

This is a section of [doi:10.7551/mitpress/14186.001.0001](https://doi.org/10.7551/mitpress/14186.001.0001)

# **The Science-Music Borderlands**

## **Reckoning with the Past and Imagining the Future**

**Edited by: Elizabeth H. Margulis, Psyche Loui, Deirdre Loughridge**

### **Citation:**

*The Science-Music Borderlands: Reckoning with the Past and Imagining the Future*

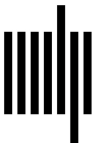
**Edited by: Elizabeth H. Margulis, Psyche Loui, Deirdre Loughridge**

**DOI: 10.7551/mitpress/14186.001.0001**

**ISBN (electronic): 9780262373043**

**Publisher: The MIT Press**

**Published: 2023**



**The MIT Press**

## 2 Musical Meaning in Transspecies Perspective: A Semiotic Model

Gary Tomlinson

Music resists definition, notoriously. The resistance is partly a problem of the language in which definition must be couched, which struggles to overcome the sheer difference between musical and linguistic experience; this is the problem of our abiding linguocentrism, and it is endemic to every kind of musicology. More essentially, the resistance arises from the complexity of music, which comprises a broad swath of human capacities and practices showing immense cultural diversity and reflecting (all available evidence indicates) a long evolutionary history (for several approaches to this history, see Wallin et al., 2000; Bannan, 2012; Tomlinson, 2015; Savage et al., 2021). Even without an encompassing definition, however, we can clarify human musicking by thinking of it as the deployment of certain kinds of signs arrayed to create kinds of meanings distinct from linguistic ones. Here, two additional hard-to-define terms confront the theorist: *sign* and *meaning*. In what follows, I outline a general model of meaning, resting on a particular conception of signs, that frames some fundamental resources of human music. The model aims to clarify the status of music within a constellation of other human activities and to illuminate its relations to certain communicative acts of other species; at the same time, it suggests some more general insights into evolutionary history. It rests on basic propositions that I explore briefly but do not elaborate or defend fully. These are offered almost as axioms, and the resulting view of meaning as a promise of fuller elaboration to come (see Tomlinson, in press).

### Two Kinds of Information

*Information* is a term widely applied to two distinct phenomena in the world. On the one hand, information describes correlated changes that come about through some causal interaction between or among systems: “causal covariance,” as Fodor (1990) put it. (“Reliable causal covariance” was his full phrase, but reliability involves not the nature of the information but its quantity in any given situation.) Such *causal*

*information* defines and enables us to quantify a relation between the systems involved. It can be conceived as occurring along a channel extending from a sender and bringing about some corresponding effect in a receiver (Shannon & Weaver, 1949). Information of this sort is relational: its channels can feed back from receiver to sender, they can be networked in parallel and serial fashion, and they can be doubled and redoubled or hierarchized in any number of routines and subroutines; but the fundamental relationality of covariance remains its defining feature.

All living things, even the simplest bacterium, are complex miracles of this kind of relational, causal information. But in the vast majority of organisms this information is *not about anything*. It is without content or meaning, a sheer causality that makes things happen, from the molecular level up through organismal and ecosystemic levels. The bonding relations between DNA and RNA, or those between these molecules and the various proteins that catalyze the relations of amino acids that bond to RNA, are archetypal instances of this biotic causal information.

A contrasting kind of information arises on the foundation of causal information but adds to it another dimension. It defines a phenomenon distinct from relational correspondence that results in a new kind of connection between things. To this connection we give various names: representation, referentiality, aboutness, intentionality, content, semantics, and meaning. This kind of informational connection is sometimes called semantic information, but I call it *semiotic information*, reflecting the fact that it arises only from signs, wherein one thing represents or refers to another, and hence only from the processes that give rise to signs, gathered under the term *semiosis*. All life-forms involve causal information; a few of them also involve semiotic information.

We could say of signs, as Marx said of commodities, that while they appear to be trivial and easily understood, they are in reality “abounding in metaphysical subtleties.” Semiotic information depends not on relations alone, like causal information, but on a relation to a relation—a *metarelation*. Conceptualizing this situation calls for something more complex than the model of a transmitter, channel, and receiver and something different even from the model of a hierarchy of routines. Most basically, a metarelation is required for semiosis because a sign is something different from a cause of its object. It is an *analysis* of its object: it divides up the object, picking out certain aspects of it to use in re-presenting it. It is constrained in the picking both by its own nature and, reciprocally, by the nature of the object. A road sign showing that deer might be in the area represents certain aspects of deer and not others, and the aspects selected are determined by both the nature of deer and the nature of the sign. Signs never capture all aspects of their objects; that would collapse the sign into the object, collapsing at the same time aboutness and content. Identity admits no space for re-presentation.

What is it that enters into this complex relation between aspects of one entity and aspects of another? What creates the metarelation? This is a third entity, one that is capable of forming percepts of certain sorts. This entity doesn't exercise complete, sovereign control over its percepts. Instead it is *called into* the aspectual constraints of what will become sign and object—called by their nature as *affordances* in its world or niche. Its percepts are always formed not only by its own capacities but also by the entities that come to form sign and object. In this way, semiosis is a process of three-way reciprocal constraint—or reciprocal affordance, which amounts to the same thing—among a percept and things or phenomena external to it. It is irreducibly a niche-constructive process.

Those familiar with the philosophy of Charles Sanders Peirce will recognize in this approach to semiotics two basic Peircean tenets (Peirce, 1955; Atkin, 2013). The first is the *partial, aspectual nature* of all the relations in the sign-making process (for example, the partiality of the relation of sign to deer and deer to sign). Peirce offered many typologies of signs derived from the many combinatorial possibilities of this partiality; the most famous of these is the division of icon, index, and symbol. The second tenet is the calling of a perceiver into the aspectual parsing of the world, an idea for which Peirce coined the term *interpretant*. This is a fundamental term in his philosophy but one that has been much misunderstood. It requires no interpretation, as we tend to use the word, but relies instead on the perceptual capacity to divide up the world—to parse or analyze it, registering some of its parts, clumping some together with others, and relating itself to those relations.

The basic distinction between the two kinds of information, causal and semiotic, is relevant to the question of meaning because *meaning is founded in the sign metarelation*. It emerges only from semiosis. Signs are always signs *of*: they introduce aboutness in the world by virtue of this fundamental nature, introducing at the same time what we connote by all the synonyms named above: reference, content, semantics, and so forth. Signs are *representational*—in the precise sense of re-presenting one thing in another. This is what signs do, and this is what the content-full information that arises from signs does; it is not what causal information does. Signs are not the same as *signals*, as this word is loosely but pervasively used by biologists and others. A signal can be non-semiotic and often comes down to a threshold mechanism in the operation of causal information. It doesn't necessarily re-present one thing in another.

## Making Signs

How do some life-forms come to form interpretants? The distinction between causal information in general and the special case of semiotic information helps clarify the

evolved capacities that enable semiosis and meaning. These should not be thought of as identifiable traits possessed by particular organisms—that is, as adaptations selected for particular functions. Such *selection for* is not how natural selection works; it is not an optimization problem, notwithstanding Dennett's (1995, 2017a, 2017b) decades-long effort to make us think it is. The capacities to create meaning are ongoing processes of negotiation with an external world, so they can't be identified as discrete properties of an organism. *Processes, not properties*: this is a motto that should hang above the door of every evolutionist (it already hangs above the doors of many). These processes are involved in the niche construction to which I have already referred and will return.

Among the processes needed to create interpretants, *memory* is crucial, but not merely the simplest forms of storage and retrieval. Instead, something like an *episodic* memory is necessary, a process in which memories are retrieved as parts of whole situations—retrieved more readily because of cues to those situations—and hence can enable a cognitive reliving of the situations (Tulving, 1972; Baddeley, 2000). The best evidence suggests that a number of animals in addition to humans form episodic memories—especially some birds and mammals—but that most animals, and all other organisms, do not (Clayton & Dickinson, 1998, Salwiczek et al., 2010, Templer & Hampton, 2013). Evidence also suggests that the episodic nature of such memory depends on processing loops back and forth between the deep-brain hippocampus and cortical layers (Allen & Fortin, 2013).

*Learning* is also central—but learning of an advanced sort arising from episodic memory (Nuxol, 2012). Associative learning is purely relational and occurs in many creatures without any semiosis, as a function of simple neural nets involving excitation and inhibition connected with innate reward or punishment signals. A well-studied example is the sucrose sensitivity of honeybees, a simple neural net that forms associations concerning food sources and much else (Menzel & Giurfa, 2001; Gil & De Marco, 2005; Smith et al., 2008; Peng & Chittka, 2017). In contrast, the situational learning of a songbird, such as the song sparrow's capacity to learn to gauge the varying challenges from the songs of several neighbors, is semiotic through and through (Beecher et al., 1996; Beecher & Campbell, 2005; Beecher et al., 2020). It depends on the retrieval and processing of whole episodes from a bird's life. (I present a more detailed avian example later.)

*Attention*, finally, is a more basic process than episodic memory or learning, at least in its simple forms. It is related to the salience of a stimulus—the way an organism can single out a particular stimulus from all the stimuli coming at it. Again, honeybees' sensitivity to sucrose provides a good example. For sign and meaning making, an especially complex attentional process is required, one that can sustain a recursive analysis

of incoming stimuli, taking them apart and focusing on them at both comprehensive and partial levels. This mereological or part-to-whole complexity shows the bond between complex attention and episodic memory, also made up of parts and wholes; it also points toward the aspectual nature of signs. Studies of such complex attention (Knudsen, 2007, 2018, 2020) suggest that it is the product of mediations of information in which bottom-up salience filters near the sensory input interface with further processing from top-down systems higher up in the brain. Such neural mediations are, I think, fundamental for the emergence of semiotic information, and I will touch on them again later.

Recursive attention, episodic memory, advanced learning: these foundations for semiosis are not discrete properties of certain animals but rather developing processes in their engagements with their niches. Among animals that manifest them, they help us focus on a processualism that has recently radicalized ideas of niche construction.

### Radical Niche Construction

In general, niche construction refers to the reciprocal or feedback process by which organisms build their selective environments even as those environments build them (Odling-Smee et al., 2003). Alterations in the niche brought about by populations of organisms change the selective pressures the niche exerts on the organisms, eventually changing their genomes. Niche construction tends to be thought of as a dynamic operating across long timescales, with environments and populations of organisms slowly shifting in tandem with one another—the ancestors of beavers, for example, gradually adapting to aquatic life even as their behaviors created more aquatic environments (Rybczynski, 2007).

Here, the causal circuit seems clear: a population of organisms affects its environment through its phenotypic traits, which are ultimately dependent on its genome; these effects alter the environment, in turn making certain variants in the population's phenotype more advantageous; selection finally shifts the genome of the whole population toward a genome creating the advantageous traits.

Radical niche construction goes farther: it attempts to chart across *all timescales* the pervasive plasticity of niche-constructive feedback and its impact on natural selection. Niche construction in this view is not only a long-term process but also organisms' much quicker plastic responsiveness to their changing environments. Natural selection results not in fixed capacities with discrete, advantageous functions but in open systems shifting in relation to aspects of their environments. And—most important—this plasticity reaches *from the niche all the way to genes*, which turn out to be nothing like

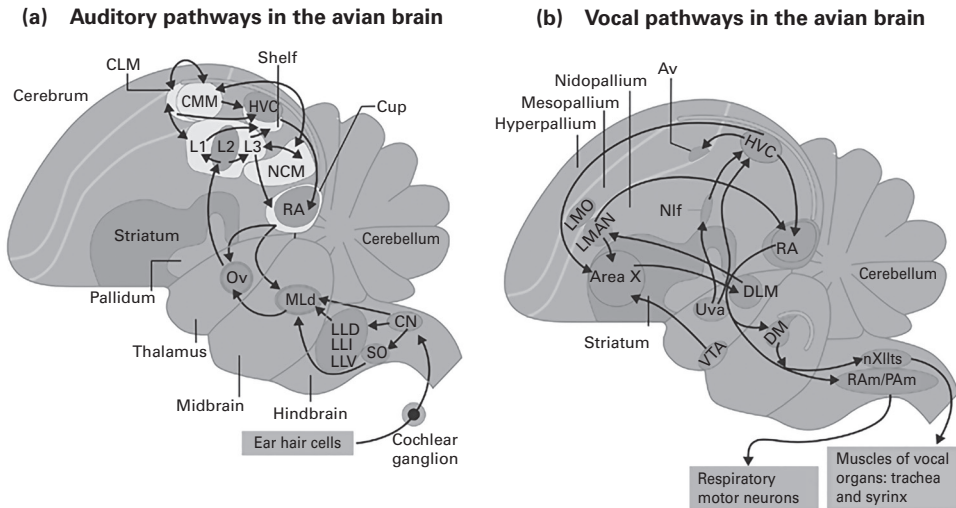
blueprints for life-forms but instead are in constant flux with the environments around them (Linksvayer et al., 2012; Laubichler & Renn, 2015).

Once again, honeybees provide an example. Dozens of pheromones are crucial in the intricate regulation of the honeybee colony or superorganism. They are produced by individual bees according to complex bioinformational pathways involving genes, RNA transcription of various sorts, proteins that genes construct, and more (Bortolotti & Costa, 2014; Ueno et al., 2015). But *the pathways run in both directions*. The genetic instructions don't run the show; instead, they are regulated by the proteins they produce, which in turn are regulated by the pheromones *they* help produce. Brief exposure to a single chemical in the cocktail that functions as an alarm pheromone alters factors inducing RNA transcription in the olfactory centers of the bee brain, shifting gene expression from moment to moment and initiating a chemical cascade that up- or down-regulates the expression of hundreds of genes. The whole network extending from niche to genes is altered almost in the blink of an eye—or the whiff of a scent (Pankiw, 2004; Alaux et al., 2010).

The effects of such plastic genomic expression enter into all aspects of honeybee existence. Similar cascades from environmental input, for example, regulate the transformation of nurse worker bees into foragers. It is now clear, in fact, that similar cascades regulate the genomic expression of all life-forms, sending chemical signals that regulate the transcription of so-called immediate early genes, which in turn regulate the expression of “late” genes.

With such radical niche construction in mind, let's return to semiosis and ask where we might seek neural substrates for the interpretant and the metarelation. We need to seek them not simply in the redoubling of parallel processing in large brains, and not even in the serial extension of processing along a sequence of distinct modules in such brains, although both probably play a role. An additional element of neural architecture is built on top of these, bringing massive parallelism and serialism to bear in modulating the processing of other connected centers. Instead of peripheral, sensory neurons directly signaling the highest processing centers along a more or less straight line of neural transmission, large vertebrate brains have processors connected to processors, all reconnected in looped feedback systems of brain centers or nuclei.

The song system in a songbird's brain, a system of nuclei enabling audition, processing, and production of song, offers an example (Bolhuis & Gahr, 2006; Jarvis, 2008; Mooney et al., 2008). This is often divided into two systems—one controlling auditory processing and another controlling song learning, memorization, and production. Figure 2.1 shows these systems in two sagittal sections of a songbird's brain, with the auditory pathway on the left and the song pathway on the right. It's easy to see that each pathway is networked in complex ways, involving many nuclei. Moreover, the



**Figure 2.1**

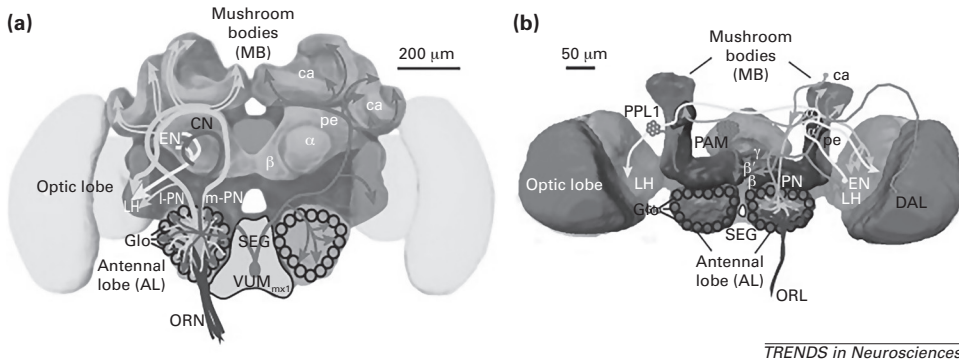
Generalized views of auditory and vocal pathways in the songbird brain. (From Berwick et al., 2012.)

two pathways are connected: the auditory nuclei are linked to the song control nuclei, linking left- and right-hand diagrams and bringing audition—the perception of niche phenomena—directly to bear on song memory and learning.

Especially important for the semiotic complexity of birdsong, I think, is the mediating role of the thalamus in these networks. It is situated between the cerebrum, with its higher processing functions, and the mid- and hindbrain. Notice that in both diagrams in the figure the thalamus doesn't merely relay processed sensory input to higher brain regions; it forms part of the feedback loops *from* higher regions involved in both song production and audition. In mammals the thalamus is a midbrain processing station mediating top-down and bottom-up networks. Recent work indicates that it is central in the complex forms of attentional focus outlined earlier, as well as being central in memory, learning, and voluntary motor behavior (Halassa & Kastner, 2017; Knudsen, 2018; Nani et al., 2019; Gu et al., 2020). The same seems to be true in songbirds.

There's nothing nearly as elaborate as these networks in the brain of a honeybee (Menzel & Giurfa, 2001; Chittka & Niven, 2009; Giurfa, 2013). As figure 2.2 shows, much of the bee's brain is taken up by the antennal lobes—the almost circular bodies near the bottom, crucial for chemosensory processing—and the optic lobes on each side, devoted to visual processing. The large areas at the top—the so-called mushroom bodies—form the integrative processing centers of the brain. The arrow starting from the bottom center and branching out into the antennal lobes and mushroom bodies (it does so bilaterally, although the diagram shows it on only one side) traces the pathway





**Figure 2.2**

The honeybee (*Apis mellifera*) brain. (From Giurfa, 2013.)

for sucrose sensitivity. It is striking in its simplicity: a single long neuron that projects from the proboscis to many regions of the brain, including motor control centers, which dictate motor responses. The complexity built into this tiny brain is amazing, but it is far outstripped by the bird brain's multiplicity of nuclei and their networks of feedback mediation through distinct levels of processing.

It is not merely the complexity of neural architecture, however, that brings about the cognitive functions of interpretant, sign, and meaning in a songbird's brain. To achieve this, the network must be set in motion as a process rather than a static architecture, a process that brings about radical niche-constructive plasticity in the face of changing affordances. The complexity of multicomponent and multilevel processing fosters an experience of input from the world proportionate to the varied complexity of the brain architecture involved. It is from this, I think, that a new fold is introduced in the experience of certain animals—and from this, they gain the parsing power that makes their percepts analytic and at the same time opens those percepts to the formative rebound from the things they analyze. From this folded, recursive percept arises the relation to a relation of things in the world, the essence of sign and meaning. Thus a radicalized niche-constructive process underlies the calling into the interpretant.

The complexities of bee behavior depend on modest attention, memory, and learning, all rendered processual and reactive to the changing environment, all transmitting causal information through the networks of radical niche construction. But the capacity of birds and some other animals to create aboutness and meaning depends on something more: complex attentional focus, meshing high- and low-level processing, and episodic memory, recalling whole situations in the past and shaping learning on

*TRENDS in Neurosciences*

the basis of them. The systems of systems exemplified by the songbird are harnessed to the plastic capacity of all organisms to remake themselves in radical, momentary negotiation with their niches.

### Birdsong Meanings

Explicit here is the placement of birds and bees on different sides of the ontological divide between semiotic and causal information. This is the divide between complexity *with* and *without* meaning; on both sides there is complexity aplenty. Honeybee society comes about through the operation of immense, intricate, beautiful, finally awesome networks of relational, causal information. There are no signs; there is no metarelation, no meaning.

Even the famous waggle dances of honeybees do not operate through signs, symbols, or anything resembling language. Every aspect of their communication has yielded up its secrets more fully over the last thirty years (see Dyer, 2002; Thom et al., 2007; Grüter & Farina, 2008; Grüter et al., 2008; Hrcir et al., 2011), and each kind of information communicated turns out to involve causal networks alone. Sensory input involving cues that are mainly mechanical and chemical is connected through short, direct neural pathways to a stereotyped response. This is not meant to underplay the complexity involved. The cues are integrated across sensory modalities in the information-processing mushroom bodies; the chemosensation taps into the pheromone cascades modulating gene expression; memories, long term but not episodic, are cued and retrieved in bees that already have foraging experience; and all this enters into the balanced, niche-constructive economies extending between foraging worker bees and worker bees in the hive that off-load their nectar and tend to the brood. Nevertheless, it all works without interpretant formation, metarelation, or signs.

Birdsong is different, involving full-fledged semiosis. The pseudoduetting of Australian magpie-larks offers a quick case study of the avian interpretant at work. Mated pairs of magpie-larks sing real duets in which the two birds synchronize their own contributions of motifs, or syllables. The syllables they sing are drawn from a species-specific repertory and, in duetting, each bird contributes syllables different from those of its partner; this alternation distinguishes the duets from their solo songs, which repeat a single syllable from the repertory. The whole performance includes not only singing but also a visual aspect: wing movements alternating between the birds in coordination with the singing. Duetting pairs perform from prominent posts in their fairly open, eucalyptus-rich habitats, seemingly to ensure the clear visibility as well as audibility of their performances. The precision of the birds' synchrony increases along with

their growing experience together as a pair—they learn to sing and dance together—and the heightened coordination elicits heightened responses from birds witnessing the performance. The meanings conveyed by magpie-larks' audiovisual duets, in other words, depend on the pair-bonded birds' coordination being perceived and gauged by potential rivals for mates and territory (Hall & Magrath, 2000, 2007; Rek & Magrath, 2016, 2017; Rek, 2018).

But there are also pseudoduets (Rek & Magrath, 2017). When one of the mated birds is absent, the magpie-lark remaining at home sometimes sings a solo song composed of contrasting syllables like a duet, instead of the usual repeated single syllable. The bird imitates, in other words, two birds performing a duet. Given the general meaning of true duets, the purpose of performing a pseudoduet seems to be to deceive listeners, signifying a coordinated coalition even though one bird is absent. This interpretation is strongly supported by a major difference between true and deceptive performances: pseudoduets are performed from hidden posts, rather than out in the open like true duets, and they are never accompanied by the wing movements of true performances. The whole visual component of true duets is suppressed in what seems to be a calculated attempt to make the deception more effective by concealing the absence of elements that would expose it.

The interpretant process in birds witnessing duets, whether true or pseudo, shows all the general features required for full semiosis: the recursive focus on stimuli, parsing or analyzing aspects of them; the resulting part-to-part representational relation between those aspects—aspects of the sign, aspects of the broader social situation, and aspects of the object; and the complex attention, episodic memory, and learning of situations and events within that social context. The sign that results is indexical, pointing both to the coalition in the social, niche-constructive context and to its strength and durability. The syllables in the songs also serve as indexes: magpie-larks perceive, in the context of their own learned song repertoires, aspects of the duets they witness that differ from solo songs and signify the coalition of the bonded pair; additionally, their perceptions are nuanced in degree, according to the coordination of the performance.

The interpretant formation on the part of the deceiving bird is even more complex. In essence, the singing bird forms an interpretant of its own interpretant, so that its own nondeceptive percept (shared with the listener) becomes the sign vehicle for an object that now comprises both the original sign and object. The sign vehicle and object brought into relation in the listener's interpretant now function together as the object of a new sign vehicle; these are brought into relation only by the singer's interpretant. A hierarchy of interpretants, absent from the listener's semiosis, builds the singer's.

The formation of this complicated semiosis, as well as similar semiotic processes in other songbirds, is dependent on the combinatorial nature of the song: its construction from small units—variously called notes, syllables, or motifs—and the nature of

their arrangement. The magpie-lark singer constructs, and the listener gauges, distinct arrangements for solo song versus duet and distinct degrees of synchronization among the syllables of the song. Such arrangements can become immensely varied and complex, even for species whose repertoires contain relatively few syllables, given the syntactic rules that often govern transitions from one syllable to another. (For a finite state diagram of the possibilities for a Bengalese finch, with about ten syllables, see Okanoya, 2012.) Moreover, it is becoming clear that birdsong communication also depends on minute details of the individual gestures that make up the songs, which differentiate one gesture from another (Amy et al., 2015; Fishbein et al., 2019).

This sort of complexity is widespread in birdsong, and it has long puzzled birdsong researchers. The basic question is this: if the message of the song is either territorial (“get off my yard!”) or sexual (“choose me!”), why expend considerable cognitive and physical resources on such syntactic intricacy? Territorial and mating signals in countless other animals are simpler and mostly nonsemiotic. The magpie-lark example shows what is becoming clear in other instances of birdsong: the meanings of the songs vary according to their combinatorial nuances in interaction with the situations or life episodes in which they’re deployed. The meanings depend, in other words, on *the combinatorial structure as niche-constructive process*.

### Hyperindexicality and Music

Meaningful syntactic arrangement in birdsong calls to mind human language, but these are not semiotically equivalent. We need to be cautious in likening birdsong to language because, although birdsong is complexly combinatorial, with nuanced differentiation of its component gestures, it seems not to be *compositional*. Linguists use this word to refer to the *two* levels of meaning in human language: meaning is found both in individual words and in words assembled in syntactic arrangement. The elements that make up birdsongs do not carry individual meanings the way human words do. Several researchers have advanced claims that they do—that there is meaning in individual syllables or motifs (Abe & Watanabe, 2011; Engesser et al., 2015; Suzuki et al., 2016). In each case, other researchers have responded with simpler, more plausible explanations of the communication observed, more in keeping with other things we know about birdsongs (Beckers et al., 2012; Bowling & Fitch, 2015; Bolhuis et al., 2018).

Birdsongs create indexical signs through syntax and combinatoriality but not compositionality. Birdsong is indexical because it forms a pointing or indicating kind of sign. It is not symbolic, because symbols derive individual meanings from their places in larger arrays of signs—like the words of language. In birdsong, meaning doesn’t “stick” to the individual syllables and motifs the way it does to words; instead, it arises

in the indexical pointing of the motifs. But even though the birdsong motifs don't carry meaning the way words do, their pointing creation of meaning is twofold: (1) the motifs point to one another in the song, according to their nuances and syntactic relations; and (2) by virtue of this internal pointing, the song as a whole points outward to the social situation in which it occurs. The motifs come to have meaning in their combination according to syntaxes like that of the Bengalese finch song.

Such an arrangement involves arrays of signs and some syntactical rules for combining them, both characteristic of symbolism; thus, we could call it *presymbolic* or *protosymbolic*. But this would, I think, confuse important issues and assert a false teleology: the progressive notion that birdsong is somehow on its way to symbolism. We should instead call the arrangements of indexes in birdsong *hyperindexical*.

I introduced this concept a few years ago in two books on human evolution to capture a stage of ancient hominin communication, before the last 100,000 years or so of human modernity (Tomlinson, 2015, 2018). This stage was not symbolic and was without full-fledged modern language, but it nevertheless negotiated complex social interactions by constructing arrays of indexes. In these Paleolithic societies, hyperindexicality was not only evident in the antecedents of modern language—in protolanguage, as it is often called. It was also at work in antecedents of modern music—*protomusic*—and in the structures of these societies' nascent rituals and in their increasingly elaborate, composite technologies. Hyperindexicality characterized all the most complex gestures of these societies, so we can speak of a *hyperindexical age* in the evolution of our hominin ancestors.

Hyperindexicality lives on today in all modern human societies and in all these gestures—ritual, technology, and even certain aspects of language, such as its phonology and intonational shapes. But the place where it is most highly developed, most intricate in its gestures, and most eloquently meaningful in their combinations is human musicking. Music is pervasively indexical, since its gestures point to one another, creating expectations of ongoing structures built from them. It is hyperindexical in joining arrays of gestures together under syntactic governance. To appreciate fully the indexical nature of music, we must picture music in itself, stripped of the webs of mainly linguistic symbols in which it is always embedded in today's human societies—and no doubt in human societies reaching back tens of thousands of years. In these societies the symbolic meanings of music are (and have been) deep and rich. But they are accretions built onto music's fundamental indexicality, layers of meaning added by a species that cannot help itself in this regard: *Homo loquens*, *Homo symbolicus*.

Think instead of an earlier hominin, our direct or indirect ancestor, presapient, without symbolic powers or modern language but adroitly deploying hyperindexical semiosis in its niche construction. Think of this ancestor vocalizing and moving and employing material prostheses ("musical instruments") to make rhythmic and sonic

patterns and entraining itself and other members of its group to these patterns. This is the protomusic I describe in *A Million Years of Music*, which formed one aspect of hominin communication in the hyperindexical age, alongside combinatorial technologies, ritualized activities and spaces, and protolanguage.

To make the telos of modern language a condition of such societies is a mistake that is still made often today, and it is evident in most of the theories of early “musical languages” dating back to Darwin and beyond. This distorts both the nature of hyperindexical societies and their subsequent histories. What was at stake for these early hominins was a particular interpretant formation, proliferating a particular kind of sign—the index—in a long-lasting stage of semiotic information transmission. We can call this stage a regime of signs, borrowing a phrase from Deleuze and Guattari, but it operated on a timescale much longer than the one they imagined for such regimes.

Today, human hyperindexicality finds its most striking manifestation in musicking. Beyond humans, it finds its most striking development in birdsong, although other, less widely dispersed instances can be adduced, particularly among cetaceans (Whitehead & Rendell, 2014). Birdsong is fundamentally like human song in its hyperindexical semiotic mode; the conditions under which a syntax of indexes can arise form the broadest, deepest connection between the two. We’ve tended to miss this forest for the trees in comparisons of birdsong and human song, which have been dominated by questions of birds’ cognitive processing of musical specifics—pitch, rhythm, and even meter. This research has discovered fascinating cognitive convergences between birds and humans and also some striking differences (Patel et al., 2009; Bregman et al., 2016; Honing, 2019; Garland & McGregor, 2020; Duengen et al., chapter 3 of this volume). It may be, for example, that birds’ processing of frequencies yields nothing quite like the pitch the human brain creates; and although metric entrainment seems to occur in some birds, the question of why it is so limited in extent beyond humans remains open. (Timbral processing, meanwhile, which takes distinct if overlapping forms in human music and language and is closely related to the cognition of pitch, remains mostly a terra incognita beyond humans.)

Such questions, however, should not be allowed to obscure the *indexical semiotic commons* we share with a significant swath of the animal kingdom, including many, many birds and some mammals. Here is a place where a richly elaborated, universal human activity—musicking—is contiguous with the elaborated indexical niche constructions of some fellow creatures. These constructions are liable to fall into our conceptualization of musicking—to be called *songs*, for example, as in the case of birds and several kinds of whales—because of this general, shared semiotic nature. Beyond this indexical commons, and no less miraculous in its effects, is the realm of causal information and of life-forms operating without signs or meaning.

This highlights the large implications of the distinction between causal and semiotic information with which we began. Semiosis founds meaning, and meaning culture, even in its most expansive, nonanthropocentric definitions, which extend it well beyond *H. sapiens* in the world today (see, e.g., Wrangham et al., 1994; Laland & Galef, 2009; Whitehead & Rendell, 2014). Human language is still more self-evidently dependent on semiosis, and symbolism, the particular type of signifying that language most distinctively embodies, is nothing other than a stage of semiotic elaboration on the far side of hyper-indexicality. The burgeoning of human symbolism, language, and culture have together been identified as a “major transition” in earthly evolution—one of those branchings in biotic diversification that have loomed large in evolutionary thought since the 1990s, adding abrupt, wholesale changes to incremental ones in our thinking about natural selective process (Maynard Smith & Szathmáry, 1995). Here, too, a forest has been missed for the trees. The specifically human outgrowths of semiosis manifested in language have been taken as the major transition, when it is the far broader advent of metarelation, sign, and interpretant, today spanning thousands of species, that deserves the name.

What, finally, would a cognitive musicology be like that founded its empiricism on a semiotic model such as the one described here? It would, first of all, see that the relations between human and nonhuman musicality are not relations of musicality per se at all, but instead are relations of shared modes of indexical niche construction manifested in different behaviors. It would ask how these distinct behaviors are differently processed, understanding that nothing like the symbolic, linguistic webs in which all human musicking is entangled today entangle nonhuman indexical systems. It would see beyond the indexical commons to the far broader commons of causal information on which all life depends, a causality manifested, for all organisms, in the moment-to-moment flux of niche construction. But in seeing this, it would also discover the difference that entered the world when certain evolved capacities resulted in the possibility of interpretant, metarelation, and meaning.

## References

- Abe, K., & Watanabe, D. (2011). Songbirds possess the spontaneous ability to discriminate syntactic rules. *Nature Neuroscience*, *14*, 1067–1074.
- Alaux, C., Maisonnasse, A., & Le Conte, Y. (2010). Pheromones in a superorganism: From gene to social regulation. *Vitamins and Hormones*, *83*, 401–423.
- Allen, T. A., & Fortin, N. J. (2013). The evolution of episodic memory. *Proceedings of the National Academy of Sciences*, *110*, 10379–10386.
- Amy, M., Salvin, P., Naguib, M., & Leboucher, G. (2015). Female signalling to male song in the domestic canary, *Serinus canaria*. *Royal Society Open Science*, *2*, 140196.



- Atkin, A. (2013). Peirce's theory of signs. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy*. <http://plato.stanford.edu/archives/sum2013/entries/peirce-semiotics>.
- Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, 4, 417–423.
- Bannan, N. (2012). *Music, language, and human evolution*. Oxford University Press.
- Beckers, G. J. L., Bolhuis, J. J., Okanoya, K., & Berwick, R. C. (2012). Birdsong neurolinguistics: Songbird context-free grammar claim is premature. *NeuroReport*, 23, 139–145.
- Beecher, M. D., Çağlar, A., & Campbell, S. E. (2020). Birdsong learning is mutually beneficial for tutee and tutor in song sparrows. *Animal Behaviour*, 166, 281–288.
- Beecher, M. D., & Campbell, S. E. (2005). The role of unshared songs in singing interactions between neighboring song sparrows. *Animal Behaviour*, 70, 1297–1304.
- Beecher, M. D., Stoddard, P. K., Campbell, S. E., & Horning, C. L. (1996). Repertoire matching between neighboring song sparrows. *Animal Behaviour*, 51, 917–923.
- Berwick, R. C., Beckers, G. J. L., Okanoya, K., & Bolhuis, J. J. (2012). A bird's eye view of human language evolution. *Frontiers in Evolutionary Neuroscience*, 13. <https://doi.org/10.3389/fnevo.2012.00005>.
- Bolhuis, J. J., Beckers, G. J. L., Buybregts, M. A. C., Berwick, R. C., & Everaert, M. B. H. (2018). Meaningful syntactic structure in songbird vocalizations? *PLOS Biology*. <https://doi.org/10.1371/journal.pbio.2005157>.
- Bolhuis, J. J., & Gahr, M. (2006). Neural mechanisms of birdsong memory. *Nature Reviews Neuroscience*, 7, 347–357.
- Bortolotti, L., & Costa, C. (2014). Chemical communication in the honey bee society. In C. Mucignat-Caretta (Ed.), *Neurobiology of chemical communication*. CRC Press/Taylor and Francis.
- Bowling, D., & Fitch, W. T. (2015). Do animal communication systems have phonemes? *Trends in Cognitive Sciences*. <https://doi.org/10.1016/j.tics.2015.08.011>.
- Bregman, M., Patel, A. D., & Gentner, T. Q. (2016). Songbirds use spectral shape, not pitch, for sound pattern recognition. *PNAS*, 113, 1666–1671.
- Chittka, L., & Niven, J. (2009). Are bigger brains better? *Current Biology*, 19, R995–1008.
- Clayton, N.S., & Dickinson, A. (1998). Episodic-like memory during cache recovery by scrub jays. *Nature*, 395, 272–274.
- Dennett, D. C. (1995). *Darwin's dangerous idea: Evolution and the meanings of life*. Simon & Schuster.
- Dennett, D. C. (2017a). A difference that makes a difference: A conversation. *Edge*. [https://www.edge.org/conversation/daniel\\_c\\_dennett-a-difference-that-makes-a-difference](https://www.edge.org/conversation/daniel_c_dennett-a-difference-that-makes-a-difference).
- Dennett, D. C. (2017b). *From bacteria to Bach and back: The evolution of minds*. Norton.
- Dyer, F. C. (2002). The biology of the dance language. *Annual Review of Entomology*, 47, 917–949.



- Engesser, S., Crane, J. M. S., Savage, J. L., Russell, A. F., & Townsend, S. W. (2015). Experimental evidence for phonemic contrasts in a nonhuman vocal system. *PLoS Biology*, *13*, e1002171.
- Fishbein, A. R., Idsardi, W. J., Ball, G. F., & Dooling R. J. (2019). Sound sequences in birdsong: How much do birds really care? *Philosophical Transactions of the Royal Society B*, *375*, 20190044.
- Fodor, J. (1990). *A theory of content and other essays*. MIT Press.
- Garland, E. C., & McGregor, P. K. (2020). Cultural transmission, evolution, and revolution in vocal displays: Insights from bird and whale song. *Frontiers in Psychology*, *11*, 3389.
- Gil, M., & De Marco, R. J. (2005). Olfactory learning by means of trophallaxis in *Apis mellifera*. *Journal of Experimental Biology*, *208*, 671–680.
- Giurfa, M. (2013). Cognition with few neurons: Higher-order learning in insects. *Trends in Neurosciences*, *36*, 285–294.
- Grüter, C., Balbuena, M. S., & Farina, W. M. (2008). Informational conflicts created by the waggle dance. *Proceedings of the Royal Society B*, *275*, 1321–1327.
- Grüter, C., & Farina, W. M. (2008). The honeybee waggle dance: Can we follow the steps? *Trends in Ecology and Evolution*, *24*, 242–247.
- Gu, Q. L., Lam, N. H., Halassa, M. M., & Murray, J. D. (2020). Circuit mechanisms of top-down attentional control in a thalamic reticular model. *bioRxiv*. <https://doi.org/10.1101/2020.09.16.300749>.
- Halassa, M. M., & Kastner, S. (2017). Thalamic functions in distributed cognitive control. *Nature Neuroscience*, *20*, 1669–1679.
- Hall, M. L., & Magrath, R. D. (2000). Duetting and mate-guarding in Australian magpie-larks (*Grallina cyanoleuca*). *Behavioral Ecology and Sociobiology*, *47*, 180–187.
- Hall, M. L., & Magrath, R. D. (2007). Temporal coordination signals coalition quality. *Current Biology*, *17*, R406–407.
- Honing, H. (2019). *The evolving animal orchestra: In search of what makes us musical*. MIT Press.
- Hrncir, M., Maia-Silva, C., McCabe, S. I., & Farina, W. M. (2011). The recruiter's excitement—features of thoracic vibrations during the honey bee's waggle dance related to food source profitability. *Journal of Experimental Biology*, *214*, 4055–4064.
- Jarvis, E. D. (2008). Brains and birdsong. In P. Marler & H. Slabbekoorn (Eds.), *Nature's music: The science of birdsong* (pp. 226–271). Elsevier.
- Knudsen, E. I. (2007). Fundamental components of attention. *Annual Review of Neuroscience*, *30*, 57–78.
- Knudsen, E. I. (2018). Neural circuits that mediate selective attention—a comparative perspective. *Trends in Neuroscience*, *41*, 789–805.
- Knudsen, E. I. (2020). Evolution of neural processing for visual perception in vertebrates. *Journal of Comparative Neurology*, *528*, 2888–28901.

- Laland, K. N., & Galef, B. G. (2009). *The question of animal culture*. Harvard University Press.
- Laubichler, M. D., & Renn, J. (2015). Extended evolution: A conceptual framework for integrating regulatory networks and niche construction. *Journal of Experimental Zoology B: Molecular and Developmental Evolution*, *324*, 565–577.
- Linksvayer, T. A., Fewell, J. H., Gadau, J., & Laubichler, M. D. (2012). Developmental evolution in social insects: Regulatory networks from genes to societies. *Journal of Experimental Zoology: Molecular and Developmental Evolution*, *318*, 159–169.
- Maynard Smith, J., & Szathmáry, E. (1995). *The major transitions in evolution*. Oxford University Press.
- Menzel, R., & Giurfa, M. (2001). Cognitive architecture of a mini-brain: The honeybee. *Trends in Cognitive Sciences*, *5*, 62–71.
- Mooney, R., Prather, J., & Roberts, T. (2008). Neurophysiology of birdsong learning. In H. Eichenbaum (Ed.), *Learning and memory: A comprehensive reference* (vol. 3, pp. 441–474). Elsevier.
- Nani, A., Manuello, J., Mancuso, L., Liloia, D., Costa, T., & Cauda, F. (2019). The neural correlates of consciousness and attention. *Frontiers in Neuroscience*, *13*, 1169.
- Nuxol, A. (2012). Episodic learning. In *Online encyclopedia of the sciences of learning*. [https://doi.org/10.1007/978-1-4419-1428-6\\_1362](https://doi.org/10.1007/978-1-4419-1428-6_1362).
- Odling-Smee, F. J., Laland, K., & Feldman, M. W. (2003). *Niche construction: The neglected process in evolution*. Princeton University Press.
- Okanoya, K. (2012). Behavioural factors governing song complexity in Bengalese finches. *International Journal of Comparative Psychology*, *25*, 44–59.
- Pankiw, T. (2004). Cued in: Honey bee pheromones as information flow and collective decision-making. *Apidologie*, *35*, 217–226.
- Patel, A., Iversen, J. R., Bregman, M. R., & Schulz, I. (2009). Experimental evidence for synchronization to a musical beat in a nonhuman animal. *Current Biology*, *19*, 827–830.
- Peirce, C. S. (1955). *Philosophical writings of Peirce* (J. Buchler, Ed.). Dover.
- Peng, F., & Chittka, L. (2017). A simple computational model of the bee mushroom body can explain seemingly complex forms of olfactory learning and memory. *Current Biology*, *27*, 224–230.
- Rek, P. (2018). Multimodal coordination enhances the responses to an avian duet. *Behavioral Ecology*, *29*, 411–417.
- Rek, P., & Magrath, R. D. (2016). Multimodal duetting in magpie-larks: How do vocal and visual components contribute to a cooperative signal's function? *Animal Behaviour*, *117*, 35–42.
- Rek, P., & Magrath, R. D. (2017). Deceptive vocal duets and multimodal display in a songbird. *Proceedings of the Royal Society B*, *284*, 20171774.

- Rybczynski, N. (2007). Castorid phylogenetics: Implications for the evolution of swimming and tree-exploitation in beavers. *Journal of Mammalian Evolution*, *14*, 1–35.
- Salwiczek, L. H., Watanabe, A., & Clayton, N. S. (2010). Ten years of research into avian models of episodic-like memory and its implications for developmental and comparative cognition. *Behavioural Brain Research*, *215*, 221–234.
- Savage, P., Loui, P., Tarr, B., Schachner, A., Glowacki, L., Mithen, S., & Fitch, W. (2021). Music as a coevolved system for social bonding. *Behavioral and Brain Sciences*, *44*(e59), 1–22.
- Shannon, C. E., & Weaver, W. (1949). *The mathematical theory of communication*. University of Illinois Press.
- Smith, D., Wessnitzer, J., & Webb, B. (2008). A model of associative learning in the mushroom body. *Biological Cybernetics*, *99*, 89–103.
- Suzuki, T. N., Wheatcroft, D., & Greisser, M. (2016). Experimental evidence for compositional syntax in bird calls. *Nature Communications*. <https://doi.org/10.1038/ncomms10986>.
- Templer, V. L., & Hampton, R. R. (2013). Episodic memory in nonhuman animals. *Current Biology*, *23*, R801–806.
- Thom, C., Gilley, D. C., Hooper, J., & Esch, H. E. (2007). The scent of the waggle dance. *PLOS Biology*, *5*, 1862–1867.
- Tomlinson, G. (2015). *A million years of music: The emergence of human modernity*. Zone.
- Tomlinson, G. (2018). *Culture and the course of human evolution*. University of Chicago Press.
- Tomlinson, G. (in press). *The machines of evolution and the scope of meaning*. Zone.
- Tulving, E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson (Eds.), *Organization of memory* (pp. 381–402). Academic Press.
- Ueno, T., Takeuchi, H., Kawasaki, K., & Kubo, T. (2015). Changes in gene expression profiles of the hypopharyngeal gland of worker honeybees in association with worker behavior and hormonal factors. *PLOS ONE*. <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0130206>.
- Wallin, N. L., Merker, B., & Brown, S. (2000). *The origins of music*. MIT Press.
- Whitehead, H., & Rendell, L. (2014). *The cultural lives of whales and dolphins*. University of Chicago Press.
- Wrangham, R. W., McGrew, W. C., de Waal, F. B. M., & Heltine, P. G. (1994). *Chimpanzee cultures*. Harvard University Press.

© 2023 Massachusetts Institute of Technology

This work is subject to a Creative Commons CC-BY-ND-NC license. Subject to such license, all rights are reserved.



The MIT Press would like to thank the anonymous peer reviewers who provided comments on drafts of this book. The generous work of academic experts is essential for establishing the authority and quality of our publications. We acknowledge with gratitude the contributions of these otherwise uncredited readers.

This book was set in Stone Serif and Stone Sans by Westchester Publishing Services.

Library of Congress Cataloging-in-Publication Data

Names: Margulis, Elizabeth Hellmuth, editor. | Loui, Psyche, editor. | Loughridge, Deirdre, editor.

Title: The science-music borderlands : reckoning with the past and imagining the future / edited by Elizabeth H. Margulis, Psyche Loui, and Deirdre Loughridge.

Description: Cambridge, Massachusetts : The MIT Press, 2023. | Includes bibliographical references and index.

Identifiers: LCCN 2022014716 (print) | LCCN 2022014717 (ebook) | ISBN 9780262047647 (paperback) | ISBN 9780262373036 (epub) | ISBN 9780262373043 (pdf)

Subjects: LCSH: Music—Psychological aspects. | Musical ability. | Cognition. | Neuropsychology.

Classification: LCC ML3830 .S293 2023 (print) | LCC ML3830 (ebook) | DDC 781.1/1—dc23/eng/20220328

LC record available at <https://lcn.loc.gov/2022014716>

LC ebook record available at <https://lcn.loc.gov/2022014717>