Supplementary Material to 'Constructing a Naturalistic Theory of Intentionality'

Examples of Applying the Theory to Cases of Minimal Intentionality

Applying the theory of intentionality to a particular case involves several steps. First, one needs to identify the relevant F-component, that is, the subprocess of F that is involved. Second, one needs to assess whether this F-component has a corresponding X-component. Such assessment is ideally an empirical one, by experimentally investigating X. In the absence of such empirical data, evolutionary arguments and common sense can often produce a plausible assessment. If one concludes that there is no corresponding X-component, then there is no intentionality, nor content (other than in the eye of the beholder). If one concludes that a corresponding X-component is likely, then one can make an educated guess of its structure from the assumption that the fitness estimate x (the outcome of X) has evolved to be a reasonable estimate of the actual fitness f (the outcome of F). The inferred structure of the X-component then establishes what it refers to and what role it has in X, that is, it specifies its content. Note that intentionality and content can only be ascribed to an X-component as a whole; trying to ascribe clear-cut micro-content to the micro-constituents of an X-component runs into the same (usually unsolvable) problems as trying to ascribe a clear-cut role to a single neuron in a large neural network.

We will now apply the above procedure to several examples of minimal intentionality that have been discussed in the literature. One such example is bacterial magnetotaxis[1]. The discussed magnetotactic bacteria contain tiny magnets that help them to align to the geomagnetic field, and to swim downward, away from (detrimental) oxygen-rich water. Bacteria in the northern and southern hemispheres incorporate the magnets in opposite orientations with respect to swimming direction, which complies with the fact that the geomagnetic polarity in these hemispheres is reversed with respect to the sea floor. This system raises two questions. First, can one say that the orientation of the magnet represents the external world, potentially erroneously (e.g., in a bacterium from the northern hemisphere that has been transposed to the southern hemisphere)? And second, what would it then represent: the polarity of the geomagnetic field, or the direction of lower oxygen?

Applying the theory to this case goes as follows. The relevant F-component here consists of two parts contributing to F: first, the ambient oxygen level and how that affects the bacterium, and, second, the mechanism that keeps the bacterium out of oxygen-rich water. The latter mechanism consists of the local geomagnetic field, the bacterial system producing alignment, and the bacterial system that lets the bacterium move accordingly. It is likely that the bacterium utilizes some estimate of the ambient oxygen level for its X, because this level is typically highly important for its fitness and may vary. Thus, minimal intentionality is not absent here. The corresponding X-component needs to estimate how well the bacterium is kept out of oxygen-rich water. An obvious way to do that is to monitor the current oxygen level, for example through a physiological parameter that is strongly influenced by (detrimental) oxygen-rich conditions. Such a measure would be readily evolvable, also because there may be more than one reason (apart from depth) why local oxygen levels would vary. When X, which includes this X-component, produces a small x, then the bacterium needs to increase the variability of its form. For example, it may increase the variability of its behavioural dispositions to move in any direction, which may increase the chances that it reaches water with lower oxygen levels. Alternatively, it may increase the variability of its metabolic pathways, which can increase the chances that it finds a way to cope with higher oxygen levels (assuming that it is already using any determinate mechanism that has specifically evolved for coping with this situation).

One might think that X could have evolved a system that specifically monitors the veracity of the bacterial geomagnetic subsystem, instead of or in addition to an oxygen monitor. However, that seems implausible. The veracity of the geomagnetic subsystem is unlikely to vary during the lifespan of an

[1] Millikan, R. G. (1984). *Language, Though, and Other Biological Categories*. Cambridge MA: Bradford/The MIT Press.

individual bacterium, given the robustness of the geomagnetic field and the robustness of the response of magnets to magnetic fields. Thus, there is probably no evolutionary benefit from having X monitor the performance of this system. When a bacterial species migrates gradually from northern to southern hemisphere, the magnetic subsystem may become realigned, but only through evolutionary change. However, this does not involve minimal intentionality in the sense discussed here.

In conclusion, the geomagnetic subsystem does not, by itself, represent anything, because it belongs to an F-component and not to an X-component. It is not an origin of minimal intentionality. Nevertheless, it may be regarded as an intentionality aid, that is, as a factor that shapes the intentionality of an X-component (the literature sometimes ascribes 'derived intentionality' to such intentionality aids, in contrast to 'original intentionality', which is here ascribed exclusively to X). This is so because the geomagnetic subsystem is part of an F-component that is targeted by an X-component that estimates how well the bacterium is kept out of oxygen-rich water. The latter is, then, the content (in a minimal sense) of that X-component, that is, what it represents (in a weak, minimal sense). If the geomagnetic subsystem is not working as implicitly expected (such as in a hemispherically misplaced bacterium), this affects how accurately the X-component can contribute to estimating fitness. The X-component implicitly expects (through X and x) that the geomagnetic subsystem is working to keep the bacterium out of oxygen-rich water. In other words, the geomagnetic subsystem can produce errors from the point of view of X. The two questions above are thus answered as follows: the orientation of the magnet can indeed represent, to X, external reality in an erroneous way, and, to X, it represents the direction of lower oxygen, not the polarity of the geomagnetic field. However, this is only a derived form of representation, as it depends on having a role in the process that is estimated by X, rather than on being part of the estimator itself.

A second example in the literature on minimal intentionality is the bug-detecting system of frogs and toads[2] (Millikan 1984, Neander 2017). It is assumed here that this is at most a form of minimal intentionality, and not the type of intentionality that requires a mind of some kind (assuming that frogs do not have minds, which is actually an open question at this point in time). Bug-detection in these animals involves a visual subsystem that responds to nearby, small objects that cross the visual field within a defined range of speeds. The animal responds by attempting to catch the object with its tongue. Usually, the object is an edible insect, but the animal responds to other small objects as well, for example ones tossed by an experimenter. Again, there are two questions. Does the system involve minimal intentionality, and, if so, what does it represent: 'edible bugs' or 'moving objects'?

The F-component in this case is the system that keeps the animal nourished by letting it catch and eat edible insects. This system consists of environmental factors (such as potential moving prey and visual circumstances) and organismal factors (such as parts of the visual and motor systems). The fitness consequences of this F-component are large and may vary, which means that it is likely that a corresponding X-component exists. This X-component then represents how well the bug-catching and bug-eating system works: if most catches fail, or if most prey is inedible or poisonous (as evaluated by the same X-component), this should lead to a low value of x. Subsequently, the animal should change the variability of its behavioural dispositions (e.g., change posture more often, change hunting spots more often, and so on). On average, higher variability increases the chances of higher fitness (again assuming that the repertoire of evolved and learned strategies for directed improvement has already been utilized).

Part of the F-component are 'bug-detecting' neurons, which respond to suitable visual motion. Such neurons do not have minimal intentionality by themselves, because they are part of an F-component and not of an X-component. The performance of such neurons is presumably quite robust, and could be regulated by conventional cybernetic control (for example, by recalibrating a neuron if it has drifted away from its proper operating range). Therefore, it is unlikely that their performance is explicitly monitored by an X-component. Nevertheless, the X-component identified above estimates the F-component to which

[2] Millikan, R. G. (1984). *Language, Though, and Other Biological Categories*. Cambridge MA: Bradford/The MIT Press; Neander, K. (2017). *A Mark of the Mental: In Defense of Informational Teleosemantics*. Cambridge MA: The MIT Press.

these neurons belong, and implicitly expects them to operate in a certain way. They operate correctly when they respond to the right kind of visual motion, irrespective of what causes it. They only operate erroneously, from the point of view of X, when they respond in a way that is different from what X expects (e.g., when they fail to respond at all to suitable movement). But the X-component itself is presumably more discriminating: it checks if the caught objects are indeed edible. In other words, the minimal intentionality of this X-component is directed towards 'edible bugs' and not towards 'moving objects'. However, the part of the X-component that evaluates the edibility of a caught object is separate from the neural system that detects visual motion. Thus 'bug-detecting' neurons represent, to X, just 'moving objects', not 'edible bugs'. Note that this kind of representation is again not an original, but a derived one, as it depends on the original minimal intentionality of an X-component.