Supplementary information: *The nature of communication.*

Because it emphasises interdependence, our definition of communication (stated in the main paper) may appear to suggest that communication is an inherently cooperative act. Yet many instances of communication are antagonistic: two dogs that bare their teeth in an aggressive contest over, say, food, are communicating with one another about their relative fighting abilities, but are otherwise engaged in a hostile interaction. This apparent problem makes clear the need to distinguish between different types of cooperation involved in communication. Here, we adopt a three-way distinction [26; see table S1]. This will also allow us to specify the goals of our study more precisely.

[table S1 about here]

First, signals and responses must be calibrated to one another: signaller and receiver must agree upon what a signal 'means'. (For example, in human language, speaker and listener must agree that "dog" refers to canine animals, and not to feline animals; otherwise meaningful communication cannot even take place.) We call this *communicative cooperation*. This type of cooperation is necessary for communication to take place in the first place; without it, the interaction is not communicative.

Second, signals may or may not be honest; they may or may not reliably correlate with some feature of the world. We call this *informative cooperation*. If signals are not informatively cooperative, then the system is likely to collapse. How this outcome is avoided, and hence how communication systems can remain evolutionarily stable, is the defining problem of animal signalling theory [3, 27-29]. Note that informative and communicative cooperation are dependent on one another. A system that is communicatively uncooperative cannot be honest (or even dishonest), since the signals do not yet mean anything. Similarly, a system that is informatively uncooperative will soon collapse, and hence there will be no communication to be cooperative about. Consequently, both informative and communicative cooperation are necessary for communication to be evolutionarily stable.

Finally, communication may occur in cooperative or competitive contexts (e.g. building a nest together vs. fighting over territory). We call this *material cooperation*. Material cooperation is not necessary for communication to exist, nor for it to be stable. Communication can be materially uncooperative, while at the same time being communicatively and informatively cooperative, for example between teeth-baring dogs.

These distinctions allow us to state the goals of the present study more specifically: we are investigating the *origins of communicative cooperation*. There are many models and empirical studies of informative cooperation [see 3, 29 for reviews]. There are also many models, both mathematical and computational, that investigate how pre-existing signal forms become attached to particular meanings; that is, how a communication system might move from a state of communicative non-cooperation to a state of communicative cooperation [e.g. 30-33]. Still other theoretical work has shown that the evolution of communication may depend upon what behavioural strategy is pursued by the participants prior to communication [34]. However previous research has not systematically investigated the *origins* of communicative cooperation i.e. how the necessary interdependence between signals and responses might emerge in the first place.

type of cooperation	***gloss***	***necessary for communication to be stable?***
communicative	Are signals and responses calibrated to one another? (Do signaller and receiver agree on what a signal 'means'?)	Yes
informative	Are signals honest? (Do they reliably correlate with some feature of the world?)	Yes
material	Is communication used in cooperative or competitive contexts (e.g. building a nest together vs. fighting over territory)?	No

Table S1: *The different types of cooperation involved in communication*.
Because our framework emphasises the interdependence of signals and responses, it stresses the inherently cooperative nature of communication. Yet many communicative scenarios are antagonistic – and so it is important to distinguish between three different types of cooperation that are involved in communication. Only the first two in this table (communicative and

informative cooperation) are necessary for evolutionary stability. For further discussion see [26].

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Supplementary Information: *Proof that ($\mathbf{P}_{null}$, $\mathbf{Q}_{null}$) is evolutionarily stable.*

We show that any unilateral change in strategy will not increase the payoff of either player. This shows that ($\mathbf{P}_{\text{null}}$, $\mathbf{Q}_{\text{null}}$) is a Nash equilibrium. It then follows that not communicating is evolutionarily stable, since all Nash equilibria in role-asymmetric games are evolutionarily stable strategies [35]. (Role-asymmetric games are those where the players have different roles, which is the case here.)

For ($\mathbf{P}_{\text{null}}$, $\mathbf{Q}_{\text{null}}$),

$$w_A(P_{null}, Q_{null}) = \sum_{t \in T} \varphi(t) \Pi_A(t, r_0)$$

What happens if the actor changes strategy to $\mathbf{P}'$, where $\mathbf{P}' = \mathbf{P}$, except that $p(a_J \mid t_I) \neq 0$ for some specific $K, J \neq 0$, and $p(a_0 \mid t_I) = 1 - p(a_J \mid t_I)$? Now we have

$$w_A(P', Q_{null}) = \sum_{t \in T} \varphi(t) \Pi_A(t, r_0) - \varepsilon(a_J) \varphi(t_I) p(a_J \mid t_I)$$

Since $\varepsilon(a_J)$, $\varphi(t_I)$ and $p(a_J \mid t_I)$ are all positive, then $w_A(\boldsymbol{P}_{null}, \boldsymbol{Q}_{null}) > w_A(\boldsymbol{P}', \boldsymbol{Q}_{null})$, and therefore $\mathbf{P}'$ is a strictly worse strategy for the actor than $\mathbf{P}_{\text{null}}$.

Similarly, at ($\mathbf{P}_{\text{null}}$, $\mathbf{Q}_{\text{null}}$),

$$w_R(P_{null}, Q_{null}) = \sum_{t \in T} \varphi(t) \Pi_R(t, r_0)$$

What happens if the reactor changes strategy to $\mathbf{Q}'$, where $\mathbf{Q}' = \mathbf{Q}$, except that $q(r_K \mid a_J) \neq 0$ for some specific $K, J \neq 0$, and $q(r_0 \mid a_J) = 1 - q(r_K \mid a_J)$? Then $w_R(\boldsymbol{P}_{null}, \boldsymbol{Q}') = w_R(\boldsymbol{P}_{null}, \boldsymbol{Q}_{null})$, since actor always performs a_0, and never a_J, so r_K never actually occurs.

Therefore neither player has an incentive to unilaterally change strategy at ($\mathbf{P}_{\text{null}}$, $\mathbf{Q}_{\text{null}}$), and hence ($\mathbf{P}_{\text{null}}$, $\mathbf{Q}_{\text{null}}$) is a Nash equilibrium.

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