

## Chapter 10

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### Human Cognition as a Product and Agent of Evolution

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This paper explores two complementary ways of examining the relationship between evolution and cognition: the first arguing that human cognition has evolved to make sense of other evolutionary products, the second describing the impact of human cognition on the selection of domesticated plants. The first section of the paper reviews research that delineates the correspondences among different biological classification systems. A series of studies establishes that: (1) Jivaroans, scientific ornithologists, and ornithologically naive United States undergraduates agree in their recognition of patterns of resemblance among a collection of South American bird specimens; (2) variation in the agreement among the diverse groups of informants seems to reflect variation in the clarity of the pattern of resemblance [Boster, Berlin, and O'Neill 1986; Boster 1987]; (3) the diverse groups agree on their categorization because they attend to the same features to differentiate the sets of specimens, apparently reflecting a pan-human perceptual strategy that selects those features of a collection of organisms that yield the most informative categorization [Boster and D'Andrade 1989]; (4) there is greater intracultural variation than cross-cultural variation in biological similarity judgments [Boster 1991]; and (5) the classificatory strategies at work here are apparently related to more general features of human categorization such as typicality judgment [Boster 1988]. These results suggest that many features of human cognition are best understood as having evolved to interpret and discriminate other products of evolution.

The second section of the paper concerns the consequences of

human strategies of discriminating and categorizing natural kinds, focusing on the relationship between classification, cultivation and selection of Aguaruna cultivars of manioc (*Manihot esculenta* Crantz). Here I review research that argues that the procedures cultivators use to distinguish crop varieties have the effect of selecting for increased variability in the features they use to distinguish the crops: cultivators change the world in the process of understanding it in such a way as to make their procedures for understanding more appropriate [Boster 1984a; 1984b; 1985]. This section completes the argument that human cognition has co-evolved with the natural world; it both shapes and has been shaped by other living things.

My objectives in writing this paper are self-indulgent: to summarize some of my own contributions to the study of ethnobiology and to describe the broader context of that work and its implications. I do not report any new experimental findings; my effort instead is directed to sketching out the overall coherence of a series of publications over some years. The most important propositions will be numbered for future reference,

### Cognition as a Product of Evolution

I will begin by reviewing research that describes and explains the correspondences among different systems of biological classification. I will first summarize the evidence for various sorts of universals in folk biological classification. I will then argue that the source of these commonalities in classification lie both in the natural order (the objective organization of biological diversity) and in the character of human cognition.

A number of researchers have described strong correspondences among the systems of biological classification of different cultural groups. Four types of universals have been described: universals in the linguistic form of classification, in the mapping of categories on to their referents, in the judgment of similarity among organisms, and in the choice of characteristics of organisms to attend to.

Berlin and his collaborators [Berlin 1972, 1976; Berlin, Breedlove and Raven 1973, 1974] have documented strong universals in the linguistic form of biological classification. They have

shown that (I) most folk biological classification systems are shallow taxonomies. Most named categories are at the folk generic rank (e.g. oak, robin, otter), which is the most psychologically salient rank of the folk taxonomy. Some of these, especially culturally important species, are further subdivided into folk specific categories (e.g. live oak, pin oak), while all but the most anomalous are included in superordinate 'life-form' categories (e.g. tree, bird, mammal).

Various researchers have also noted profound regularities in the ways that folk biological categories map on to scientific species [Berlin 1973; Bulmer 1970; Diamond 1966; Hunn 1975]. This work has argued that (II) folk biological classifications tend to 'carve nature at the joints', naming the same objective discontinuities in nature as those recognized in scientific classification.

For each of these first two universals, the evidence and argument is linguistic; both depend on examining people's names for organisms and observing either how the names relate to each other (as when one examines the inclusion relationships among categories in a folk taxonomy), or how they relate to their referents (as when one examines the mapping of folk categories on to their biological ranges). However, there are a number of problems inherent in depending on the linguistic form of folk taxonomies to argue for universals. One is convincing fellow investigators of the naturalness and flexibility of your analytic framework: this appears to be the principal criticism of Berlin's theory of folk taxonomic rank [Ellen 1979; Healey 1978-9; Hunn 1982; Randall 1976]. Secondly, this approach to universals presumes that informants all agree what organisms should be called. In fact, informants typically do not universally agree on the identification of plants and animals. Finally, depending on named category as a clue to categorization limits one's choice of cultural groups to investigate: one can't elicit information from people who have no prior experience of and hence no names for the organisms.

Given these difficulties in documenting the first two types of universals in biological classification, I have chosen to focus my own research on documenting possible universals in people's discrimination of biological diversity using methods that do not depend on people's names for organisms. This can be termed a psychological (as opposed to a linguistic) approach to universals in biological classification; it exploits the fact that when people

confront biological diversity, they are able to make a whole host of discriminations among organisms, only a small fraction of which are actually marked by named categories. For example, we can readily discriminate between different instances of 'Eucalyptus' even though we may only have one name that captures the whole category.

The central finding of this work has been that (III) culturally diverse groups (Jivaroans, scientific ornithologists, and ornithologically naive United States undergraduates) agree in their recognition of patterns of resemblance among a collection of South American bird specimens' [Boster Berlin and O'Neil 1986; Boster 1987].

Boster et al. [1986] confronted the problem that earlier arguments for a strong correspondence between folk and scientific biological classification systems depended on methods that falsely assumed that native informants agree in classification. Instead, we used the pattern of disagreement in identification to infer the informants' implicit categories. We showed that folk and scientist alike were responding to the same objective pattern of resemblance among birds by demonstrating that the folk confuse species that the scientists classify as related.<sup>2</sup>

Boster 1987 tested the generality of these findings. Because both the Jivaro and the scientists are expert ornithologists, it is conceivable that the high agreement between them is a consequence of the fact that all have had ample opportunity to study the organisms and have represented their understandings in explicit nomenclatural systems. The question that arises is whether informants who have no prior knowledge of the birds recognize the same underlying pattern of similarity and difference as that recognized by the Jivaro and the scientists. To test this, I asked University undergraduates who had never seen these South American birds before to sort them according to their overall similarity.<sup>3</sup> Despite the cultural differences among the three informant groups and the differences in the cognitive tasks each performed, all groups recognized substantially similar patterns of resemblance among the bird specimens. It appeared that recognition of the pattern of resemblance among organisms does not depend on formal training in taxonomy, intimate knowledge of the organisms, or possession of named categories for the specimens.

The second major result of this research was that all groups of

informants agreed more strongly on the pattern of resemblance among non-passerine birds (e.g. woodpeckers, toucans) than on the pattern of resemblance among passerines (e.g. wrens, tanagers). We interpreted this difference in people's categorization of these two subsets of birds as evidence that (IV) the objective pattern of similarity among organisms varies in its clarity and that alternative biological classification systems correspond only to the extent that the objective pattern is clear [Boster et al. 1986; Boster 1987].

The next paper in this series, Boster and D'Andrade 1989, addressed a question suggested by this work: is the source of cross-cultural similarities in biological classification in the world alone or is it in the mind as well? Given the strong agreement among diverse informant groups and the apparent dependence of the strength of agreement on the clarity of the objective pattern of resemblance, it was conceivable that the objective pattern of resemblance of specimens alone was responsible for the agreement among culturally distinct groups. In other words, it was conceivable that the correlational structure of the attributes of the bird specimens was sufficiently strong that, no matter what attributes were attended to, the same classification would have resulted. Boster and D'Andrade used nine size and seven colour measurements of the passerine and non-passerine bird specimens used in the earlier experiments to help assess why the diverse groups of informants agree on their categorization. We articulated two possibilities: the structured-world and the structured-mind hypotheses. The structured-world hypothesis held that diverse groups of informants may attend to radically different characters of organisms but, because the characters themselves are intercorrelated, the same structure is discerned no matter which characters are chosen. The structured-mind hypothesis held that in addition to assuming the intercorrelation of characters, diverse groups of informants choose the same salient attributes of the specimens to differentiate them.

The results supported the structured-mind hypothesis. Not only do diverse cultural groups categorize the birds in similar ways but they appear to pay attention to the same characteristics. We found that all informant groups, whether they were South American Indians, United States undergraduates, or ornithologists, based their categorization of the passerines on the same set of characters and based their categorization of the non-

passerines on a different suite of characters. (V) Agreement among informant groups appears not to be simply due to the correlational structure of the stimuli; the different groups apparently share a perceptual/cognitive strategy of selecting those features that will best discriminate the collection of specimens.

These findings, suggestive of a pan-human (or possibly pan-mammalian) perceptual strategy for making sense of biological diversity, prompted further inquiry into the psychological basis of cross-cultural agreement in folk biological similarity judgment. Accordingly, Boster [1991] investigated the relationship between the intracultural variation and cross-cultural universals in biological similarity judgment. There were three major results from this study. First, there was a high degree of consensus among the United States undergraduate informants on the sorting of both subsets of birds; the pattern of agreement among informants fit Romney, Weller and Batchelder's [1986] cultural consensus model. Secondly, agreement with the aggregate of one's own group is correlated with agreement with the aggregates of responses of other groups of informants. Thirdly, aggregates are closer than individuals are, and there is more intra-cultural than cross-cultural variation in judging the similarity of the birds. I interpreted this result as providing further indication that (VI) cross-cultural universals in biological similarity judgment are ultimately based in the characteristics of individual cognition: groups agree because individuals do.

Boster [1988] also attempts to relate the classificatory strategies at work in these experiments to more general features of human categorization such as typicality judgment. 'Typicality' refers to the fact that often some members of categories are regarded as more representative of the category than other members. For example, chairs are regarded as more typical examples of furniture than rugs, robins are regarded as more typical examples of birds than penguins. The objectives of the paper were to show that typicality judgments (at least of birds) could be explained by the structure of the scientific taxonomy and that diverse informant groups (United States undergraduates, Jivaroans and scientific ornithologists) all responded to the birds in ways that reflected the birds' relative structural typicality. The first objective was met by demonstrating that (VII) typicality ratings of birds [Rosch 1975] are more strongly correlated with

the number of related species than with the frequency of the birds in the observers' immediate environment or with the frequency of mention of the birds in written materials [cf. Mervis, Caitlin and Rosch 1976]. In other words, typical birds are those that are members of large orders and families, not those whose names are read most often or that are seen most frequently. This confirms the interpretation of Rosch and Mervis [1975] that resemblance to other category members rather than familiarity best predicts informants' typicality judgments.

The second objective was met by showing that, due to the structural basis of typicality effects, informants respond to passerines in other ways that reflect the passerines' structural position as most similar to other birds. (VIII) Informants make finer discriminations of the most typical birds (passerines) than among less typical birds (non-passerines) yet disagree more often in identifying them, and report greater difficulty in judging the similarities among them. Specifically, in spite of the fact that the United States undergraduates had not seen these South American bird species before and did not have names for any of them (with the occasional exception of woodpeckers and toucans), most informants regarded the passerines as more like their idea of typical birds. If typicality judgments were only a result of familiarity, the United States informants would not consistently pick one or another of the novel specimens as more typical examples of birds. United States undergraduates also said they had more difficulty sorting the passerines than the non-passerines. Similarly, the Jivaroan informants agreed with each other much more often on the names of the non-passerine specimens than they did on the passerines. Paradoxically, the Jivaroan informants appear to have tried to discriminate the passerine specimens more finely than the non-passerines, thereby tackling a more difficult task with this group of specimens: they merge genera and species of non-passerines while distinguishing species of passerines. This last finding suggests that the way to explain some aspects of human thought is to look at the structure of what they are thinking about: here, there is evidence that the internal structure of categories reflects the objective structure of the domain.

### The Evolution of Cognition and of Natural Kinds

I would now like to argue that these results, taken together with those of other ethnobiological and cognitive researchers, suggest that many features of human cognition are best understood as having evolved to interpret and discriminate other products of evolution. I will begin by summarizing where we have come so far in the argument.

First, the natural world is well structured. Evolution can be regarded as a mechanism that generates natural structure, creating a pattern of similarity and difference among organisms. Organisms may appear similar either through diverging little from a common ancestor (phylogeny) or through convergent adaptation to particular niches (convergence). The resulting pattern of similarity and difference is robust and is recognized in similar ways by members of diverse cultural groups (findings II, III). The universals in the form of folk biological classification systems as shallow taxonomies reflects the universal experience of biological diversity as evolutionary products with a branching pattern of similarity and difference (finding I).

Secondly, human cognition is highly responsive to the natural structure. The clarity of the objective pattern of similarity among organisms appears to be responsible for variation in the degree of correspondence among alternative biological classification systems (finding IV). The objective pattern of similarity also appears to determine which organisms humans will regard as most prototypical (finding VII).

Thirdly, it appears that human response to natural structure is governed by a coherent cognitive faculty that affects perception and memory and other aspects of mental performance. Humans actively construct an understanding of natural structure, extracting those characteristics of a diverse assemblage of organisms that will best discriminate them (finding V). It appears to be the sharing of perceptual/cognitive strategies at the individual level that is responsible for the consensus among culturally diverse groups in classification: cross-cultural universals in folk biological classification are based in individual cognition (finding VI). The objective structure coherently influences many different aspects of cognition at once, affecting typicality judgments, discrimination, errors in identification and

the perceived difficulty of the task (finding VIII).

Many other characteristics of human cognition can be understood as having been forged to make sense of biological diversity. Natural kind categories appear to have a privileged place in human category formation. It is as though a strategy of categorization that works best for organisms were adapted to make sense of novel objects such as human artefacts.

For example, Rosch's notion of basic level object (a generalization of Berlin's concept of the folk generic) was seen as capturing the correlational structure of the features of concrete objects [Rosch, Mervis, Gray, Johnson and Boyes-Braem 1976]. The basic level objects maximize similarity of instances within categories and maximize difference between instances of different categories. It is the most abstract level that can be captured by a single visuo-spatial representation. The correlational structure reflects the organic coherence of living things and the function or purpose of artefacts. Most organisms are characterized by very high feature intercorrelations because many of the features of organisms reflect different aspects of an adaptation for a particular function. For example, the feathers, hollow bones and wings of birds all reflect an adaptation for flight. These features do not freely vary in the biological world; they come as a cluster because they are all parts of an adaptive package for flightedness. Artefacts tend to have weaker correlational structures than living things because their purposes are more limited: a chair minimally need only serve to be sat upon, it need not breathe, feed and reproduce as well [cf. Waddington 1966].

Similarly, the formation of categories on the basis of family resemblance to a prototype makes the most sense when dealing with natural kinds (as opposed to artefact or abstract categories). Evolution often produces assemblages of related organisms which literally share a family resemblance to one another but do not share necessary and sufficient diagnostic features (much to the dismay of systematists!). This is part of what makes the Prototype-surround tactic in recognizing natural kinds such a powerful one. It allows humans to recognize the gestalt coherence of features even when confronted with instances that are missing one or another of the prototype's suite of intercorrelated features. Typicality and correlational structure are linked: typical members of categories capture the correlational structure of

features better than atypical members and share more features with the prototype for the category [Malt and Smith 1984]. Children early on grasp the greater coherence of natural kinds and make more inductive inferences about natural-kind categories than about artificial categories [Gelman and O'Reilly, 1988].

There is also substantial evidence for strong neural localization of the capacity to discriminate living things. Several investigators have shown that individuals may suffer specific deficits in their identification or recognition of animals or other living things as a result of various kinds of insults to the brain, including herpes simplex encephalitis [Sartori, Job, Miozzo, Zago and Marchiori 1993; Sheridan and Humpreys 1993; Silveri and Gainotti 1988], Alzheimer's dementia [Silveri, Daniele, Giustolisi and Gainotti 1991], infarct [Hart, Berndt and Caramazza 1985; Hart and Gordon 1992], or other forms of brain injury [Basso, Capitani and Laiacina 1988; Farah, Hammond, Mehta and Ratcliff 1989; Farah, McMullen and Meyer 1991; McCarthy and Warrington 1988, 1990; Young, Newcombe, Hellawell and de Haan 1989]. The same subjects are usually reported to have much better recognition of artefacts and other non-living things. While some authors have argued that these apparently category-specific deficits are best explained as a consequence of the intrinsic differences in the visual discriminability [Gaffan and Heywood 1993] or familiarity [Funnell and Sheridan 1992; Stewart, Parkin and Hunkin 1992] of living and non-living things, on balance the results suggest a striking difference in the perceptual processing of natural and unnatural kinds.

If these aspects of human cognition have been shaped by evolution to make sense of biological diversity, we are probably not alone. These perceptual skills are probably homologous with those of other higher vertebrates. In other words, if one could train chimpanzees, rats, or even pigeons to do the bird-similarity judgment tasks described here, I expect that the results would be similar to the human responses. Among the most important tasks that animals face in adapting to an environment is recognizing the similarity and difference among other organisms and forming appropriate categories of them. There is an enormous fitness advantage to being able to recognize that a novel plant species is related to a species already known to be either edible or poisonous. It would be a similarly fatal error to mistake a

potential predator for a prey species. In fact, not only is categorization an essential survival skill, but there is some evidence that animals (and plants) exploit the characteristics of other species' capacity for categorization to their own advantage. One can interpret the widespread phenomenon of mimicry in this light as a response to the category systems of potential predators: one can avoid being eaten by masquerading as something inedible. There would be no point in the masquerade if the predator did not form categories of edible and inedible [Cott 1966].

One need not assume that animals have been selected to be systematists directly; the capacity to recognize the similarity and difference of different species is probably part and parcel of the perceptual apparatus that allows animals to recognize either the constancy of an object from different perspectives or in different settings, or to recognize the similarity of individuals from the same species [Lorenz 1966; Herrnstein 1984].

The capacity for categorizing natural kinds has probably been more completely researched in pigeons than in any other non-human species. Pigeons appear to be much more adept at learning natural categories than at learning artefacts, readily discriminating photographs containing people [Herrnstein and Loveland 1964], trees, bodies of water or individual humans [Herrnstein, Loveland and Cable 1976] and even fish [Herrnstein and de Villiers 1980] but not more artificial categories such as cubes [Cerella 1977] or cartoon characters [Cerella 1980, 1982]. Furthermore, pigeons can readily learn to discriminate oak leaves from non-oak leaves but had much more difficulty discriminating an individual oak leaf from other oak leaves [Cerella 1979]. It is likely that pigeons are not narrowly specialized on recognizing natural objects per se, but rather at recognizing 'polymorphous categories' that have the correlational structure of natural kinds. For example, pigeons do quite well at discriminating letters, making a similar pattern of mistakes to the one that humans make [Blough 1982].

The evidence on the acquisition of natural-kind categories by pigeons is suggestive of the sort of data one would want on the categorization skills of higher vertebrates generally. One might expect evidence of neural modules specialized for the recognition of gestalts and family resemblances among instances in biological domains and other domains with prototype-surround category

structures. The numerous reports of category-specific deficits in the discrimination of living things described above suggest the existence of some such neural sub-system in humans [Hart and Gordon 1992, most likely involving temporo-limbic structures [Sartori et al. 1993; Silveri et al. 1991].

### Cognition as an Agent of Selection

To review, in the first section of this paper I summarized evidence of a number of universals in folk biological classification. I argued that these universals have their origin both in the fact that the objective pattern of similarity and difference among organisms is clearly structured and that human beings share a domain-specific cognitive strategy for selectively attending to those features of a collection of organisms that will best discriminate them. I also speculated that other aspects of human cognition and categorization could be understood as having evolved (and hence were best suited) to discriminate biological diversity. In this second section of the paper, I argue that when humans use these same cognitive strategies to discriminate domesticated plants and animals, they exercise sufficient control over the reproduction of the domesticates to select for perceptual distinctiveness. I argue that the process of differentiating the cultivars on the basis of the most diagnostic characters has the effect of increasing the range, continuity and independence of variation of those characters. The end result of this process is to increase the distinctiveness of the cultivars and thus increase the number of cultivars that can be distinguished and maintained in cultivation. I have developed this argument in detail elsewhere [Boster 1984a, 1984b, 1985] in describing the selection of Aguaruna cultivars of manioc (*Manihot esculenta* Crantz); here I simply summarize the model and evidence and frame it in the broader context of human biological classification.

The Aguaruna Jivaro of the tropical forest of northern Peru maintain more than a hundred cultivars of manioc, their most important crop. I studied their classification, cultivation and selection of manioc cultivars in an effort to understand how they could tell the difference among so many different varieties and why they would bother. It appeared that manioc cultivars are

selected not just for their ability to survive against natural pests and disasters (natural selection), or for their culturally desirable flavours or yields (cultural selection), but for being distinctive (perceptual selection). Although small inventories of cultivars could conceivably be maintained without good discriminating features by simply remembering where one planted each one, the cultivator's ability to observe and remember perceptible distinctions is critical to the maintenance of an inventory of a hundred varieties. Before a new cultivar can be selected for yield or flavour or other non-directly observable characters, it must be distinguishable on the basis of its combination of characters from those already in cultivation. A cultivar that fills a gap in the morphological continuum of existing cultivars would be more likely to be accepted than one that is extremely similar to cultivars already maintained. Cultivators identify cultivars on the basis of characters that show the greatest range of variation and perceptual salience. In Aguaruna cultivars, these are leaf-shape, petiole-colour, and stem-colour. Cultivars that are similar to each other in these 'good' characters are more likely to be confused with one another than those that are similar in other characters. Thus perceptual selection is not random, but is directed toward increasing variation in those characters that are already regarded as valuable for identification. They thereby enhance the value of the characters they choose in distinguishing the varieties. If the cultivators could not distinguish among cultivars, their cultivar inventories would shrink to those clones that produce the most planting material, due to the random loss of rarer cultivars.

This process of selective acceptance of cultivars on the basis of perceptual distinctiveness has eight important consequences that are borne out [Boster 1985]: (1) The overall range of variation in important taxonomic characters is increased over wild relatives. (2) Large perceptual gaps between cultivars on these taxonomic characters are gradually filled; at saturation, all cultivars are separated by just-noticeable differences on a morphological continuum. (3) Important taxonomic characters of the cultivars species-wide tend to vary independently of one another. (4) Geographic races defined by taxonomic characters are absent; the cultivar inventory maintained by the Aguaruna represents a large proportion of the total range of variation in taxonomic characters of the cultivated species as a whole. (5) The important

taxonomic characters that distinguish cultivars in the inventory maintained by the Aguaruna vary independently from one another just as the characters of the species-wide collection of cultivars do. (6) Aguaruna cultivators use the same salient characters to distinguish cultivars as do the botanists. (7) Aguaruna cultivators treat the continuously varying cultivars as approximately equally difficult to distinguish perceptually. (8) Aguaruna cultivators confuse those cultivars they regard as most similar to one another; similarity of cultivars on the most important taxonomic characters (petiole-colour, stem-colour, and leaf-shape) independently contribute to the confusion of cultivars.

This model helps explain why cultivated plants show such extreme variation in features that have little to do with the utility or survival of the plant [Dodds 1965; Harlan 1975; Yen 1968]. It is precisely those taxonomic characters that have very few functional consequences that are most valuable perceptually as characters to discriminate the cultivars; a cultivator could not accept taxonomic characters that hurt flavour *or* yield, or that made cultivation more difficult. Pigmentation characters are ideal because they have relatively little adaptive significance for the plants (compared with stem habit, for example). Although occasionally native cultivators may deliberately select for the strange or bizarre [Harlan 1975: 110, 1381, it is likely that most selection of perceptual distinctiveness is unconscious.

There is a procrustean aspect to this process: in effect, the cultivators force the cultivars to fit their perceptual strategies. While I have argued that the perceptual/cognitive strategy of discriminating organisms evolved to make sense of biological diversity, when it is applied to discriminate the 'captive audience' of domesticated species, it has the paradoxical effect of making them less like wild species. As indicated earlier, biological form is generally characterized by very high feature intercorrelations. It is this aspect of organisms that humans exploit in forming prototype-surround categories of them. However, because cultivators discriminate cultivars on the basis of combinations of characters (not simply on each character independently), they exert a selection pressure to break down the intercorrelations among characters by retaining cultivars with novel combinations of characters. For example, if pigmentation in different parts of the plant co-varied (to either all light or all

dark pigmentation), an unusual plant that had lightly pigmented petioles but darkly pigmented stems would be much more likely to be retained in cultivation. Humans are not the only species who apparently change the world in the process of understanding it. Human perceptual selection of manioc varieties is analogous to other processes of perceptual co-evolution (e.g. moths and bats [Roeder 1963]; pollinators and plants [Barth 1985; Jones and Little 1983]; predators and prey [Cott 1966]). The co-evolution of the visual and sensory systems of pollinators and the floral morphology of the plants they pollinate is the most similar to the case of human-crop interactions. The plants have an 'interest' in making themselves attractive to potential pollinators and must advertise their incentives of nectar and pollen in ways that match the sense modalities of the pollinators. Hence, the predominant pigmentation of the flowers matches the visual system (or relative lack of it) of the pollinator: bird-pollinated flowers tend to be red, bee-pollinated flowers blue and yellow, bat- and moth-pollinated flowers white. As in the process of selection for perceptual distinctiveness described above, the perceptual strategy used by the pollinator in finding nectar and pollen sources exerts a selection pressure on the plants; plants that do not advertise in the appropriate sense modality are less likely to be pollinated and set seed. For insects as well as humans, the use of the perceptual strategy has the effect of enhancing its value for discriminating the plants.

In sum, as the biological world has radiated, the capacity to recognize the order in that radiation has co-evolved. The evolution of human cognition to understand the natural world is part of a more general process among living things. Mind has evolved both to understand and to shape nature.

#### Notes

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1. It is important to be clear that the experiments used to demonstrate this agreement among alternative classification schemes either implicitly or explicitly constrained the informants to make use of morphological (as opposed to functional or utilitarian) criteria to discriminate the specimens. If one elicits judgments about biological similarity using methods that allow the informants to make use of other knowledge they have about the organisms, they very well may use it. For example, when Boster and Johnson [1989] asked informants to judge the similarity of fish using an unconstrained pile sort task, the expert fishermen made use of their extensive knowledge of the behaviour and utility of the fish to sort them, while novices (who were limited to basing their similarity judgments on the pictured shapes of the fish) sorted the fish more closely according to the scientific classification.
2. In the Jivaroan bird experiments, adult Aguaruna and Huambisa informants were asked to identify prepared bird specimens laid out on long tables. All the birds were native to the surrounding tropical forest. We constructed two measures: one a measure of how each pair of bird species were confused with one another by Jivaroan informants (specimen overlap) and the second a measure of how close each pair of bird specimens were in the scientific classification (taxonomic distance). Our measure of the correspondence between the folk and scientific systems of classification was simply the correlation between these two measures.
3. In the United States research, University of Kentucky students were asked to participate in two specimen-sorting experiments, a free pile sort and a successive pile sort. Subjects were screened to ensure that they had no formal training in zoology nor any familiarity with these South American birds. In the free pile sort, subjects were asked to arrange specimens into groups on the basis of their overall similarity. Each subject performed this task separately on subsets of forty passerine specimens and forty non-passerine specimens. The judged similarity of each pair of specimens was measured by counting how often the pair was placed in the same group. In the successive pile sort, subjects were first asked to place the specimens into groups on the basis of their overall similarity. Subjects were then asked to divide whichever group they thought most heterogeneous into two coherent subgroups.

The subject continued to divide groups until all specimens were separated. Next, the subject's initial groups were restored and the subject asked to merge the most similar pair of groups. The subject continued to merge groups until all specimens were merged. Each subject performed the task separately on subsets of fifteen passerine and fifteen non-passerine specimens. These subsets of specimens were chosen such that the passerine and non-passerine subsets had the same underlying scientific taxonomic structure. For this purpose, the Piciformes (including woodpeckers, toucans, galbulas and jacamars) were chosen as a representative non-passerine order. The judged similarity of each pair of specimens was measured by counting the rank order in which they were split apart. The ornithologist who identified the specimens also performed the dividing experiment, using species names on index cards as stimuli rather than as specimens. These judgements broke ties in the taxonomic distances, disambiguating, for example, which species in a genus are most similar. Again, the judged similarity of species was measured by counting the rank order in which they were split apart. The data analysis involved comparing the judged similarity of each pair of specimens with the measure of confusion by the Jivaro in the bird identification experiments and with proximity in scientific classification.

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