



## **The evolutionary roots of creativity: mechanisms and motivations.**

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27 *Evolution*, for the purpose of our argument, refers to the process of the gradual change of form and  
28 behaviour, as a result of differential advantages of some forms or behaviour over others. In the case of  
29 *biological evolution*, we talk of *fitness* and mean the numbers of offspring produced and surviving. In  
30 the next section, we decompose the idea of *creativity* into tractable components, to allow us to examine  
31 whether music and other forms of vocal communication (including language in humans) share similar  
32 functional roots and may have evolved out of similar cognitive precursors. Whether a society values or  
33 eschews creativity, whether we agree on what constitutes good or bad music, or where one stands in the  
34 balance between humans as cognitive individuals and humans as cultural components, is secondary to  
35 understanding the essence of the concepts.

## 36 **2 Components of Creativity**

### 37 **2.1 Valuing creativity and creating value**

38 We begin our decomposition of creativity with the relationship between perceived creativity and attributed  
39 value.

40 In Western society, “creativity” is most commonly used to refer to the embodied cognitive process  
41 that gives rise to pieces of music, sculptures, paintings, poems, and other things that are taken or pre-  
42 sented as art. We, less conventionally, include science and engineering in our list of creative endeavours.  
43 Creativity is intensely context dependent: reproducing the style of Monteverdi in the 20th Century would  
44 be regarded negatively as pastiche or plagiarism or an exercise of style replication. Creativity is heavily  
45 dependent on the nature of the creator: for example, Harold Cohen’s AARON painter program [1] has  
46 made paintings that have hung in galleries and sold for thousands of dollars; his daughter was (in 1999)  
47 also a keen artist, producing (then) the kind of drawings one might expect from a 3-year-old, for which  
48 most people would not be inclined to pay. Cohen, however, rates his daughter’s creativity as much greater  
49 than that of his program [2]. Accordingly he makes a distinction between Big-C creativity and Little-  
50 C creativity, also seen elsewhere in the literature [2], where Big-C is Picasso level, and Little-C is what  
51 AARON can manage. Margaret Boden [3] makes another perhaps more tractable distinction between *psy-*  
52 *chological creativity*—the act of generating an artefact that is novel and of value to an individual—and  
53 *historical creativity*—that of generating an artefact that is novel and valued in historical terms. However,  
54 this notion must be generalised: rather than two discrete kinds of creativity, value and novelty should not  
55 be thought of as simple quantities, but as relations between observers and the created artefact. Thus, for  
56 example, we can account for cycles of fashion: retro styles may be valued by both teenagers and their  
57 parents, the former enjoying their (relative) novelty and the latter doing exactly the opposite. We return  
58 to the matter of novelty below.

59 Value is dependent not only on the observer, but also on the context in which the observation is made.  
60 It is present in many more pursuits than the artistic ones mentioned above, and in manifold ways. A  
61 prime example is mathematics, where the creation of the proof of a theorem is more highly valued if  
62 it is “elegant”, according to the principles of the particular branch of mathematics to which it applies;  
63 mathematics has its own aesthetics, as does engineering. Often, the aesthetic of one context is utterly  
64 incomprehensible, and even offensive, to observers comfortable in another: consider, for example, the  
65 riot that followed the première of Stravinsky’s *The Rite of Spring* in the 1920s. Thus, the value relation  
66 is between not just the observer and the artefact, but between the observer and the artefact in a given  
67 context. Finally, value is also a function of the creator. Expectations are based on past experience. We are  
68 disappointed when our favorite author, admired musician or best-loved car company turns out a product  
69 that underperforms.

70 In summary, we treat value as a relation between an artefact, its creator and its observers and the  
71 context in which creation and observation take place.

## 72 2.2 Exploration, Transformation and the Paradigm Shift

73 Boden [3] also introduces an important philosophical distinction, between *exploratory* creativity, where  
74 the *conceptual space* being explored is fixed (though possibly not all visible, and possibly infinite) and ex-  
75 ploration occurs within that space (for example, different songs in a particular style), and *transformational*  
76 creativity in which the space itself is subject to change (developing from one style to another). Coupled  
77 with successful persuasion, transformational creativity is what leads to a *paradigm shift* in Kuhn’s phi-  
78 losophy of science [4]. Boden proposes that Little-C creativity is exploratory, and Big-C creativity is  
79 transformational, but history is littered with exceptions to this: Mozart, for example, perfected a style  
80 that Haydn introduced, but Mozart is universally regarded as the greater creator. Wiggins [5] shows  
81 that, in any case, transformational creativity is formally exploratory creativity at the meta-level, where  
82 the conceptual space of artefacts is replaced by the conceptual space of conceptual spaces. This way of  
83 thinking, where the conceptual space can be taken to define the class of artefacts at which a creator is  
84 aiming, yields some elegant ways of discussing what happens when a creator pushes the boundaries of  
85 the expected, in a process taxonomised as different kinds of *aberration* by Wiggins [5]. This concept  
86 allows further objective, mechanistic, description and prediction of creative behaviour [5].

87 Humpback whale song has a nearly invariant pattern of theme transitions, so much so that Frumhoff  
88 [6] called the few backwards transitions therein “aberrant” (though the common terminology here is co-  
89 incidental). There also are three different kinds of theme in humpback song. The variation in structure is  
90 somewhat like a theme and variations; but they recur, so while they fit Boden’s exploratory framework,  
91 their generation is not as free as that term might suggest. However, a restricted exploration of a (no-  
92 tionally) larger language can be modelled in this context as a conceptual space accompanied by a value  
93 measure, which filters out unvalued artefacts; we return to this below.

## 94 2.3 Creativity: process or property?

95 Boden’s approach raises some interesting questions concerning the conceptual space, and the attribution  
96 of value to artefacts in it: these things are separable, and the conceptual space is neutral with respect to  
97 both value and novelty: it inherently captures cognitive generation, not the subsequent value or novelty of  
98 that which is generated. Thus, the paintings of Harold Cohen (for he was a successful human-only artist  
99 before AARON), and of AARON, and of Cohen’s daughter, all co-exist, equally, in the conceptual space  
100 of paintings: it is only when they are evaluated by an observer (possibly the artist) that issues of novelty  
101 and value arise. In a less Western-centric perspective, we might conflate these two and argue that novelty  
102 is a kind of value, since in some cultures it does not have the high status accorded in the West, and in  
103 some it is actively eschewed in favour of the strict maintenance of tradition. This feature of creativity in  
104 the social context does not decrease the importance of novelty in the evolutionary context, as we shall see  
105 below.

106 Thus, we see that the production of the painting per se is not what guarantees its value: while, of  
107 course, the artefact must exist to be valued, it is interaction between production and (probably, at least  
108 initially, introspective) evaluation by an artist, and then by a social community, that identifies relative  
109 value and relative novelty, of both the artefact and the way it was made. Thus, we can decompose  
110 creativity into a series of steps and tests within a process, of which a “creative” agent is capable, and can  
111 begin to study it. This is altogether more scientifically tractable than the philosophical debate about the  
112 ineffable nature of creativity itself.

## 113 2.4 Size does not matter

114 Given the nature of the conceptual space as distinct from novelty and value of the concepts in the space,  
115 a natural question to ask is: need there be a difference in kind between big-C and little-C creativity?  
116 For some authors, the answer is clearly “no”: Plotkin describes creativity as the sine qua non of everyday

117 language generation [7]; for others, the word should only be applied to the great creators of great historical  
118 import.

119 From the perspective of the current paper, this latter view is destructively problematic. We aim here to  
120 understand what evolutionary advantage may have been given to humans and/or animals by the ability to  
121 be creative. At the extreme level, it is hard to argue for evolutionary advantage in the authorship of very  
122 large scale created constructs such as symphonies. However, it has been argued that sexual selection may  
123 be a factor in smaller creativity [8, 9]. Thus, if we were to restrict our definition to great human creators,  
124 ruling out minor creative acts, we would also rule out a priori the possibility of incremental development  
125 of creative faculties over evolutionary time. Instead, it is necessary to look for the roots of that ability  
126 both in humans and non-humans, with a view to understanding how the extreme (“great creativity” in the  
127 terms of the relevant culture) emerged from the ordinary (everyday creative activity). One unbiased way  
128 of approaching the question how creativity evolved is thus to deconstruct the components and explore  
129 which ones exist in non-human animals and to what degree.

130 Equally, there is no scientific evidence to support the position that the ability to create did not evolve,  
131 step by step, as opposed to merely appearing fully formed in humans, and there is evidence of creativity  
132 or proto-creativity in other species, both in animals belonging to the same direct evolutionary lineage [10]  
133 and those more distantly related [11]. Therefore, when studying the development of creativity in our own  
134 and other species, it is necessary to admit and value the creation of less-than-amazing artefacts (as we  
135 do in our children) in order to encompass the overall development of the faculty, over evolutionary and  
136 ontogenetic time.

## 137 **2.5 Novelty and its Perception**

138 We now consider another key dimension of creativity, novelty, and the ability to perceive it. In Western  
139 culture, as we argue above, the attribution of creativity entails the attribution of novelty—various authors  
140 have argued that the human creative drive is the search for novelty [12], or, differently termed, curiosity  
141 [13]. While this is not the case in all cultures, the fact remains that novelty detection is a feature of  
142 creative behaviour—whether it is a feature to be valued or (in some contexts) suppressed. Regardless of  
143 one’s response to novelty, the fact that one can respond to it means that it can be detected, and we propose  
144 that this is a fundamental component of creative behaviour. It is to be noted, however, that too much  
145 novelty prevents recognition, a fact embodied in the famous Wundt curve of hedonic response to novelty  
146 [14, 15]: the inverted-U shape captures the notion that not enough variation is boring, while too much is  
147 unpleasantly incomprehensible, yielding a sweet spot in between. This is illustrated in Figure 1.

148 Novelty detection is a requirement for noticing changes in the environment, a feature all animals need  
149 for survival. When a pattern deviates from the known, it is novel and can signal good things (a new  
150 food source) or bad things (a new type of predator). Thus, animals need carefully to balance exploration  
151 of novelty, because it can open up new niches that enhance evolutionary fitness or are detrimental to it.  
152 The ability to detect novelty in the environment likewise allows animals to detect novelty in behaviour of  
153 conspecifics. Famous examples are the cultural transmission of novel behaviour through a population, as  
154 observed for sweet potato washing in Japanese Macaques and opening the aluminum foil covers of milk  
155 bottles by chickadees [16].

156 Huron [17] extends this argument to affective response, exapted to music. Because the outcome of  
157 a novel experience is sometimes dangerous, it is appropriate for an animal to be alert and prepared for  
158 fight or flight in the face of novel circumstances. Thus, there is evolutionary incentive to perceive not  
159 just danger, but uncertainty and/or novelty in their own right. In humans, this situation is experienced as  
160 tension, leading to arousal and, in extremis, to fear, and simple observation suggests that other species  
161 share the same affective response. The experience of tension entails its subsequent release, which seems  
162 to be accompanied by positive affective states. Huron, following Meyer [18], suggests that tension thus  
163 stimulated by expectation, and its denial or fulfilment, is in large part responsible for affect stimulated by

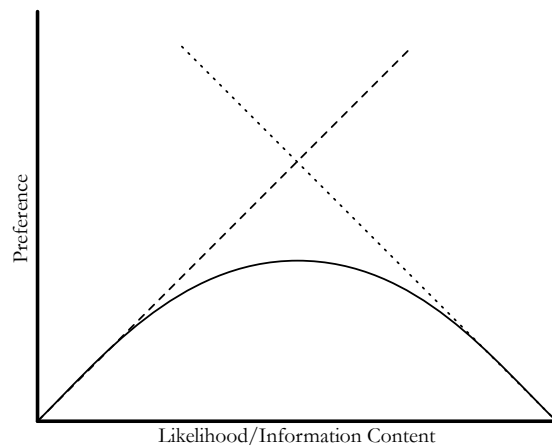


Figure 1: The Wundt Curve illustrates the rise and fall of preference ( $y$ -axis) in perceivers for complexity of stimulus ( $x$ -axis). Very simple stimuli are uninteresting, while extremely complex ones are unaccessible, either case producing dissatisfaction. Intermediate levels of complexity, however, are preferred.

164 Western music, whose emotive content is frequently theoretically conceived as an ebb and flow of tension  
 165 of various kinds. This affective experience is highly valued, and is altogether more subtle and dynamic  
 166 than the common labelling of emotional analysis of music as “tender”, “sad”, etc. [19, 20].

167 It is possible to mathematically model expectations over a well-defined symbol system (musical  
 168 melodies constructed from a known range of pitches and durations, or bird- or whale-song categorised into  
 169 appropriate symbol sets) using uncomplicated statistical techniques [21, ch. 9]. From these models, hu-  
 170 man melodic expectations can be estimated [22, 23] and birdsong can be modelled [24]. Pearce’s model  
 171 of Western tonal musical melody, IDyOM (Information Dynamics of Music) [25, 23], predicts human  
 172 expectations very well ( $r = .91$  in four studies) [26, 27]. Expectations are expressed as probability dis-  
 173 tributions over the set of symbols allowed (musical pitches, here). Given such a probability distribution,  
 174 we can estimate the unexpectedness of an event drawn from it, using Shannon’s information theory [28].  
 175 It is important to understand that this property is relative: it is computed in terms of the statistical model,  
 176 so unexpectedness is relative to the information that the model contains about the set of sequences being  
 177 modelled, and to the immediately precedent sequence. Thus, we can model an individual’s memory, and  
 178 predict the unexpectedness of perceived events. Two quantites, entropy and information content, model  
 179 uncertainty and unexpectedness, respectively [23]. More recent work on physiological and behavioural  
 180 measures of human response to live music suggests that the unexpectedness value of pitch, calculated as  
 181 above, explains a significant part of the variance in physiological measures (heart rate, skin conductiv-  
 182 ity) that correspond with arousal [29]. This constitutes evidence that unexpectedness in music correlates  
 183 with arousal in listeners, and that both correlated with the predictions of the model. These model-driven  
 184 empirical methods can be applied to any form of vocal communication, given enough examples.

185 Ikebuchi et al. [30] showed that female Bengalese finch hearts respond with tachycardia to more  
 186 complex male song (that is, song with higher information content). This is a result comparable with the  
 187 human musical response outlined above [29]. Further investigation of these phenomena via the models  
 188 introduced in Section 3 may yield understanding of the relationships between the birds’ reaction to song  
 189 and the humans’ reaction to music.

190 Weiss et al. [31] found that when nightingales heard a playback consisting of song types with branch  
 191 transition patterns, they responded with song types with bottleneck transition patterns. Conversely, when

192 they heard song types with bottleneck transition patterns, they responded with song types that tended to be  
193 branching transitions in their population—that is, they responded with the unexpected. While it remains  
194 unclear why this behaviour would arise, the fact that it does so entails the ability to detect high and low-  
195 entropy distributions, and/or high and low information content, as in Pearce et al.’s human studies and  
196 Huron’s evolutionary argument.

197 Here, then, is a scientific question which the study of creativity can ask: do other species than hu-  
198 mans exhibit similar responses to novelty and/or complexity, and, if so, how does their behaviour inform  
199 our understanding of our own? Given a sufficient amount of song produced by a particular species, or  
200 even individual, we can construct a model of the sequences, using the above techniques, and generate  
201 new sequences from it, with particular information-theoretic properties (e.g., surprising, neutral, or very  
202 obvious). We can monitor the response of the relevant animal to the constructed sequence, by means of  
203 judicious audio editing, and thus test hypotheses regarding the value of novelty and complexity in vo-  
204 cal display. This view of song construction raises the possibility that it is valued by its own species for  
205 some of the same reasons that humans value music: the affect of rising and falling tension caused by  
206 unexpectedness/information content/complexity. This is a testable hypothesis, to which we return below.

### 207 **3 Modelling the Process of Creativity**

208 In order to study creativity effectively, we need a rigorous frame of reference, including the ability to sim-  
209 ulate perception and creative generation. Historically, there are not many scientific theories of creativity,  
210 and those that do exist are fundamentally qualitative. We now survey them, in contrast with a newer,  
211 quantitative approach.

212 Wallas [32] focuses on the cognitive process of creativity. He identifies four parts of a sequence:  
213 *Preparation*, in which the creative goal is identified and considered; *Incubation*, during which conscious  
214 attempts at creativity are not made; *Illumination*, the moment of enlightenment when an idea appears in  
215 conscious awareness, sometimes called the “Aha!” moment; and *Verification*, in which the new idea is  
216 applied. These ideas highlight a further distinction that is useful in focusing on creativity: that between  
217 conscious, or deliberate, creativity and non-conscious, or spontaneous, creativity [33]. The former of  
218 these is the creativity where, for example, a professional composer must produce a TV theme in too short  
219 a time to wait for inspiration: she consciously applies rules of her craft to create what is necessary. The  
220 latter is the creativity where an idea or concept appears in one’s awareness, apparently without bidding,  
221 effort or intention, in the way described by Mozart as the beginning of his mode of creativity (Holmes,  
222 2009). Most human creativity processes, including Mozart’s overall description, are probably a cyclic  
223 combination of the two. Wallas, however, is considering spontaneous creativity resulting from earlier  
224 conscious consideration, and he considers the illumination point to be the arrival of a spontaneously  
225 produced concept in consciousness: the “Aha!” moment. Wallas’ theory requires created artefacts to  
226 undergo Validation, where they are examined to make sure they are fit for purpose. This may suggest that  
227 the theory is meant to account for larger-scale acts of creativity than, for example, spontaneous sentence  
228 production; or maybe successful communication of meaning would fulfil the definition in this example.  
229 In any case, the theory does not propose an underlying mechanism, but rather describes a series of stages.  
230 As such, it at most provides an overarching framework for the study of creativity.

231 Guilford’s model [34] is more qualitative, but does not contradict Wallas. Guilford proposes a phase  
232 of *divergent* thinking, where possibilities are opened, followed by one of *convergent* thinking, in which  
233 the creator homes in on her idea. Both phases could happen either consciously or non-consciously, and  
234 one can also imagine repeating cycles of the two phases. The model has less predictive power than  
235 Wallas’, however, and we will not refer to it further. More recently Csikszentmihalyi [35] described the  
236 subjective experience of creativity, involving the state of *flow*; again, this lacks quantitative analysis and  
237 predictive power. A final theory worthy of mention is that of Koestler [36]: the cognitive operation of

238 *bisociation* is proposed, enabling cognitive structures representing two or more ideas to be combined to  
239 produce new concepts. This theory, though convincing, is not specified with mathematical precision.

240 None of the four frameworks outlined above affords a quantitative means to examine creative pro-  
241 cesses in detail. A more recent hypothetical mechanism for a cognitive creative process is provided by  
242 the Information Dynamics Of Thinking (IDyOT) cognitive architecture [33, 37], based on Baars' Global  
243 Workspace Theory [38] and using the same information theoretic notions as the Information Dynamics  
244 of Music (IDyOM) model cited above [23]. The key idea is that cognitive creativity is a result of pre-  
245 diction, which itself is a means for managing information and action in the world. Statistical generators  
246 continually predict outcomes from sensory inputs, based on statistical models trained by unsupervised  
247 observation. They compete in terms of the information content of their predictions (quantified in terms of  
248 Shannon Information Theory [28]) for access to the Global Workspace (GW), which equates with con-  
249 scious awareness. When an item enters the GW, it may be novel, or it may be a predictable part of an  
250 on-going experience; in the former case, creativity has happened, and passage into the GW corresponds  
251 with Wallas' moment of Illumination, the preceding activity being Incubation. What enters the GW is  
252 recorded in memory and becomes available for future prediction, and thus the cycle repeats. This theory  
253 gives a concrete mechanism for creative production, and is applicable directly to discrete and continuous  
254 symbolic data represented on a computer. Thus it can be applied to transcriptions of bird- and whale-  
255 song, with a view to comparing their information-theoretic properties. This approach, then, can be used  
256 directly on real data to make testable predictions about animal behaviour, as it has done for humans.

## 257 **4 Affording Creative Behaviour**

258 Charles Darwin described two primary mechanisms of selection as driving biological evolution: natural  
259 selection and sexual selection. The critical elements for evolution by natural selection are variation in  
260 traits within a population, differential reproduction of animals with the differing traits, and inheritance  
261 of the trait from one generation to the next. Sexual selection can be viewed as special case of natural  
262 selection which acts on an individual's ability to mate. Some traits, for example ones that increase fighting  
263 ability, may improve an individual's ability to compete with members of the same sex for mating, while  
264 others, such as ornaments or song, may make a member of the other sex more likely to select an individual  
265 for mating.

266 The topic of mate choice is important for our discussion of selection for creative behavior, especially  
267 for creativity in communication. Biologists have investigated a variety of modes of sexual selection for  
268 mate choice. The simplest selection would be for a character that provides a direct benefit, such as if a  
269 female bird chooses a male whose genes produced a tail of the optimal size for flight. But suppose males  
270 also use the tail in a display to impress females. Females might have a sensory bias to choose males with  
271 even larger tails than optimal for flight, because the display is more visible [39]. Here sexual selection  
272 might drive the evolution of tails that are longer than optimal under natural selection. And if a population  
273 of females have a preference for longer tails, then this could lead to a runaway process of evolution of  
274 longer and longer tails until the benefit from sexual selection is outweighed by other natural selection  
275 pressures [40]. The evolution of large complex ornaments in males raises the question of why a female  
276 should choose a male with a trait that may make it more visible to predators and less able to escape.  
277 Zahavi [41] argued that males with such a handicap might have to be better quality, thus suggesting that  
278 handicaps help a female choose a better quality male.

279 How does creative behaviour fit onto these categories? Creative behaviour could result in biological  
280 selective advantage in all the above cases. Perhaps the most celebrated case of animal innovation in-  
281 volves a young female Japanese macaque who invented the idea of washing the sand off potatoes in the  
282 ocean and then three years later, the idea of separating grain from sand by throwing the mixture in water  
283 and scooping out the floating grain. Both of these innovations would be selected because they improve



284 foraging. This kind of innovation is particularly important in species capable of social learning so that  
285 beneficial innovations diffuse through the population. Creative behaviour may also be the substrate for  
286 sexual selection: mimicking the sounds of other birds and adding them to his own repertoire of song may  
287 signal to the female lyre bird that her mate has particularly good cognitive skills that will also help to  
288 raise their young and pass on his intelligence as well. This logic has been applied to a more specific issue  
289 for the songs of birds. Nowicki et al. [42] pointed out that the nuclei in the brain that control song develop  
290 during critical periods of development. If a young bird does not have adequate nutrition at this time, it  
291 may suffer broader developmental problems. They reasoned that large and complex repertoires of song  
292 may indicate a history of good nutrition, and they suggest that females might select males with large and  
293 complex song repertoires for this reason [42]. Or creative behaviour could evolve as byproduct of some-  
294 thing else: the need to explore to find new food sources or new territories might have selected animals  
295 that are less neophobic, and more curious, leading to more novel behaviours—not all of them necessarily  
296 beneficial to survival and reproduction. Thus, the expense of creative behaviour in terms of time, energy,  
297 and risk, which might at first seem problematic, can be motivated in biological terms, either in terms  
298 of introducing beneficial behaviors, creating a particularly attractive display, or as a demonstration of a  
299 valuable capacity that underlies creativity itself.

300 However, while the substrate of the variability required for biological evolution, as exemplified above,  
301 is genetic, the behaviours we are considering are complex, learned and cultural, involving not just gener-  
302 ation of short sequences grounded in action, but substantial long-term abstract sequence production. The  
303 larger question is therefore: why and when is there selection for innovation - forming new combinations  
304 of behaviors, vs reliance on unlearned behaviors or social learning of successful behaviors. Laland [43]  
305 discusses strategies animals might use for selecting when to rely on unlearned behaviors, when and who  
306 to copy in social learning, and when to innovate. However, he is primarily considering instrumental behav-  
307 iors for solving non-social problems rather than learning about signalling for communication. We now  
308 consider cases of animal communication that appear to be examples of creative behaviour in the terms  
309 proposed here, and then discuss how the dynamics of the communication might be quantitatively studied  
310 using a computational framework such that we propose.

## 311 **5 Creativity in Animal Communication**

312 The very attribution of the word “song” to the vocal communication behaviours of birds and whales is  
313 based on the problematic Romanticisation of that phenomenon, akin to the Romanticisation of creativity,  
314 mentioned above. First, then, we must dissociate ourselves from the metaphorical notion of theatrical or  
315 concert-hall performance, and focus instead on the functional, communicative aspects of the behaviours.

316 A comparable danger is the naïve assumption that the behaviours described below are due to the same  
317 mechanisms as superficially similar behaviours in humans. Indeed, this claim is one we would like to  
318 test. One means of doing so might be through the observation-based model of Wallas [32]. However, it is  
319 hard to know whether the Preparation and Incubation phases exist in animals: they cannot be asked, and  
320 current lack of understanding of the human mechanisms at the neural level is not detailed enough to make  
321 search for comparable effects in animals possible: we are currently limited to measures such as EEG  
322 frequency band power, which do not explain mechanism (e.g., [44]). Illumination and Verification may  
323 be more accessible because they may manifest behaviourally, e.g. when an animal immediately repeats  
324 material once it has been internalised. More work is needed in this area.

325 However, there is evidence, cited above, of the effect of information content and entropy with re-  
326 spect to a context on humans, measurable directly from physiological responses [29], and of information  
327 content on birds [45]. A more direct comparison of these two phenomena can be made, using the tripar-  
328 tite empirical approach used by Pearce et al. [27]: a computer program is used to embody the proposed  
329 mechanism, and its predictions are then tested empirically with both behavioural responses and electro-

330 psychological measures; here, the idea is extended to a comparison between species.

331 The setting in animal communication where the concept of creativity seems most relevant concerns re-  
332 productive advertisement displays called “songs”, which are a product of sexual selection. In some animal  
333 species, the songs of each individual singer are learned through listening to the songs of other individuals.  
334 When one individual learns the song of another, it will probably not be a perfect copy, as there may be  
335 errors in the stored memory, and differences in the vocal production apparatus between individuals. This  
336 process of vocal copying within a community of animal singers leads to vocal traditions—which may be  
337 formalised as conceptual spaces—that often map onto habitats as geographical dialects in song; similar  
338 effects of vocal tradition, coupled with migratory patterns, arise in human folk music [46]. However,  
339 there are also situations when an animal actively appears to innovate, producing sounds that are more  
340 novel than would be expected to arise from copy errors alone, in a step akin to transformational creativity.  
341 Existing work in this area focuses on what *is* copied, at the expense of studying the “unrecognisable” new  
342 material: the corollary, invention of new song types, seems not to have been studied formally.

343 Kroodsma [47] suggests a relationship between site fidelity and mode of vocal learning in birds,  
344 high site-fidelity being correlated with imitation and low site-fidelity correlated with improvisation. One  
345 possible explanation for this would be the need to associate a clear signal with territory, so as to mark  
346 it, but also for the signal to vary as fledglings leave the nest and lay out their own territorial boundaries:  
347 it is necessary first to innovate and then to fix, so as to identify a difference between the territories,  
348 while maintaining recognisability to members of one’s own species for the purposes of sexual attraction.  
349 Similarly, in animals such as killer whales that form groups bonded by call repertoires, innovation is  
350 concomitant with the need to form new social groups as new individuals mature: otherwise, groups could  
351 not distinguish themselves. In both these cases, the ability to recognise and value “just enough” variation  
352 is paramount. This notion of “just enough” corresponds with the maximum of the Wundt curve, described  
353 above; it also corresponds with a middling, moderate value of information content, as measured by the  
354 models outlined in Section 3.

355 The development of song through vocal learning is common among songbirds but very rare among  
356 non-human mammals [48]. Some of the best evidence comes from the songs of bats [49] and humpback  
357 whales. At any one time, the songs of different individuals within a population of whales are quite  
358 similar [50], but many acoustic features of the songs change rapidly enough that they can be tracked from  
359 month to month [51]. The changes are progressive over time in the sense that if a sound is increasing  
360 in frequency, or decreasing in duration, that trend is likely to continue for some time rather than vary  
361 randomly. The rapidity of the song change coupled with the similarity between whales at one time makes  
362 it difficult to identify whether some individuals are innovators who are copied, especially since it is so  
363 difficult to make repeated recordings from the same individual at different times given such a large and  
364 mobile population. However it is clear that a strong pressure for conformity must drive each whale to  
365 copy the song of the moment, while at the same time there must be a selection for specific innovations  
366 that are picked up by the population to change the vocal tradition. Until now, there has been no way  
367 of studying this process or identifying the benefits and process of innovation. Computational modelling  
368 based on creativity theory may help.

369 Following the Boden analysis of creativity, and our subsequent suggestion that value and novelty  
370 should be thought of as relations between observers and the created artifact, we can evaluate differences  
371 in the value of novel sounds produced by different singers in terms of whether they are copied by others  
372 or not. We know little about the psychological process by which an individual animal generates a novel  
373 sound nor about what “value” the sound may offer to that individual. But in parallel with our explicitly  
374 relativistic version of Boden’s “historical” creativity, we can study what novel sounds are incorporated  
375 into the vocal tradition of the population, modelling the whale song as a conceptual space.

376 A striking case of adoption of novel songs involves the song of the humpback whale. There are  
377 two populations of humpback whales that winter off the coast of Australia: one on the east coast and  
378 one on the west. Males sing on their winter breeding grounds and as they migrate to and from the

379 breeding grounds. These two populations are separated by thousands of km. With little interchange, each  
380 population is characterized by one song at any one time, and the songs of the two populations are usually  
381 very different. However, Noad et al. [11] noticed an unusual pattern in 1996 when 2/82 singers recorded  
382 off the east coast produced a song that was completely different from the rest of this population but that  
383 matched the 1996 song of the west coast population.

384 During 1997, some songs mixed features of both west and east coast, but by the end of the year nearly  
385 all of the east coast whales had switched to singing west coast song. By 1998, no whales were left singing  
386 the old east coast song and all had switched to the west coast song. The rarity of west coast songs recorded  
387 in the east during 1996, coupled with the following independent evolution of the west coast song on both  
388 coasts, led Noad et al. [11] to conclude that only a few singers transferred from west to east during 1996,  
389 bringing the new vocal tradition with them. This rapid and complete replacement of one vocal tradition  
390 with another suggests recognition of a value for very specific kinds of novelty is what drives the change  
391 in the song, even when this is usually a less radical process driven from within the population.

392 Analysis of songs recorded during 1998-2008 from eastern Australia and the other populations of  
393 the South Pacific show a remarkable pattern. Garland et al. [52] report that over this time period, eight  
394 different song types originated in the eastern Australia population and spread over several years across 6  
395 humpback populations from west to east, all the way to French Polynesia, 5000 km away. They suggest  
396 that as with the uptake of a new song as reported by Noad et al. [11], diffusion of a vocal tradition occurs  
397 when individual males from adjacent populations spend enough time together for one to learn the others'  
398 song [52]. However, this does not explain the directionality of information transfer. Available data on  
399 movement of individuals from one population to adjacent ones suggest that this is bidirectional with no  
400 bias to the east. The suggestion of Garland et al. for the remarkable directionality of the change is that  
401 the eastern Australia population is much larger than the others. While this may account for a more likely  
402 flow of animals from eastern Australia to the adjacent population to the east, it fails to account for the  
403 broader eastward pattern of information flow.

404 One way to think about this pattern from the current perspective would be to consider the value of  
405 particular innovations within the context of a particular vocal tradition at a particular time. The 1998  
406 song in eastern Australia was the song originally from western Australia that was valued so highly that  
407 it swept through the population in 1997. At this point, this song started to evolve within the eastern  
408 Australia population, and at the same time, its high value made it likely to spread to populations to the  
409 east. Given the time this took and the speed at which song evolves within a population, the large eastern  
410 Australia population had an advantage in being more likely to offer high value changes within the shared  
411 vocal tradition, and these high value changes would maintain the directionality as they spread to other  
412 populations to the eastward. Once this dynamic was set up, if the easternmost populations were several  
413 years *behind* in the process of innovation and selection for value, then it was less likely for any innovations  
414 in this setting to spread west.

415 There has been growing interest in studying the strategies animals might adopt when they learn from  
416 others. Laland [43] points out that the costs and benefits of social learning depend on the context, and he  
417 suggests more attention be paid to strategies of *when* to copy and *whom* to copy. One *when* strategy sug-  
418 gests copying another singer when the copier's current behaviour is unproductive. From the perspective  
419 of a singer, this would suggest copying if you are not attracting females or if you are failing in competition  
420 with males. A *whom* strategy might be "copy the majority," which would lead to conformist behaviour.  
421 Another *whom* strategy is "copy the most successful": if singing whales can monitor the success of oth-  
422 ers, and if successful whales have variations in their song, this could drive a process of change, although  
423 it is difficult to see how it would lead to the progressive evolution observed most of the time in humpback  
424 song. We still do not understand what drives the conformity in humpback song, what drives the selection  
425 of specific novelties, and how or whether this is driven by sexual selection.

426 The movement and variation of whale-song bears comparison with the movement of human music  
427 during migration. Pamjav et al. [46] conducted a large study of musical melody styles for 31 Eurasian

428 nations. They found that close musical relations indicate close genetic relations ( $F_{ST} < 0.05$  [53]) with  
429 probability 82%. This is one of the largest studies ever done of folk music, and almost certainly the largest  
430 computational study: they used databases of 1,000–2,500 melodies for each of the 31 cultures. The notion  
431 of musical similarity here revolves round a Euclidean distance metric derived from a Self-Organising  
432 Map (SOM [54]), and this is an area requiring further validation: musical similarity is strongly context  
433 dependent, and the workings of a SOM are somewhat inscrutable. Nevertheless, this work presents an  
434 interesting opportunity, given the models of music that we propose, to compare the whalesong behaviour  
435 with the human musical behaviour in detailed and explicable ways.

## 436 **6 A research programme on creativity in vocal communication in** 437 **humans and non-humans**

438 In this paper, we have identified parallels between human and animal vocal communication behaviours,  
439 at the immediate phenomenological level, and suggested that they are worthy of further investigation in  
440 the context of creativity research.

441 We decomposed the notion of creativity into an objective process of generation, coupled with a com-  
442 bination of relative value judgements, some of which, notably novelty, can be objectively modelled. This  
443 added objectivity allows us to ask questions that were not previously scientifically formulable, regard-  
444 ing the nature of vocal communication, its effect on humans and other species, and the mechanisms that  
445 underlie it.

446 We have deployed Boden’s philosophical approach to human creativity [3] to hypothesise a possible  
447 explanation for new song construction in migrating whales, and identified evidence of music migration in  
448 humans. We have presented evidence, from normally separate research fields, of comparable physiologi-  
449 cal responses to aural sequence perception in birds and humans, which might suggest similar processes at  
450 deeper levels, suggesting a computational method by which these empirical studies can be implemented.

451 We propose, therefore, that, when we examine the evolution of vocal communication in animals  
452 and humans from the perspective of creativity, we can shed new light on processes which seem to be  
453 common (though probably not commonly derived) between very distantly related species. Therefore, we  
454 suggest that the philosophical framework outlined here is a potentially fruitful means of addressing the  
455 communicative behaviour of animals that improvise (individually or collectively), and perhaps thence  
456 understanding better the mechanisms that underlie human communication and human creativity.

457 More specifically, we can propose

- 458 • comparative studies on heart rate and other physiological and electrophysiological measures in  
459 birds and in humans in response to complex aural stimulation, relative to a known vocal communi-  
460 cation form; subsequent neural studies to seek neural correlates of information content [27];
- 461 • comparative studies on the dynamics of whale migration and song variation as compared with the  
462 dynamics of human migration and song variation; subsequent modelling to compare the processes,  
463 novelty and complexity involved;
- 464 • the development of new measurement techniques to allow physiological and neural analysis of  
465 birds, whales, and other improvising animals to be compared with human analysis, and thence  
466 modelled as we have described above.

467 We believe that these approaches and others entailed by questioning the relationship between creative  
468 behaviour in humans and the superficially similar behaviours in other species offer a new and exciting  
469 approach to understanding the cognitive mechanisms involved both in vocal communication and in cre-  
470 ativity.

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