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Communication in noise is the window on cognition

Commentary on **Ristau** on *Donald Griffin*

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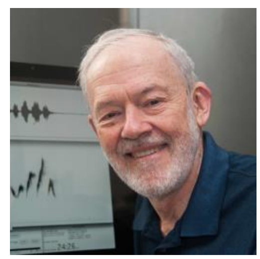
Abstract: As Griffin surmised, communication is the window on cognition, but as shown here, only if it is noisy. This commentary is an invitation to consider the full implications of the evolution of noisy communication. A combination of Information Theory, Signal Detection Theory, and Natural Selection, in a unified theory of the evolution of communication, reveals that noise is inevitable. All organisms are thus decision makers. Perception, thought, freedom of decision, self-awareness, metabolism, and natural selection all share the consequences of signals in noise. A full understanding of each requires attention to the errors of receivers. Griffin's hunch is correct with one emendation: it is noisy communication that provides the window on cognition.

R. Haven Wiley, Professor Emeritus of Biology, University of North Carolina, studied with Donald Griffin at Harvard University and with him and Peter Marler at The Rockefeller University. He then taught and studied animal communication and social behavior for 40 years at Chapel Hill. His own and his students' research on noise in communication eventually led to a unified theory of the evolution of communication and perception. **Website**



1. Griffin's Conundrum. Donald Griffin changed everything by confirming that bats use high-frequency sounds to echolocate. Gone was the old assumption of a Chain of Being, in which cognitive abilities of all animals were subsets of those of humans. Bats occupy a sensory world completely closed to humans, only approximated with the assistance of electronic devices. Griffin, then, was the first American to promote Karl von Frisch's discovery of the orientation and dance language of honeybees. It had thus become clear that no animal could any longer be assumed to be cognitively just an incomplete human. Griffin went on to emphasize that the key to understanding cognition was communication. This insight no doubt led him to promote the hiring of Peter Marler as his colleague at The Rockefeller University. Marler (1974) had provided the first evidence that communication evolved by natural selection and went on to explore the connection between predispositions and learning in the development of communication by young birds.

Griffin finally became a strong advocate for consciousness, self-awareness, and cognition by many animals (Ristau, 2024). As I began my own explorations of animal behavior, he and Peter Marler were my models. Yet I balked at Griffin's position on one issue: the relationship of minds to machines. In his first book on this topic, after briefly addressing the status of the private feelings of humans (Griffin 1976: 42-43), he demurred that "the relationship between minds and computers is outside the scope of this book". Yet a few lines later he concluded, after considering the physiology of locomotion, "I suspect, minds depend entirely on the functioning of central nervous systems, yet exhibit properties not easily predictable from even the most complete analysis of neurons and synapses". Although he never addressed this issue again, he seemed to admit grudgingly the possibility that minds are perhaps not entirely mechanical. In other words, no machine perhaps can a have mind. Regardless of my hunch otherwise, I had no response.

I settled into a career of exploring adaptations in communication and social behavior. Meanwhile the literature filled with continuing controversies about signals versus cues, information versus manipulation, kin selection versus superorganisms, mate choice versus ecology, and cognition versus rote learning. There seemed to be no agreement.

2. A Unified Theory of the Evolution of Communication. As I dug more into adaptations that counteract noise in communication by birds, I felt that pieces of answers lay all around, albeit ignored by investigators of animal behavior. What about Information Theory by Claude Shannon, who had defined noise and signals? What about Signal Detection Theory, which had become a routine basis of sensory psychology? Were these approaches relevant to explanations of phenotypic evolution by Game Theory and Decision Theory? Was ordinary Natural Selection of genes relevant?

After decades of exploring these disparate pieces and finally resolving the mathematical issues, at a time near an age for retirement, I could see that these pieces in fact all fit together into a *Unified Theory of the Evolution of Communication in Noise*. Nothing was new in itself, just the incorporation of each piece in its correct place. And the ramifications of such a unified theory were beyond my anticipation. Donald Griffin was, more than I had realized, correct in thinking that communication was the gateway to cognition. And he need not have demurred about machines and cognition. Communication is a gateway to a mechanistic understanding of cognition in all organisms.

The remainder of this essay is an invitation to consider the consequences of noise as an inevitable factor in the evolution of communication. A start in this direction is provided in my two recent books (Wiley, 2015, 2023), the second of which, "*Noise in the Evolution of Communication and Thought: How Natural Selection and Noise Shape Human and Animal Minds",* is a self-published compilation of articles (Wiley, 2017, 2021), with several additional essays, that detail the relevant topics. It is available from amazon.com or as a pdf without charge.

To begin with, clear definitions of a signal and noise are needed. A signal is any sensory input associated, more often than by chance, with a response by any receiver (so much is pure Shannon), and, also crucially, it does not provide all of the power for the response. The receiver thus is in charge of the response. Noise is any error by a receiver in responding to a signal (again pure Shannon). Noise has manifold possible sources: uncertainties during transmission of signals, as well as uncertainties in the production of signals or in the reception of signals. Noise includes masking by signals from other individuals or from signals that deceive a receiver. Regardless of its source, noise is measured by errors of an appropriate receiver for a signal.

Signal Detection Theory, well established in studies of human sensory capabilities and by extension in diverse studies of subject's responses, makes it clear that any receiver responding to signals faces an unavoidable trade-off between false alarms and missed detections. When a receiver checks its sensors, all it can know are two states of the world: either its sensory input exceeds its criterion for a response or not. A criterion might be a threshold or a complex cognition, in any case set by natural selection and experience. Yet there are actually four outcomes for the receiver as it responds or not: either a correct detection or a false alarm (if input meets the criterion) or a correct rejection or a missed detection (if it is not). A receiver sets its criteria for its responses. The frequencies and the benefits minus costs of each outcome determine the receiver's overall benefit from any criterion. Furthermore, a receiver faces a trade-off between the possibilities for false alarms and missed detections; any adjustment of a criterion for response will decrease one kind of error and increase the other. In a similar way, there is a trade-off between correct detections and rejections. The most important conclusion about communication is thus that any receiver, whenever it sets a criterion for a response, determines the trade-offs it must face.

Communication thus defined need not involve organisms, but when it does, any organism involved is also subject to natural selection. A simple arithmetic definition of Natural Selection in a population of reproducing individuals is a change in the frequency of heritable features, as a result of differences in the reproduction or survival of individuals with and without these features. By this definition of Natural Selection, an error by a receiver is defined as a response that does not increase the receiver's survival or reproduction (or sufficiently those of a close genealogical relative). Two conclusions for communication between organisms are thus that receivers must realize a benefit by responding on average, even if not in every instance of a response, and a signaler must realize a benefit on average, even if not in every instance of producing a signal.

The challenge at this point is to understand mathematically how criteria for responses and exaggeration of signals can evolve concomitantly. After all, signalers realize no evolutionary benefit without appropriate responses, and receivers no benefit without appropriate signals. Natural selection produces an initially accelerating spread of the beneficial features of both parties and eventually a decelerating spread in the approach to fixation. A special case of this general problem is the mutual evolution of mate choice and advertising behavior. When signaler and receiver mate, their progeny across generations tend to inherit features of both parties, which reinforces their mutual spread. Either case can be modeled by changes in either genes or heritable phenotypes during transmission across generations. Analytical solutions are also available for the transmission of genes in the specific case of mate choice (recently, Servedio 2024). A few analyses of the evolution of communication have included variation in responses (Johnstone & Grafen 1992), but they do not include the trade-offs required in noise. These trade-offs are now incorporated in an analytical solution for the general case of the evolution of noisy communication, as presented in my publications (see references).

There is a second important conclusion about the evolution of noisy communication: noise is inescapable. The trade-offs that receivers face in responding to signals and that signalers face in producing them make it impossible for communication ever to evolve perfection. Receivers that make no mistakes and signalers that always get an appropriate response never evolve. Communication as it evolves by natural selection is always noisy.

3. Ramifications of the Unified Theory of the Evolution of Communication and Closure for Griffin. Perception is a subset of communication. It is no more than a receiver's response to stimulation that need not come from another organism. All the conclusions about receivers in communication apply also to perception: receivers must make decisions when to respond; and errors are inevitable. Furthermore, thoughts, which are no more than communication between signaling and receiving neurons within a brain, must be subject to the same constraints on receivers in noise. A unified theory of communication thus applies to perception and thought as well.

Consider how this perspective changes the nature of some perennially thorny issues. The necessity of decisions results in freedom of choice, in the sense that receivers set their criteria for responses, by natural selection and experience, but always in noise. Self-awareness occurs in brains capable of second-order communication about memories and responses, noisy communication as always. In comparisons among diverse organisms, self-awareness must vary in complexity in accordance with the complexity of second- or higher-order communication in a brain.

Furthermore, the metabolism of organisms is a complex network of signals and receptors at the molecular level, all evolved and developed in the inevitable presence of noise. The development of any organism, including all signaling and responding, results from interactions of genes and environment, interactions that are responses of genes, singly or in combinations, to signals from their environments. These constraints imposed by noise on signals and responses apply to all organisms, from bacteria to humans and plants to fungi and animals. All organisms respond to signals, and all are all decision-making mechanisms in the presence of noise.

As Griffin and von Frisch first demonstrated, not all brains are the same, much less subsets of one super brain. Natural selection is itself no more than the result, across generations, of responses by organisms to their environments, thus a form of noisy perception and communication. Of all these contexts for noisy communication, just a few have ever been examined to assess the trade-offs required for receivers' decisions in noise.

Most studies of noise in animal behavior focus on masking noise in the environment, particularly adaptations by natural selection or experience to reduce masking by low-frequency anthropogenic noise. A few have explored the effects of noise on mate choice, recognition, or alternative ways to avoid masking (see the list of references). Nevertheless, the significance of noise for a full understanding of cognition, behavior, metabolism, or natural selection has never been thoroughly incorporated in the voluminous literature on these subjects. Yet an analysis of communication in noise indicates that a full understanding of any of these topics cannot be attained without considering receivers' errors in noise.

In the end, Donald Griffin might have some closure in his search for a completely mechanical understanding of minds. Feelings, the thorniest of his issues for a mechanical understanding, are no more than thoughts, just responses to signals within brains. The inevitable errors of signal reception in noise should open paths for mechanistic investigation of all the manifold features of cognition. Such a development might resolve Griffin's ultimate uncertainty about minds and machines.

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