interchangeable variable terms, are ubiquitous in verbal behavior. Variable terms can be substituted in such frames almost without limit, a feature fundamental to formal models. Consequently, our fluency with autoclitic frames fosters generalization to formal models, which in turn permit deduction and other kinds of logical and mathematical inference.

*Key words:* autoclitic frames, essentialism, logic, mathematics, selectionism, variability, verbal behavior

Does one plus one equal two? Every child knows that it is so, and our arithmetical rules confirm the assertion. The rules of mathematics tell us much else besides, and we accept their claims as fact. But one cup of water plus one cup of alcohol yields only 1.9 cups of solution, not two, and when we add one pile of bricks to a second pile of bricks we get merely a single pile of bricks. When we add one match to one gallon of gasoline we are left with no matches, no gasoline, and no eyebrows. In what sense, then, are the rules of mathematics ''true''? Reasoning by parallel arguments, we might ask in what sense the conclusions of logical inference are ''valid'' and in what sense our scientific models are a ''description of nature's laws''? To Skinner, mathematics, logic, and the formal models of science were examples of verbal behavior, and answers to such questions should be sought within his interpretive framework of that domain. Here, as elsewhere, Skinner left much of the extension of his analysis as an exercise for the reader, and it is the goal of this paper to offer one such extension. Specifically, I address the question of how essentialistic models in science, logic, and mathematics can arise from behavior, which is intrinsically variable. Verbal behavior, like all behavior, is the product of contingencies of selection, and as such, we would expect it to be incommensurate with essentialistic models of nature. My thesis has two parts: First, because verbal behavior achieves its power through its effect on other people, its stimulus properties are of special importance; response properties, and the selection contingencies that shape them, are of interest only to the extent that they generate relevant classes of stimuli. For example, the words ''call home'' can be equally effective on the behavior of a reader whether printed by hand, typed, sent as an electronic text message, assembled from a set of lettered tiles, or spelled out in frost on a car windshield. Response-produced stimuli do not reflect the intrinsic

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variability of the selection contingencies that produced them, and as a result, words-as-stimuli filter out variability in controlling variables. In the absence of contextual support, the listener or reader cannot reconstruct it. It is a small step from highly restricted control by verbal stimuli to fully restricted control by formal models. The second part of my thesis is that our fluency with autoclitic frames underlies our ability to manipulate symbols in formal models; both require the substitution of terms, according to context, in a web of relations that, in other respects, remains fixed. Learning to parse autoclitic frames such as *X gave the Y to the Z* surely facilitates the mastery of algebraic expressions such as *X plus Y equals Z*. Together, the two proposals suggest how we might begin to interpret model building, the essentialistic engines of science and mathematics, in behavioral terms.

## BACKGROUND

I open by reviewing two points that serve as a context for the discussion that follows: First, behavior analysis is a selectionist science in which variability is fundamental. Each behavioral variant is equally lawful and equally a product of the relevant controlling variables. In contrast, the essentialistic viewpoint holds that variability is accidental and can be ignored or mathematically filtered away. Second, the two viewpoints entail different kinds of definitions: a priori definitions and empirical definitions, that is, those that can be specified in one's armchair independently of how the world works and those that can only be discovered by surveying a subject matter. Logic and mathematics are essentialistic enterprises, and their appropriate domain is formal models of nature that typically exploit a priori definitions. Selectionist sciences arrive at their definitions of units empirically, because class boundaries are determined by contingencies, not by blueprints, and those contingencies necessarily permit variability.

### *Essentialism Versus Selectionism*

Ever since Darwin revolutionized our understanding of the relations among species, essentialism has been out of fashion as an explicit position in science, although it still holds sway in pockets of philosophy and linguistics (see Palmer & Donahoe, 1992, for a review). Essentialism is the doctrine, usually implicit, that objects in the world are imperfect manifestations of pure archetypes whose ideal characteristics define the class (Mayr, 1982). Big dogs, little dogs, hunting dogs, herding dogs, and three-legged dogs play no role in defining *dog,* because their idiosyncratic features are accidental. They are all dogs because they share an "essence" of dog. This doctrine can be traced to Plato, who formulated it as a metaphor (the objects of our experience are mere shadows on a wall) but, according to Russell (1945), he may have been anticipated by Parmenides, and perhaps others. Essentialism is explicit in creationist views of nature, just as it was, until Darwin's time, implicit in the scientific classification of natural phenomena. Most species of organisms appear to be separated from one another by gaps, sometimes large, sometimes small, but always sufficient to permit reliable sorting. The wood thrush and the hermit thrush may seem identical to the casual observer, but they differ in their song, in the definition of spots on their breasts, and several other subtle ways, and they breed only among those with the same features. Even objects in the physical world can be differentiated according dimensions that matter to us. Essentialism is a philosophical abstraction of our everyday discriminations.

But when Darwin showed that the apparent gaps between species arise from the extinction of intermediate

forms, essentialism, at least in our classification of biological nature, could no longer be defended. All organisms are linked to common ancestors by incremental changes over evolutionary time, and every living organism has an equally distinguished pedigree back to the primeval replicator. No variant is more central than another except in a temporary circumstantial sense. The characteristics of the population move on incrementally: The moth with an unusually long proboscis today may be in the middle of the pack tomorrow and at the rear the day after.

Essentialism sees variation as ''error,'' something to be ignored or averaged away. Only prototypes, essences, or averages are of interest. Outliers can be cheerfully trimmed from one's distributions of data, and the mean can be taken to represent the whole. In contrast, selectionism sees variation as fundamental, because no adaptive change could occur in the absence of variation, be it the evolution of the eye or the shaping of the finger movements of the skilled violinist. Moreover, and more fundamentally, selection contingencies are sieves, not blueprints: A kitchen sieve allows anything to pass through, provided that it is small enough: oil, vinegar, honey, water, sand, flour, carbon dioxide. A selection contingency permits anything to pass through provided its criterion has been met. Lineages of organisms can adapt to a cooling environment in many ways, for example, and a survey of existing organisms reveals a great variety of such ways. Essentialism presupposes a blueprint; only one kind of thing is specified by the blueprint, and any deviations from it are mistakes or accidents. In short, essentialism sees the prototype as ''real'' and variation as accidental; selectionism sees the variation as real and the prototype as a convenient fiction. It is this fundamental difference that gives selection its parsimony and power. Whereas essentialism must explain the origin of its blueprints, selectionism requires only a variable substrate and repeated cycles of selection, conditions that are already apparent in nature. Variation and selection are not assumptions that must be justified; they are facts.

From an essentialist viewpoint classes of events have sharp boundaries, whereas from a selectionist viewpoint, class boundaries are fuzzy and conditional. From an essentialistic viewpoint, an animal can be said to be ''really'' a wolf, and not a jackal or a dog, for every individual is simply a variation on a type. From a selectionist viewpoint, the gradation from wolf to dog over evolutionary time has no breaks, and the question whether a particular animal is ''really'' a wolf or a dog has no meaning. However, it is possible within a selectionist framework to assert that the domestic dog ''really'' did descend from the wolf and not from the jackal (Dawkins, 2009). The evolution of a lineage might have taken many paths according to circumstances, but it took only one. The dolphin is ''really'' first cousin to the hippopotamus, not to the dorado, which it more closely resembles, but such essentialistic locutions are misleading when applied to the products of iterative cycles of selection, because they suggest that the names we deploy when describing nature are right or wrong rather than just useful or misleading.

The field of psychology is inconsistent with regard to essentialism. Some linguists and cognitive scientists are still under its sway (e.g., Chomsky, 1980; Fodor, 1975; Pinker, 1994), but behavior analysis is squarely a selectionist enterprise, first because of its emphasis on the adaptive significance of variation and selection in behavior, but more importantly, and more subtly, because of a methodological commitment to empirical units of analysis (Skinner, 1935, 1938). Skinner's dictum that definitions of behavior and environment be determined by investigation rather than

by prescription set the stage for a thoroughgoing selectionist science.

*Empirical and a Priori Definitions*

It is an axiom that to think clearly one must define one's terms, but two types of definition are possible, and they differ fundamentally. Perhaps the more familiar type of definition is the prescriptive or a priori definition. Such definitions are set by the speaker and are not open to dispute. If I define a circle as a four-sided polyhedron with triangular faces, readers may rightly object that everyone else defines it differently, but that is the worst they can say about it. Once my definition is stated, they must accept it in that sense in the ensuing discussion. Such definitions can be specified from one's armchair; they may or may not be useful and need not correspond with anything in nature. If I define a human as a featherless biped, I must accept a plucked chicken as a conspecific. Such definitions can have, and usually do have, perfectly sharp boundaries.

Empirical definitions, on the other hand, are not specified a priori by the speaker but are discovered by investigating nature. A painstaking survey may reveal two populations of warblers to which we give different names. We distinguish them by slight differences in plumage, the eye-rings, and the mating calls. However, subsequent work may reveal that the proposed defining features are not correct: Variations in the eye-ring and in plumage overlap in the two populations. Only the mating call is a reliable criterion for distinguishing the populations in the field. Still later work identifies genetic markers characteristic of the two species. Empirical definitions, then, are continually subject to modification, and they have fuzzy boundaries. Thus the definition of *parallelogram* is established by prescription, whereas the definition of *dog* is empirical. Even when the object to be defined is not the product of iterative cycles of selection, our behavioral interactions with them may be. The processes of discrimination and generalization will yield variable classes even when the objects assigned to those classes are not themselves the product of selection contingencies. Thus, the two types of definition serve the domains of essentialism and selectionism, respectively.

As we might expect, Skinner's definition of verbal behavior is an empirical definition. He offered a tentative definition as behavior whose consequences are mediated by another organism (1957, p. 2), but after surveying his subject matter, he found the domain of the definition to be heterogeneous. He refined it several times and finally settled on the following addendum:

> If we make the further provision that the "listener" must be responding in ways which have been conditioned *precisely in order to reinforce the behavior of the speaker,* we narrow our subject to what is traditionally recognized as the verbal field. (Skinner, 1957, p. 225)

He was evidently trying to operationalize, in behavioral terms, the concept of *symbolic*, and rightly so, but we can see that his definition still needs refinement. First, his addendum has a teleological flavor. Second, the verbal community shapes listener behavior for many reasons, not just to reinforce the behavior of speakers. But recognizing that empirical definitions are intrinsically tentative and pragmatic, we may decide that Skinner's is good enough for getting on with.

The foregoing remarks have set the stage for our foray into the implications of a behavioral view of language for formal modeling. Verbal responses often serve as a medium between the physical environment and the listener, but in this service, they dramatically alter the nature of the controlling relation.

## WORDS FILTER OUT VARIABILITY

### *Variability in Stimulating Conditions is Lost*

A speaker may utter the tact *fish* in response to a picture of a marlin, a fillet on a slab, a can of tuna, a trout, a goldfish, a haddock, a smelt, or any one of countless other fish as well as countless fish within species, each of which is unique in some respects. That is, the class of idiosyncratic creatures and other stimuli that evoke the response *fish* is nearly unlimited. But when the response is uttered and serves as a discriminative stimulus for behavior of the listener, all of that potential variability is lost. That is to say, in the absence of other variables, the listener has no way of responding differentially to any variability in stimulating conditions. The verbal discriminative stimulus has filtered away, as it were, all of unique features of the setting, and the listener cannot recover it. (When I speak of *variability* in the controlling stimulus, I mean the idiosyncratic features of the stimulus that could vary from one instance to the next. On any single occasion, only a particular set of features will be present, but it is convenient to use the term *variability* to remind us of the many alternative stimuli that would have been equally effective in evoking the verbal response.)

This filtering effect occurs whenever the listener's response is under control of the verbal stimulus alone and can be tempered when the listener and speaker are in the same setting and under control of common variables, even though controlling variables never overlap completely. On the other hand, the filtering effect is maximal when the listener is removed from the initial controlling variables by time and space, as is the case when the listener is reading a text or is responding to a speaker whose behavior is under echoic, intraverbal, or textual control, or when the verbal stimulus is mediated by a device such as a radio, television, computer, audiotape, or telephone. Under such conditions, verbal stimuli carry all, or almost all, of the burden of controlling the behavior of the listener.

In speaking of this filtering effect, I choose to assign it, not to *tacts*, but to the neutral term *words* for two reasons. First, our present concern is the effect of a verbal stimulus on the listener, not the contingency that controls the behavior of the speaker. Only the latter relation properly specifies a tact. Second, verbal stimuli often exert their effects on listeners in contexts that are far removed from the original contingencies, as when we read a text or hear a broadcast, and to call such stimuli *tacts* is, at best, misleading. The written word, as a stimulus, is particularly disembodied and dissociated from the idiosyncratic and potentially variable conditions that evoked it, but it will commonly have a characteristic effect on the reader nonetheless, and it is this effect that is of interest here.

### *Variability in Response Form is Irrelevant*

The verbal response itself, like all products of selection contingencies, will necessarily vary from one instance to the next. "Fish" may be uttered by a child, a woman, a wheezing old man, or a fishmonger with a cart; it may be uttered in a whisper, a lisp, or a bellow; it may be uttered slowly, harshly, or hesitantly, and so on. But such variability can be ignored for present purposes. As Skinner's definition reminds us, the behavior of the listener is shaped by a verbal community, and that community establishes control primarily by the phonetic properties of verbal stimuli. Under most conditions, control by secondary stimulus properties of speech is blocked by its phonetic properties. Moreover, these contingencies have also established *categorical perception*

of phonemes, the generalization of responding within phoneme boundaries and sharp discrimination at those boundaries. Thus intraphoneme variation is likewise ineffective in controlling behavior and is presumably another instance of stimulus blocking (e.g., Kamin, 1969). As a consequence, the variability inherent in the verbal stimulus itself plays only a secondary role in controlling the behavior of the listener, and such variability is unlikely in any case to reflect variability in the controlling stimuli. If the speaker is being attacked by a mad dog, the secondary properties of the verbal stimulus (its volume, pitch, and emotional intensity) will not be lost on the listener, but such cases must be considered too rare to vitiate the current point.

*Variability in the Behavior of the Listener is Dissociated from That of Original Variables*

The response of the listener will also be variable, depending on his history with respect to *fish* as a verbal stimulus (neglecting for the moment, the contribution of concurrent variables). The listener may respond by thinking of a fish, or by looking for the fish, or by telling an anecdote about a fish, or by responding intraverbally in various ways, and of course when competing variables are prepotent, the stimulus may have no evocative effect at all. But as noted, this variability arises from the subject's history and is wholly unrelated to variability in the stimuli that evoked the verbal response.

*Words Blur the Line Between Selectionism and Essentialism*

Words can serve as an essentialistic medium, because they make it impossible for the fundamental variability in natural classes to make itself felt. Each fish will evoke a different constellation of responses in an observer, for each instance is unique, but the *word* "fish" will respect none of that variation. Any variability in the listener that arises from the word will depend on the listener's history, not on the variables that control the speaker. As a consequence, verbal behavior can serve as an idealized domain of sharply defined classes, consistent and inflexible rules of inference, perfect substitutability of terms, precise evaluation of equality and quantity, exact translation of elements, and quantifiable relations among concepts. In other words, verbal behavior can serve as a medium for logic, mathematics, and our models of nature.

*Essentialism and Models of Nature*

The appropriate domain of essentialism in human behavior is not in our classification of nature but in our models of it, and here its role is an honorable one. In a typical model, a priori definitions specify essentialistic categories. A circle is a set of points on a plane equidistant from a given point. A dodecahedron is a regular polyhedron with 12 pentagonal faces. A degree is 1/360th of a circle. The probability density of the normal curve is equal to $(1/\ \sigma\sqrt{2\pi})\ \exp\ [-(X-\mu)^2\ /\ 2\sigma^2]$. These essentialistic concepts do not, and need not, map onto the dirty, warty, erratic, intrinsically variable world. There are no circles, dodecahedrons, or normal distributions in nature, only in our models of nature. If we blow up a hydrogen atom to the scale of the solar system, a circle would still be an invisibly thin and continuous line slicing through its immense void in a perfect arc. Essentialistic circles do not exist in nature. Our bicycle wheels, ripples in a pond, and even our precisely machined bearings are circular only to our crude senses; at the idealized level of pure geometry, they are absurdly gross approximations. More to the point, they simply are not circles at all, because they do not meet the conditions specified in our prescriptive definition. The normal

distribution may, with reasonable accuracy, claim that two thirds of the population of men are between 67 and 73 in. tall, but in the same breath it asserts that a finite proportion are less than an inch tall. Most of mathematics and much of the theoretical edifice of science are essentialistic. Despite the discrepancy between essentialistic and natural categories, such models have proven extraordinarily useful, because they enable us to quantify the relations among terms, to follow paths of inference, and to predict and control nature with remarkable precision. Their very essentialism permits precise extrapolation and invariant manipulation of terms.

My purpose here is not to explain how such modeling can be so useful but to explain its relation to verbal behavior. As noted above, when contextual support is absent, the listener's behavior is under highly restricted control by verbal stimuli. The listener is cut off from the variable conditions that evoked the relevant verbal stimulus, and the contingencies maintained by the verbal community usually lead to the blocking of any control by variations in the verbal stimulus itself. Thus, under these conditions we generalize completely within words and discriminate sharply between words, with no role played by other stimuli in the control of listener behavior. Because the distinction between essentialistic and selectionistic classes is primarily the role played by variability, the distinction evaporates under such conditions. Control of listener behavior by purely verbal stimuli is, in effect, essentialistic. That is, in the absence of relevant contextual control, selection contingencies maintained by a verbal community shape listener behavior that we call essentialistic. Because verbal behavior often occurs without relevant contextual support, we all acquire a fluent repertoire of such listener behavior long before we encounter formal models of nature. Perhaps it is this circumstance that explains why an implicit essentialism is so pervasive in common discourse.

## AUTOCLITIC FRAMES AND FORMAL MODELING

Moving from definitions to propositions, our essentialistic models assert that all swans are white, no Greeks are misers, all members of Tribe A are liars, and that Achilles runs exactly 10 times as fast as the tortoise. As behaviorists, we understand such statements to be behavior under the control of a set of conditions, behavior shaped by a relevant history. Therefore the claims are intrinsically fuzzy. To the extent that they are useful we say that they are "true," but otherwise *truth* is not a term in our analysis. In contrast, as logicians, the statements are independent of history, conditioning, or conditions in the world. If the propositions are given as axioms, or follow from axioms, they are true. Not approximately true, but necessarily and absolutely so, because essentialistic truth is meaningful only in the context of our formal models. Many mathematical expressions are propositions and can be true or false in this sense.

### *Autoclitic Frames Underlie the Structural Properties of Verbal Behavior*

At the heart of propositions lie *autoclitic frames*. In Skinner's lexicon, an autoclitic frame is an interrupted or incomplete intraverbal sequence into which variable terms are inserted according to context. *On the shelf, on the table,* and *on the bench* are three examples of the frame, *on the X.* The frame is constant from one instance to the next, and is controlled by a common condition, but the variable terms change according to circumstances. In this case, the common condition is that of superposition. Grammatical elements we call *verbs* usually determine relatively elaborate frames in which variable terms are

embedded within strings that are intraverbally controlled. The verb *give* implies a giver, a recipient, and something given; *put* entails an agent, something to be placed, and a location where that something should be placed. Thus, we have the canonical autoclitic frames *X gave the Y to the Z* and *X put the Y on the Z*. Prepositional phrases are frames (*in the X, next to the X, between the Xs*, etc.), and they are commonly nested within other frames (verb frames or sentence frames). As is the case with other verbal operants, autoclitic frames are classified by function, not form. A second frame with the form, *on the X,* is differentiated from the above by its controlling conditions, namely, that something is available by orienting to a device, as in *on the radio, on TV, on the computer*. Sometimes the same terms and relations can appear in several different frames: *X gave Z Y* (e.g., *Bill gave the porter a dollar*). As I have remarked elsewhere, autoclitic frames govern the ordering of verbal elements and therefore underlie our tendency to honor the whimsical rules of grammar (Palmer, 1998, 2008). That is, because autoclitic frames are partly intraverbal, they impose structure on verbal behavior, structure that can be interpreted as grammar.

### *The Substitution of Terms in Autoclitic Frames Underlies Symbol Manipulation*

A distinctive feature of autoclitic frames is that the variable terms can be substituted without limit, and yet effective control of listener behavior is maintained. Owing to ubiquitous contingencies maintained by verbal communities, speakers and listeners become highly fluent at executing and interpreting the substitution of terms. Autoclitic frames come to strength in the speaker's behavior in characteristic contexts, and the combination of frame, variables, and characteristic context is sufficient to control listener behavior effectively under a vast variety of conditions. For example, the commands *Put your king's knight on square f3, Put the butter in the fridge, Put the letter in the mailbox,* and so on, might be novel to a given listener, but the specified behavior will typically be executed smoothly. In these examples, an autoclitic frame in the behavior of the speaker controls what we might call a *behavioral frame* in the repertoire of the listener. The variable terms control which features of the environment are to be interwoven with that behavioral frame. In *X gave the Y to the Z*, the behavioral frame for the listener is to assign the variable term X the role of giver, the term Y the role of gift, and the term Z the role of recipient. In *Sing X again!* the listener is to assign X the role of the action to be repeated. A speaker will shout, *Watch out for the X!,* and the listener will respond by rapidly orienting to X, even when that constellation of circumstances is novel for both parties. Such frames are ubiquitous in verbal behavior, and listeners and readers respond fluently and effortlessly to them. Thus, autoclitic frames are extraordinarily versatile and powerful tools for evoking effective behavior in the listener, even when the speaker has never uttered that particular instance before and the listener has never engaged in the relevant behavior before.

Our fluency with the interchange of terms in autoclitic frames serves us well in our manipulation of symbols in our rules of inference in logic and our mathematical procedures. An expression such as *Let X be the height of the tree* in an algebra problem is like the request *Let Jake play the role of King Lear*, and both are examples of the frame *Let X be Y,* or its equivalent. To respond effectively to *Janet is a member of ABAI* facilitates responding to *Phi is a proper subset of delta.* We learn to respond to autoclitic frames such as *Some Xs are Ys; No Xs are Ys*; *If X then Y; When X*

*occurs, Y occurs; X is equal to Y; X is twice as big as Y,* and countless others in our ordinary commerce with a verbal community before we learn to exploit them in formal modeling. That is, such frames originally acquire meaning for a listener, not in the context of formal models or logical domains, but from a history of exposure to the controlling contingencies themselves, the contingencies that tend to evoke such frames. The propositions *All the cows are home; All the salt shakers are empty; All the students are in their seats;* and *All the books are paperbacks* can be confirmed by inspection, and the frame *All the X are Y* acquires relevant control, for both speaker and listener, under such conditions. As a consequence, the frame *All the X are Y* occasions listener behavior that will generalize to novel cases.

We generalize from expressions that can be verified to those where verification is impossible. That is, we commonly generalize on the basis of the *form of the words,* not on the conditions that evoke them. As noted above, in such cases the intrinsic variability in controlling conditions has been abstracted away. If we were to actually verify that *all the cows are in their stalls*, we would find that the barn is a bedlam of activity, that Elsie is only halfway in her stall because the cat is asleep in it, and Bossy is reaching over the partition and scratching her chin on Clover's back, and so on, but such variability is what we expect, and we do not upbraid the speaker. But when words stand alone, devoid of context, or in a formal model, the variability in controlling conditions is lost. Thus *all swans are white* can serve a paradigmatic proposition, or axiom, even though the species of swans has fuzzy boundaries, and even though whiteness, like all visual stimuli, embraces a generalization class of which pure whiteness is just one member, and even though no one has ever seen all swans.

Of course, audience variables are relevant. In mathematical, philosophical, and logical discourse, the relevant verbal communities shape highly restricted speaker and listener behavior. As Skinner remarked,

> Contingencies established by the scientific community work to prevent exaggeration or understatement, misrepresentation, lying, and fiction. Audience variables are clarified by specifying a "universe of discourse" as a subdivision of the repertoire to be employed, from which terms appropriate to other audiences are specifically excluded. Scientific verbal behavior is most effective when it is free of multiple sources of strength; and humor, wit, style, the devices of poetry, and fragmentary recombinations and distortions of form all go unreinforced, if they are not actually punished, by the scientific community. (1957, p. 420)

Thus generalizations about nature, rules of thumb, and empirical definitions, all couched in appropriate autoclitic frames, are acquired under messy conditions, but they are transformed in essentialistic model building as axioms, inflexible rules, and prescriptive definitions. This transformation is abetted by the ability of words to isolate the listener from many of the conditions that affect the speaker as well as by the scholarly audience that shapes relevant behavior under highly restricted stimulus control.

## CONCLUSION

I have suggested that logic, mathematics, and our models of nature are precise because they are essentialistic and that verbal behavior serves these models in a way that nonverbal behavior cannot. Verbal behavior abstracts away the fundamental variability in selection contingencies. A single invariant response form serves as a symbol of a class of fundamentally varying phenomena. Contingencies maintained by verbal communities ensure that any variability in the form of the response itself plays no role in the control of listener behavior, an effect that is supported in any case by

blocking. Thus, humans are able to take advantage of idealized rules that emerge from essentialistic models to make inferences about the world. Some rules of inference in such models are supported by prescriptive definitions; others follow as generalizations guided by autoclitic frames. Logical and mathematical propositions illustrate such frames, with fixed elements providing the structure of the frame and variable terms embedding the frame into the current context. We generalize from frames that can be evaluated directly by experience to those in which the relations are purely verbal. The highly restricted or essentialistic interpretation of such expressions is fostered by contingencies maintained by scholarly communities.

I have tried to show how an understanding of verbal behavior can inform an interpretation of essentialistic model building. But I have not attempted to explain the power of such model building. I am not convinced that logic and philosophy have advanced much in the last two millennia, but mathematics and physics certainly have done so. Indeed, our mathematical and physical models of nature are considerably more accurate than our everyday understanding of nature. Because our most successful models of the physical world entail assumptions and predictions that baffle common sense, our models seem to understand nature better than we do. This is a mystery to me, and I don't pretend to be able to explain it.

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