Problems for Predictive Information

ABSTRACT: Predictive information is a popular and promising family of information-based

theories of biological communication. It is difficult to adjudicate between predictive

information-based theories and influence-based theories of biological communication because

the same acts seem to count as communicative on both theories. In this paper, I argue that

predictive information theories and influence-based theories give importantly different

descriptions of deceptive signals in some non-evolutionarily stable communicative systems

observed in nature. Moreover, predictive information gives a counter-intuitive description while

some of its rival influence-based theories do not. I argue that there are no clear ways for

defenders of predictive information to respond to this apparent problem without sacrificing

important virtues of their theory.

0.0 Introduction

Opponents of information-based theories of biological communication allege that

"information" is an underdeveloped and ultimately unhelpful concept for understanding

biological communication. Nothing like information is literally transferred. Instead of appealing

to this vague and slippery notion, these opponents claim that we can give a full description of

biological communication by appealing to influence without any appeal to information transfer.[1]

The popular and influential family of views that Scarantino (2013) calls "predictive information"

theories meets these challenges by presenting a clear understanding of information and describing how that information is literally transferred.[2] According to this family of views, an act or structure carries predictive information about a state because it is correlated with that state.[3] One problem for adjudicating between the influence-based and these information-based definitions of "communication" is that they appear coextensive. The same interactions seem to count as communicative on both views.

This paper demonstrates that in some out-equilibrium cases the two families of theories come apart, and predictive information-based theories give counter-intuitive descriptions of observed phenomena. Furthermore, there is no clear way to respond to these problems for predictive information without sacrificing important virtues of the theories. The value of this paper is threefold: First, it presents a novel problem for a popular family of theories of biological communication. Second, this paper shifts the terrain of the ongoing debate from theoretical virtues and vices of predictive information-based theories to how the theories accommodate first-order facts about communication. Third, the kind of case described below may be useful beyond the scope of this paper as a testing ground for successful theories of deceptive communication not considered here. The implications for whether or not something like predictive information-based theories of communication succeed or fail should be of interest to anyone interested in communication. If biological communication operates like a conduit for information, as it is often described, the there must a kind information that is transferred. What's at stake in finding a satisfactory account of information, in this context, is understanding the nature of biological communication. This larger debate has downstream implications for thinking

about how continuous and/or discontinuous human natural languages are with other kinds of communication.

Given the fact that biological communication need not be evolutionarily stable and the prevalence of mimicry in nature, proliferation of mimicry can lead to a scenario where an act or structure no longer statistically correlates with the state it once did. This can happen slowly as the number of mimicked signals overtakes the number of honestly produced signals (Figure A). It can also happen quickly through a rapid extirpation of the mimics' model. Depending on adaptation rates of the original signal's receiver, the mimicked act or structure will still be effective for a period of time after the extirpation of the model. In these cases, mimicry may be widespread with no honest signaling (Figure B). Given the timescales involved, the former cases are difficult to study, but the latter case has been observed in nature. It turns out that widespread mimicry with no honest signaling can last decades.[4]

I demonstrate that such cases lead to scenarios with apparently counterintuitive results wherein, according to predictive information theories of communication, either apparent signals are not actually signals, or apparently honest or deceptive signals are not respectively honest or deceptive. In light of this conclusion, we can (1) reject the view that predictive information is always transmitted in biological communication, (2) modify what counts as predictive information, or (3) maintain the view that predictive information is the content of signals.

Here is a roadmap for what follows. In Section 1, I give a brief overview of predictive information. In Section 2, I describe an observed case where honest signalers go locally extinct, but the mimicry continues for decades. I explain why this case breaches the coextension of the two families of views. In Section 3, I look at the three options, and I argue that option (1) is

available for influence-based theorists among others. Routes for option (2) that avoid the problems effectively abandon central goals of predictive information theories. Option (3) bars apparently communicative interactions from counting as signals. I concede that there may be reasons for not counting these apparent interactions as signals, but I argue that endorsing these reasons may deflate the disagreement between information-based views and influence-based views.

1.0 Predictive Information

Skyrms (2010) claims that the *informational content* of an act or structure consists in how that act or structure changes probabilities. The *quantity of information* consists in the degree to which it changes probabilities. Signals, then, carry information about some state because they change the probability of that state. Imagine that only 25% of snakes in some ecosystem are venomous, but 80% of brightly colored banded snakes are venomous. The bright bands of some particular snake carries information about the status of the snake because it changes the probabilities that she is venomous from 25% to 80%. Skyrms writes that this information flows through signals in biological communication, though this information is, in a sense, everywhere whether it is transmitted to anything or not. Dark clouds bear information that rain is impending regardless of whether or not anyone can interpret them.

Scarantino's analysis of predictive information is similar to Skryms's but, unlike Skyrms's, Scarantino's analysis includes the receiver: "X carries information about Y relative to background knowledge k when P(Y given X & k) ≠ P(Y given k)" (Scarantino 2013: 86). Here, some potential receiver with knowledge that the probability changes given some act or structure is needed for an act to transmit information. In other words, the snake's skin pattern carries

information to some receiver, only if some other organism "knows" that this pattern increases the likelihood of her being venomous. Whatever Scarantino means by "knowledge" is not psychologically demanding. There need be nothing more than a disposition to act in some way in the face of some stimulus. This sense of "knowledge" is, however, factive. In the snake example, the background knowledge is a disposition to act in a way advantageous *given actual probability differences*.

These accounts demonstrate that predictive information can clearly meet some of the challenges of the opponents of information-transfer. The source of the information is objective correlations between different states in the world such that one state raises the probability of another. Natural selection favors the ability for receivers to exploit this covariance. This provides a naturalistic explanation for the source and reception of the information flow. The channel of the information flow can potentially exploit any sensory faculties at the receiver's disposal. The demand for a "literal transfer" is met; there is an objective probability that some state obtains, and that probability is received by some organism who may use it as an input to various action decisions.

Three observations need to be made before proceeding. First, as said earlier, the transfer of information is only a necessary condition for signaling on the theories I am concerned with. Various predictive information theories may have other conditions that need to be met before something counts as a biological signal. Second, an important virtue of the theory that predictive information is the content of biological signals is how the theory understands deception. A token deceptive signal raises the probability of a non-obtaining state. A non-venomous, brightly-banded snake raises the probability that it is venomous even though it is not actually

venomous. The mimicked signal is deceptive. In Skyrms's parlance, it transmits "misinformation."[5] The informational content of the venomous and non-venomous snakes' signals are the same. The information simply counts as misinformation for one and not the other. Skyrms term "misinformation" is not widely shared; however, a sense of the need for some philosophical account of biological deception is emerging.[6]

The third observation is that the probability change that predictive information tracks is a change in objective probability. This observation is more obvious on Skyrms' account where information is everywhere. As will be discussed later, Scarantino depends on predictive information tracking changes in objective probability for his defense against the charge that information transfer is only metaphorical. There are other cases of out-of-equilibrium communication that include new signals, continually evolving strategies, communicators with divergent goals, and changes in the environment that affect the sender's and/or receiver's payoffs. Many of these cases may yield interesting results for theories of information and warrant further inquiry, but I do not further consider them here.

2.0 The World Can Change Faster than the Predictors

A signaling system need not be evolutionarily stable to function.[7] One threat to the stability of communication systems is the proliferation of deception.[8] Continuing our hypothetical example, a growing number of non-venomous snakes may mimic the banded skin of the venomous snakes (*Batesian mimicry*). If mimicry proliferates enough, then the probability change of being venomous given bright bands can reach zero. This happens at T_3 in Figure A. By T_5, the skin pattern ceases to carry predictive information.[9] Note that for the banded skin to cease carrying predictive information, the probability of being venomous given banded skin does not

merely need to fall to .50. It needs to fall to or below the probability that the snake is venomous irrespective of the skin pattern: .25 in this hypothetical example.

One might expect that receivers will stop responding to the skin pattern before the change in probability reaches zero. However, this is not an evolutionary necessity. Receivers will eventually stop responding to the skin patterns, but if the adaptation rate is sufficiently higher in the mimic snakes than in the receivers, this inevitability may be slow coming. In the meantime, snakes will still produce the bands, and receivers will respond to the bands even though the banded skin carries no predictive information.

This loss of predictive information does not come about only by proliferation of the cheaters. It can also come about by the extirpation of the honest signalers. This exact phenomenon has been observed. Akcali and Pfennig (2014) examine the continued evolution of mimic scarlet kingsnakes in the Sandhills region of North Carolina following the local extinction of eastern coral snakes, the model for the mimic. The coral snake went locally extinct in the Sandhills around 1960 (T_{3*} in Figure B). Akcali and Pfennig examined kingsnake specimens from the following decades and discovered that the signalling system did not break down. Instead the kingsnakes evolved a more precise mimicry of the now absent model.[10] The evolution of the scarlet kingsnake's more precise mimicry does not just piggyback the evolution of kingsnakes in regions with coral snakes. Akcali and Pfennig show that in other regions the precision of mimicry has not changed during the same time period. The change is also not a mere accident of the environment; biologically similar but non-mimetic snakes in the region have not changed during the same time period.

In the post-1960 Sandhills, bright bands decrease the probability that a snake is venomous. The odds that any snake in the area is venomous is higher than zero; the odds that a brightly banded snake is venomous is 0. On Skyrms's account, the colored bands must carry information that the snake is not venomous. There is another kind of information that signals carry on Skyrms' account.[11] So far, I have only discussed what Skyrms calls "information about the state;" however, when a signal consistently correlates with a particular response to that signal, that signal carries information about that response. It carries information about the established response because it changes the probabilities that the response will occur. Skyrms calls this "information about the act."[12] The present day kingsnakes in the area still carry the same information about the act – that responders will avoid them – even though they carry different information about the state. This is essentially another way of stating the mismatch between the systematic effects of the signal and the state that it signals. Because misinformation is a kind of information about the state, the bright bands do not carry misinformation. The kingsnakes actively deceive without carrying deceptive content.

On Scarantino's account, the colored bands carry no information to receivers because no receivers have relevant background knowledge. On neither account does the kingsnake's bands carry misinformation, despite successfully manipulating the receivers. The content of the signal has changed, but not the effect. The behavior deceives receivers, but this is no longer explained by the informational content.

Compare the predictive information accounts of this phenomenon to an influence-based theory of communication. Thom Scott-Phillips defines communication as "an interaction in which an action [or structure] causes a reaction, where both the action and the reaction are

designed to be a part of the interaction." Scott-Phillips defines "signal" as the action or structure in communication. Content plays no role. To better understand his proposal consider the coral snake's skin pattern. Presumably, natural selection favored animals that avoided venomous coral snakes, and one of the means of discriminating coral snakes from other snakes was visual. At this point, the coral snake's bright bands are only a *cue*, not a full-fledged signal because it is not designed to cause the reaction (avoidance) in other animals. Only the reaction is designed by natural selection to be a part of this interaction. Now that the reaction has been reinforced by evolution, the coral snake benefits by being more easily discriminated from other snakes, and thus natural selection favors the production of more easily identifiable skin patterns. Now the skin pattern is designed to be a part of the interaction. At this point in the process, the interaction constitutes communication, and the pattern is a signal.

In this evolutionary story, there is a designed reaction in some animals to avoid brightly banded snakes. This creates evolutionary pressures for mimicry. This pressure leads to the mimic scarlet kingsnake's production of the skin pattern, which is also designed to cause the avoidance reaction. The response is still designed to be a reaction to tokenings of the brightly banded skin type, even though natural selection designed it because of the coral snake's tokenings and not the kingsnake's. So, on Scott-Phillips's account, deceptively produced actions or structures still count as communicative signals. I am not aware of an influence-based analysis of deception or honesty, but given the role that teleological notions like "designed for" play in influence-based theories, it seems to me that we should understand honest signals as signals whose responses could fulfill their *biological function*, using something like Millikan's (1984) definition of "biological function." Dishonest signals are signals tokened in circumstances in which their

response could not fulfill their biological function.[13] If this is right, then the mimic's skin pattern, in this scenario, counts as deceptive before and after the extinction of the model. There appears to be, then, a mismatch between whether the kingsnake's pattern constitutes a signal, or at least a deceptive signal, on the predictive information view and the influence-based view.

As mentioned above, the target of this essay is not every information-based theory of biological communication, but a narrow family of views. Other theories do not entail that the informational content of kingsnakes' skin patterns has changed after the local extinction of coral snakes. For example, some teleosemantic views that do not require cooperation between signal producer and receiver will count the kingsnake's skin pattern as a signal with the content that the snake is venomous even after the local extinction of coral snakes. Stegmann's (2009) consumer-based teleosemantic theory has this conclusion.[14] I should also point out that other out-of-equilibrium may yield counterintuitive results for different analyses of predictive information.

3.0 Three Responses

So far, I have described a scenario in which predictive information theories cannot reckon a structure type as a signal for being venomous despite it having the same effect as a signal for being venomous. Influence-based theories do not posit signal content for all biological signals. Instead of discriminating signals on the basis of content, they discriminate signals on the basis of design. In the scenario under question the structure is still designed to cause the response it in fact causes. This scenario is exemplified by the scarlet kingsnakes in the Sandhills region of North Carolina. There seem to be three possible responses to the scenario: first, reject the theory that predictive information transfer is a necessary component to signaling; second, revise

predictive information so that the kingsnake's skin pattern does transmit information that it is

venomous; or third, maintain the view that predictive information is still the content of signals,

and accept that the kingsnake's skin pattern ought not signal its being venomous. More simply

put the options are (1) reject predictive information transfer, (2) revise predictive information

transfer, or (3) continue to accept that predictive information transfer is necessary for biological

communication. Below I raise worries for the second and third options that any theorists taking

these routes ought to address.

3.1 Option 1: Signals need not have Predictive Information as Their Content

The first option is to reject the view that signals must have predictive information as their

content. Signals do not necessarily transfer predictive information. Endorsing this option may

entail adopting some other analysis of information or adopting an influence-based theory of

communication eschewing information altogether. Above I suggest that Thom Scott-Phillips's

influence-based theory of communication uniformly handles communication in evolutionarily

stable systems and in systems overrun with deception. I do not take this paper to provide

evidence that influence-based theories are preferable to other information-based theories, though

the Sandhills region snakes provide a useful testing ground that can be applied to other

information-based theories.

3.2 Option 2: Revise the Theory

For convenience, call the last coral snake in the Sandhills "Coretta" and some current

kingsnake in the Sandhills "Kevin." Remember Scarantino's analysis of predictive information:

"X carries information about Y relative to background knowledge k when P(Y given X & k) ≠

P(Y given k)." Neither Coretta's nor Kevin's skin patterns transmit information that they are

venomous on this analysis because at the times of their respective skin productions, the skin type is no longer correlated with being venomous. We could revise Scarantino's analysis of information to accommodate the cases: X carries *information** about Y relative to background *beliefs* b when P(Y given X & b) ≠ P(Y given b). Like Scarantino's use of "knowledge," "belief" here is not psychologically demanding; it may only be a disposition to act. The difference is that "belief" is not factive. The receivers of Coretta's and Kevin's signals possess beliefs b such that given b and the banded skin pattern, the (now subjective) probability that the snake is venomous increases.

Defenders of predictive information should not welcome an information* transfer view of biological communication.[15] Consider the reason that Scarantino includes the background knowledge condition in his analysis. Against criticism that information transmission talk is only metaphorical, Scarantino argues that there is a literal sense in which information is transmitted. Below I argue that the knowledge condition is necessary for linking the natural information in an act or structure to a receiver.[16]

We ought not say that informational* content is transmitted by the sender because the change in subjective probability may be entirely invented by the receiver. Consider some ancient Greek sailor who believes that a storm is correlated with Poseidon's anger. According to the revised theory, the storm carries information* about Poseidon's anger to the sailor. However, we should not say that information about Poseidon literally flows from the storm to the sailor because the information was never in the storm.

On Skyrms's analysis information is everywhere. The move from background knowledge to belief is a move from a change in objective probability to a change in subjective probability

because beliefs need not track the world. The subjective probability, however, is not in the act or structure. It is not, in Skyrms's words, everywhere. The information emerges in the receiver's interpretation of the act or structure. We might say that the act or structure causes some response in the receiver, and that response has probabilistic information as its content, but this is just to say that some variant of an influence-based view of communication is correct, and information is not transmitted. On Scarantino's analysis, the existence of the correlations are receiver-independent, but the correlations are only *informative* given the existence of relevant background knowledge. In whatever sense information is transferred, information* is not.

3.3 Option 3: Predictive Information is the Content of Signals

This option maintains the view that all signals have predictive information as their content. The current scarlet kingsnakes in the Sandhills region like Kevin do not deceptively transmit the predictive content that they are venomous. The last coral snakes like Coretta did not honestly transmit that content. There are two routes for taking Option 3. The first route is to deny that the skin patterns on Coretta and Kevin constitute signals. The second route is to hold that they do constitute signals, but that the signal is wrongly interpreted by the receiver.

The problem with the first route is that it seems to undercut the usefulness of the category of signals. An explanation of signals is supposed to help us better understand certain kinds of interactions between animals. If the extension of signals$_1$ only includes acts that transfer predictive information but the extension of signals$_2$ (appealing to influence-based or teleosemantic theories) additionally includes interactions involving Coretta and Kevin, then so much the worse for signals$_1$. Taking Option 3 under-generates signals, if we can reasonably assume that ethologists are probably more concerned with signals$_2$.

The worry that Option 3 under-generates signals is defeasible if either of two conditions are met. First, it is defeasible if there is no better candidate alternative theory. I have offered Scott-Phillips's influence-based view as a candidate theory that captures what I take to be the right phenomena. The second condition on which the worry is defeasible is if the dissimilarities between the excluded and included phenomena outweigh the similarities. For example, I complain that holding that signals must carry predictive information under-generates signals, leaving out some deceptive behavior that should be reckoned as signals. But, not all deceptive behavior is a signal even on the influence-based theories. For example, camouflage is not a signal according to Scott-Philips's influence-based theory. The observer is merely exploited or manipulated, she is not communicated with according to the theory. Imagine my criticism leveled against this influence-based theory: it undercuts the usefulness of the category of signals because it does not include camouflage. This criticism stings only if we have an antecedent reason for thinking that camouflage ought to be considered a signal. Similarly, the criticism I have leveled against not counting Kevin's or Coretta's skin as a signal depends on having antecedent reasons for counting them as signals. What are these reasons? The primary reason is that if corals' and kingsnakes' uses of brightly banded skin prior to the local extinction of coral snakes are part of the *explananda* of a theory of signals, not enough has changed between those uses of skin types and Coretta's and Kevin's uses such that the latter cases are not part of the *explananda*. It seems that the only thing that has changed is that predictive information is not transmitted in the latter cases, but the transmission of predictive information is supposed to be the *explanans*. It is methodologically dangerous to count Kevin's and Corretta's skin production outside of the *explananda* just because they don't fit with the particular *explanans* that is under

debate. Other candidate differences like the fact that the communication system that Kevin and Coretta participate in is not evolutionarily stable or that it will eventually collapse cannot be the barriers around the relevant *explananda* or else it will exclude a lot of what ethologists study in biological signaling. That said, it is difficult to give additional non-question begging reasons for why Corretta's or Kevin's skin types constitute signals because a theory of what constitutes signals is the topic under debate. This is why I consider the response offered here to be compelling but open to criticism. Taking Option 3 may be the most promising response for defenders of predictive information, but it should incumbent upon them to explain the relevant dissimilarities between Corretta's and Kevin's productions and the earlier productions of the skin type without recourse to information transfer or evolutionary stability. I will return to this issue in Section 4.

The problem with the second route (that Coretta and Kevin transmit predictive information that is wrongly interpreted) is that it undercuts the explanation for deceptive signals. Remember that a deceptive signal is one that transmits misinformation, but under the second route of Option 1, Kevin's skin pattern does not transmit misinformation. Information is received but wrongly interpreted. In this case the signal is not deceptive. This is the wrong result because Batesian mimicry is a paradigm case of deception. There are cases of wrongly interpreted signals in nature, but this is not one of them. This route, then, seeks to save the theory of predictive information at the cost of one of the chief virtues of the theory. It also puts the theory at a disadvantage to theories that do reckon all cases of Batesian mimicry deceptive. It also has the odd result that Coretta (the last coral snake) does transmit misinformation. Her skin is deceptive

according to the theory despite successfully causing receivers to avoid actually venomous encounters with her.[17]

4. Conclusion and Possible Deflation

The primary goal of this essay is to demonstrate that predictive information theories of communication and influenced-based theories of communication do not propose coextensive definitions of "signals." There are three options: (1) abandon a predictive information analysis of signals, (2) revise predictive information, or (3) reject that certain apparent signals are in fact signals. I have offered *pro tanto* worries for Options 2 and 3. Throughout the essay, I have assumed that there is a genuine disagreement between the predictive information theories and influence-based theories. I conclude this paper by casting doubt on that assumption in a way that deflates the debate.

In Section 3.1, I argued that given that certain phenomena (brightly banded skin pre-1960s) fall under the *explananda* of a theory of signals, we should expect the brightly banded skin thereafter to also fall under the *explananda* of a theory of signals. I have also assumed that the *explananda* of a theory of communication is particular networks of animal behaviors (i.e. animal behavior comprise the facts to be explained), but there are alternatives. A theory of communication could seek to directly explain the transfer of information, where the *explanans* is some particular theory of what that information is and how it is transferred.[18] If this is the project's goal, then my concerns in Section 3.1 are deflated, but so is the disagreement between predictive information theorists and influence-based theorists. The former gives a theory of information transfer, and the latter gives a theory of animal behavior. Nothing depends on all animal behavior studied by the latter exhibiting the kind of behavior that gives rise to

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information transfer.[19] Theories of information transfer may have uses in modeling something that happens in many communicative interactions, especially when those interactions are idealized. Theories of communicative behavior may have uses in understanding the evolutionary histories and peculiar differences in communicative interactions. The charges on the one side that "information" is unhelpful and underdeveloped are false as are the charges on the other side that communication cannot be analyzed without appeal to information transfer. These observations, however, only follow if the two camps are actually interested in different, though related, *explananda*.

Lastly, this examination of predictive information is just an examination of the theory that signals have predictive information as their content. I do not take any stand here on the role that predictive information could play in other domains like mental representations.

Notes

1. See Rendall, Owren, and Ryan (2009) and Rendall and Owren (2013) for this criticism. Stegmann (2013) gives a neutral summary of the debate between information- and influence-based theories, including this criticism. See Scott-Phillips (2014) for one among several influence-based theories of communication that makes no appeal to information.

2. There are different options for describing the relationship between predictive information transfer and biological communication. Skyrms (2010) appeals entirely to information transfer for a theory of signaling; Scarantino (2010, 2013) appeals to information transfer plus influence; Shea (2007) appeals information transfer plus teleological notions like function. The common bond is that predictive information is transferred.

3. Predictive information has its roots in Dretzke (1981).

4. Akcali and Pfennig (2014) is discussed below.

5. Skyrms (2010), 74.

6. See Artiga and Patternote (2018) for numerous examples of biological deception, an overview of some ways of analyzing biological deception, and a novel analysis of deception.

7. Maynard Smith and Harper (2003), Ch. 5, explore signaling systems whose instability exists because the sender and receiver are not cooperative.

8. Dawkins and Krebs (1978) and Krebs and Dawkins (1982) discuss this potentiality. See Searcy and Nowicki (2005), 218-224 for an overview of some discussions about signal stability in the face of deception.

9. If the cost of being deceived is low enough, deception might proliferate so much that there will have been more deceptive productions than honest productions across time going back to the emergence of the signal. This happens at T4. Whether we take the relevant correlations to be with a production at a moment or across the widest possible time, this kind of case can be generated.

10. The trend is similar to regions where coral snake population is reduced but still present. In such regions, because signal receivers are less likely to approach a coral snake, they can be more discriminating. Because of the high payoff and relatively low cost of avoiding coral snakes, though, they still have evolutionary pressure to avoid the even small number of coral snakes. That this phenomenon would occur in the Sandhills region with no coral snakes is surprising.

11. Thanks to an anonymous reviewer for asking about this.

12. Skyrms (2010) p. 38. Godfrey-Smith (2011) suggests it is better to think of this aspect of a signal as imperative content ("Do x.") rather than predictive ("You will do x.").

13. One worry for this proposal is that the account of honest and deceptive signals sketched here will inherit an indeterminacy problem that Neander (1995) and others have raised for teleosemantic theories of mental content. The worry should not prove problematic for a theory of honesty and deception, however, as long the states that fix whatever plays the role of truth conditions for the signals are indeterminate between states that actually co-occur. How to solve this problem if the states do not, or cease to, co-occur is a serious project, but one that goes beyond this paper.

14. On Shea's (2007) reading of Millikan (1984) and (2005) and Papineau (1987) and (1993), Millikan's and Papineau's teleosemantics share this conclusion, though Millikan's and Papineau's views are concerned with intentionality in general and not just biological communication. I have nothing to say about theories that more directly appropriate Shannon's (1948) definition of information such Seyfarth *et al.* (2010) in which information is a reduction of uncertainty in the recipient. Such proposals may not committed to changes in objective probabilities.

15. Scarantino (2010) argues that biological signals have natural meanings in Grice's (1989) sense. This account would abandon that position.

16. Some readers may not find Scarantino's link between producer and receiver persuasive. I need not take a position on this. I need only assert that if he successfully establishes the view that information is *transferred* via this link, then that link is severed on an information* view.

17. One anonymous reviewer suggested that the predictive information theory could be augmented such that *deception* is analyzed in the way influence-based theories understand it, but not signaling in general. This seems too great a concession for any information-based theorist who cares about deception to make. All the tools for analyzing deception in such a way are going to be extendable to giving an entirely influence-based account of communication. If deception can be analyzed using only influence, so can communication.

18. Much of Skyrms (2010) suggests that this is the project for at least some analyses of predictive information.

19. See Symons (2016) for a discussion of the possible goals of an information theory.

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