This was published in
Biology and Philosophy *(June 2002) 17/3: 409-422.*

MIRROR IMAGERY AND BIOLOGICAL SELECTION

An organism cannot be more fit than its perfect duplicate (relative to the same environment). But what about individuals that differ only in being mirror images of each other? These enantiomorphs share the same absolute properties and the same relations between their parts. They differ only in how they are oriented in space.

1. Scale eating fish

Michio Hori (1993) has presented evidence for natural selection of one trait over its mirror image. In Lake Tanganiyka there are seven species of cichlid fish that eat other fishes' scales. All of the species fall within the genus *Perissodus* and have asymmetrical mouths that are adapted to tearing off scales. Their mouths can be either twisted to the right or to the left. Left twisted fish always attack the right side of their prey. Right twisted fish always attack the left side of their prey.

Hori concentrated on *P. microlepis.* He found that most of their prey of this species learn to guard against attack. Only about 1 in 5 attacks succeeds. Prey fish remember which side attacks came from and so are more vigilant about fish approaching from that side. Hence minority scale eaters have an advantage.

Scale eaters inherit their handedness by a simple Mendelian one locus-two alleles system in which right handedness is dominant. Hence the minority fish become more common until their advantage in surprise attacks disappears. This leads to the prediction that the ratio of lefties to righties should be 1 to 1.

Actually, the ratio seesaws. Over five years, the population shifts from a lefty majority to a righty majority. Hori suggests that the oscillation is a time lag effect. Successful predators eventually bear more young. But the young take two years to mature. Once the new majority become active scale eaters, the prey adapt to the new direction in which most attacks are coming. Now the new minority has an advantage. Hence, the seesaw tilts in the opposite direction.

Hori is principally interested in the scale-eaters because they provide a rare illustration of frequency dependent selection. (He displays no interest in the mirror imagery aspect *per se*.) Frequency dependent selection has deep significance because of R. A. Fisher's classic explanation of gender ratios. In The Genetical Theory of Natural Selection R. A. Fisher raised fundamental questions about sex. Why are there only two genders? Why is there so commonly a 50/50 distribution between males and females? His answers became the point of departure for all subsequent work on gender distribution.

2. Thought Experiments

Fisher approached these gender issues with a close study of hypothetical organisms -- which I will emulate. He quotes Arthur

Eddington: “We need scarcely add that the contemplation in natural science of a wider domain than the actual leads to a far better understanding of the actual” (1928, 267) Fisher was laboring against his fellow biologists’ distrust of thought experiments:

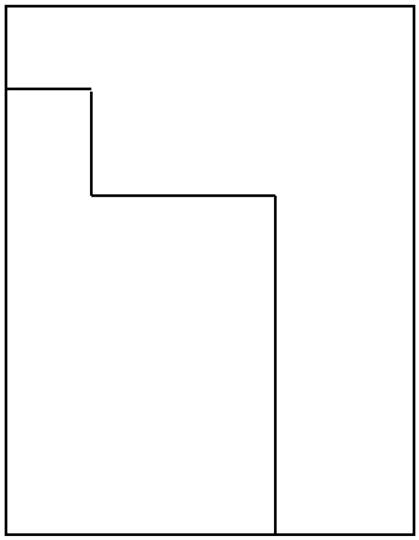
> For a mathematician [Eddington’s] statement is almost a truism. For a biologist speaking of his own subject, it would suggest an extraordinarily wide outlook. No practical biologist interested in sexual reproduction would be led to work out the detailed consequences experienced by organisms having three or more sexes; yet what else should he do if he wishes to understand why the sexes are, in fact, always two?”
> (1930, vii-ix)

Fisher shrugs off the charge that he is engaged in idle science fiction and proceeds to chronicle the coordination problems of three-sexed organisms. He combines this line of speculation with the disadvantages of asexual reproduction to obtain a game-theoretic explanation of the prevalence two-gendered species. Fisher then addresses the further mystery of why males and females are so commonly equal in number. By hypothetically varying the percentages, Fisher shows how the balance between the genders emerges as a strategic optimum. The basic idea is that there is an advantage to producing young of the minority gender. A member of the minority gender is the rarer commodity in the mate market. They can drive a better bargain. Consequently, parents who tend to produce members of one gender are vulnerable to exploitation. A parent's only stable strategy is to produce young of each gender with equal likelihood. As Fisher acknowledged, this rough reasoning needs to be qualified. There are gender differences in mortality, rate of sexual maturation, and other factors that bear on parental investment.

Despite the running start furnished by Hori's cichlid fish, hypothetical scenarios are needed to study the implications of mirror imagery. For it is unlikely that any complicated organism has *comprehensive* mirror variants. Suppose Lefty and Righty are cichlid fish that have hearts on the left side but have their mouths twisted in opposite directions. Their mirror image variation would be confined to their mouths. They cannot be duplicates because their internal parts have different relationships with one another. For instance, Lefty's lips would be closer to his heart. If Lefty and Righty are comprehensive mirror image variants, then every part of Lefty is the reversal of every part of Righty. There would be no difference in terms of distances and angles. They would be genuine enantiomorphs. Under these circumstances, we may ask whether Lefty and Righty are duplicates. I answer yes and shall argue that this answer undermines the possibility of any natural selection for handedness. Natural selection is blind to comprehensive mirror imagery.

3. Imaginary flat fish

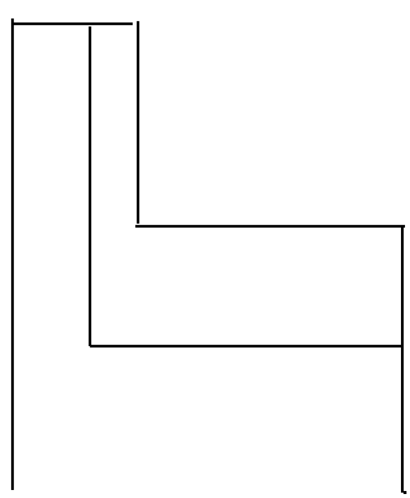
Consider a simplified world featuring "deebee fish". You can get a feel for these flat fish by taking a pair of index cards and cutting an angular **b** shaped figure like so:



You now have two **b** shaped figures and two **b** shaped complement figures. Take a **b** shaped figure and its complement and flip them over. This yields a **d** shaped figure along with a **d** shaped complement. Notice that a **b** and **d** figures are enantiomorphs. Although they have the same shape, a rigid two-dimensional movement (sliding the cutouts on a tabletop) cannot make one exactly occupy any spot the other vacated.

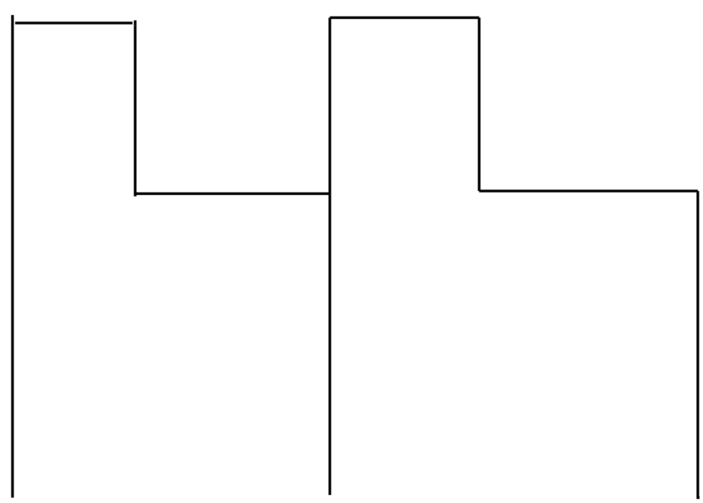
The rigidity of the three dimensional operation of flipping is important because it preserves the intrinsic properties of the figure. Sure, you can turn a **b** shape into a **d** shape with scissors and glue. But cutting and pasting does violence to the figure in the sense of affecting its absolute properties. You can turn a left-handed glove into a right-handed glove by pulling it inside out. Although this inversion of the glove did not involve any disassembly, it does alter the internal relations of the glove. For instance, what were the exterior parts of the glove thumb are now closer to each other. The same intrinsic change would be involved with a glove-shaped organism that was able to pull itself inside out. Evolutionary theory is sensitive to violent mirror reversals. It is only dyslexic with respect to rigid transformations.

Deebee fish live at the bottom of the ocean. The pressure is so great that the fish cannot flip themselves. Thus a **d** fish cannot turn itself into a **b** fish. Deebees prey solely on their complements. To gain nutrition, the deebee and its complement must fit perfectly to form a rectangle. Since deebee prey come only in one size, deebees cannot afford to grow or shrink. A maturing deebee just becomes denser. After its density reaches a critical threshold, the deebee undergoes fission:



The two resulting deebees then take on water to bloat to feeding size. In this sense, deebees breed true: a **d** fish divides into two **d** fish, a **b** fish divide into two **b** fish.

Deebees would be especially simple if they reproduced asexually. But asexual organisms have a problematic status. For instance, if a necessary condition for being a member of the same species is the ability to inter-breed, then asexual organisms do not constitute a species. To steer clear of these issues, we shall complicate the lives of deebees by introducing sexual reproduction. In particular, deebees share genetic information by concatenating. Here is the mating position for two **b** fish:



(To view the mating position of the **d** fish, hold the diagram to a mirror.) As is known from protozoans, algae, and fungi, there can be sexual reproduction without any gender differentiation. These organisms have uniform sized gametes and so have no division into males and females.

No part of a **b** fish is a gene for being **b** shaped rather than **d** shaped. A **b** fish has only **b** offspring in virtue of its geometry, not its genes.

In addition to sex, the deebees face a second complication: their prey can change orientation. When sufficiently pestered, deebee complements laboriously flip over and assume the opposite orientation. Given these defensive adjustments by their prey, the **d** fish and **b** fish are kept in balance.

Like Hori's scale eaters, the deebees appear to illustrate frequency dependent natural selection. But the deebees do not satisfy a precondition of natural selection: variety. The deebee population is covertly homogenous. The **d** fish and **b** fish merely differ in orientation. If a diver were to flip a **b** fish over, a **d** fish would result. The flipped **b** fish would feed only on **d** complements, breed only with other **d** fish, have only **d** descendants, and in general behave just as a **d** fish. The explanation is that the **b** fish <u>is</u> a **d** fish.

From the evolutionary perspective, there is nothing really going on with the deebees. Since there are no biological differences between **b** fish and **d** fish, there are no heritable differences. An organism cannot change its biological type by sheer travel through the same environment.

Travel can affect reproductive success. If a hungry organism shows up in the wrong place at the wrong time, he may become dinner instead of finding dinner. Organisms with different propensities to travel can vary in fitness. Such was the case with the ancestors of the deebee prey. Some deebee complements were stuck in their orientation. Others had the ability to flip when sufficiently pestered by deebee fish. Therefore, there must have been an intrinsic difference between flexible deebee complements and their inflexible counterparts. The flexible and inflexible deebee complements satisfied the variety condition for natural selection. In particular, deebee fish eventually eliminated the inflexible complements, leaving only the flexible complements.

Evolutionary theory is still blind to the explanation of *why* the flexibility conferred an advantage to the deebee complements. When a deebee complement switches its orientation, it is intrinsically the same organism situated in the same environment. So from behind the blinders of evolutionary theory, we cannot answer the question of *how* the creature's act of mirror reversal increases its reproductive success. On its own, evolutionary theory can accept the greater success as an inexplicable fact of life. But the real explanation is only available with resources outside of evolutionary theory.

Of course, deebee fish are not really fish. All fish, even very flat flounders, are three dimensional organisms. However, the phenomenon of surface bonding shows that two-dimensionality is not entirely alien to biological thinking. Many organic compounds have been derived from inorganic compounds in test tubes. But it remains difficult to see how proteins and nucleic acids could have formed abiotically because they are linked by specific chemical bonds. One proposal is that they could form in an orderly way if the process occurred on a chemically suitable surface:

> One reason why surface bonding is important is that the molecules are held in a particular orientation, and are free to move only in a single dimension. If some of them were upside down, or all of them were free to move in three dimensions, they would never link together. Binding to a surface would increase the local concentration of interacting molecules, and so speed up the reaction. Equally important, it would ensure that reacting molecules were held in a given orientation relative to one another, and so increase the specificity of the reactions. (Smith and Szathmary 1999, 33).

Of course, molecules are three dimensional even if their third dimension is negligible for certain purposes. In contrast, deebee fish are strictly two dimensional organisms like the geometrical figures that people Edwin A. Abbott's Flatland. The deebees have been contrived to examine evolutionary theory in the way Newton used point masses to study Kepler's laws of planetary motion.

4. A closer look at duplicates

Two organisms are duplicates exactly if they share all their intrinsic properties (shape, charge, glucose content, etc). These are qualitative properties that the organism has on its own. In contrast, extrinsic properties (being a brother, being a parasite, being an orphan, etc.) are possessed by virtue of relations with other things or by virtue of the absence of such relations (Langton and Lewis, 1998). Attributions of extrinsic properties to an organism are covertly about other things. Since attributions of intrinsic properties to an organism are entirely neutral about what else exists, these properties can be ascertained just by study of the organism itself.

We must be wary of pseudo-duplicates. Some casual observers of baby alligators regard them as duplicates of their parents. If baby alligators really were duplicates of their parents, then there could not be natural selection in favor of bigger alligators. The impression that baby alligators and parent alligators are duplicates motivates a good question: Why do alligators have a size limit? If each stage of the growing alligator is a duplicate of an earlier stage, then nothing internal changes when the alligator gets bigger. So if the alligator remains in the same environment, biologists would appear to run out of variables with which to account for a size limit. Alligators would only stop growing through accidents. This would be an embarrassment for evolutionary theory since alligators seem to have a law-like size limit. And certainly size matters to the mortality of alligators. Little alligators are gobbled up in great numbers by predators -- which include big alligators.

The belief that baby alligators are duplicates of their parents is a superficial mistake. But the puzzle can be reinstated by importing a hypothetical organism from W. K. Clifford (1901: 100). This organism is a cube that grows steadily larger. It absorbs nutrition through its sides. Does it have a size limit? Clifford assumes that a one inch cube can maintain its size by feeding through two of its sides. Since the cube organism feeds though all six of its sides, it grows to two inches. The volume of a two inch cube is eight times the volume of a one inch cube. But the surface of the two inch cube is only four times as large as the surface of the one inch cube. The ratio of surface to volume further decreases when the cube achieves a size of three inches. Now all six sides must be dedicated to maintaining the organism. Thus the geometry of the cubical organism imposes a limit on its growth. Since the volume of the organism is cubed while surface area is squared, the animal must eventually exhaust its ability to feed. The ratio of an organism's surface area to its volume is an internal relation. Hence, the size of an organism is an intrinsic property.

Size is also an intrinsic property of environments. Doubling everything would not create a duplicate environment. Although the increase would not be detectable by linear measurements (for our rulers would have expanded), the increase would make a difference to planetary orbits and other phenomena governed by geometrical laws.

Any purely spatial property of an organism is an extrinsic property. Identical twins can be duplicates even though they stand a meter apart. Nor is their duplicate status threatened by rotation. If one spins clockwise while the other spins counter-clockwise, they remain duplicates. If one twin sleeps with his head to the east while the other sleeps with his head to the west, they still wake up as twins. Given this indifference to space, we see that the twins are duplicates even if they are mirror images of each other.

The importance of duplicates is evident from their role in experimental design. Identical twin studies are highly informative because they control one of the two master variables used in evolutionary biology. When identical twins are unavailable, biologists use near duplicates (for instance, heavily inbred mice). And when near duplicates are unavailable, they try to wash out heritable differences by randomly assigning many animals to the treatment and control groups.

Scientists also seek duplicate environments. Trivially, any environment is a duplicate of itself. So putting two organisms in the same environment allows the experimenter to control for environmental differences. Failing this, the experimenter tries to create two separate but equal environments: same food, same lighting, same internal layout.

The boundary between an organism and its environment is sometimes unclear. There is the further complication that organisms change their environments. Sometimes the changes are beneficial to their offspring. When these improvements are cumulative, some thinkers claim the organisms are inheriting their environments (Laland and Odling-Smee, 2000). Might the deebee fish inherit their orientation in the same way?

Since the purported selection for deebees would be frequency dependent, there would be no accumulation of advantages. Being a lefty may start as an advantage but would eventually become a liability. The deebees do not change their environments in the way a fire resistant pine tree changes its environment by dropping flammable pine needles on the ground. All deebees share the same stable environment.

`Environment' is a flexible term. At one tautologous extreme, it can designate everything that is not the organism. This negative reading trivializes the notion of the environment because it would follow that no two organisms can share the same environment. In order to make substantive claims, biologists use a positive conception of `environment' that serves as a uniform field for competition and cooperation.

One price for keeping `environment' capacious enough to house many duplicate organisms is that some facts of life will be unexplained. Some of these will be particular facts such as specific birth and death dates. Others will be general facts. The facts about comprehensive enantiomorphs will constitute a worrisome subset of these: general facts about life that are predictable from premises outside of evolutionary theory. The worry is that one of the desiderata of a theory is explanatory scope. The facts about comprehensive enantiomorphs seem intuitively part of the range of facts biologist target for explanation. Yet they are under pressure to deny that there can be biological selection for comprehensive enantiomorphs. Evolutionary biologists can recognize a selective advantage for the trait of variability in orientation (as in the case of the deebee complements). But they cannot account for why the variability made a difference to reproductive success.

My view is that the best reaction to the evolutionary biologist's explanatory embarrassment is to assimilate it other mild disappointments. Many momentous events in the history of life are due to geology and astronomy. Evolutionary biology may have nothing to contribute to the explanation of why dinosaurs became extinct. Physics and coarse assumptions about the preconditions for metabolic processes are enough to explain why there were no living things one second after the Big Bang. The subtleties of evolution play no role here and they may play no role in explaining other facts about life -- including the facts about comprehensive mirror image variants.

5. The fourth dimension

The two dimensionality of the deebees is important because I want a case in which there clearly exists a higher dimension that permits non-violent mirror reversals The deebees serve as stepping stones to three dimensional organisms.

Topologists point out that familiar objects could be mirror reversed if there were a fourth dimension. The fourth dimension is well understood algebraically. Just as projective geometry can be represented by adding a third dimension to the two dimensional Cartesian plane, four dimensional objects can be studied by adding a fourth variable to projective geometry's x, y, and z axes.

Mirror reversal is also possible if space is non-orientable. In 1827, August Ferdinand Mobius illustrated the idea with a version of the now famous Mobius strip. A **b** fish that is slid around such a strip returns as a **d** fish.

Just as a Mobius strip requires a third dimension for its twist, our familiar three-dimensional space is non-orientable only if there is a fourth dimension for its "twist". So the issue of whether three dimensional objects can be mirror reversed without affecting their intrinsic properties comes down to the issue of whether the fourth dimension is really possible.

The fourth dimension has entered popular culture through science fiction tales such as H. G. Wells' "The Plattner Story" and Martin Gardner's masterpiece of popularization The Ambidextrous Universe. Despite these imaginative presentations, the fourth dimension remains difficult to visualize. The best that anyone has done visually is to draw an analogy with lower dimensions. Edwin A. Abbott's Flatland pioneered this analogy in 1884.

Flatland analogies are only weak evidence that a fourth dimension is possible. However, the algebraic work of topologists conclusively establishes the formal consistency of a fourth dimension. Some philosophers nevertheless maintain that the fourth dimension is *metaphysically* impossible (Van Cleve 1987, 225-227). But I will assume that physicists are right in thinking that the existence of a fourth dimension is a contingent matter.

I will also go along with the scientific consensus that there happens to be no fourth (space-like) dimension. Some of the evidence is straightforward. *Three* beams can be at right-angles to each other but four beams cannot. The location of any object is completely specified by *three* coordinates: latitude, longitude, and altitude. Some of the evidence against the fourth dimension is subtle. Max Jammer (1969, 179) points out that a four dimensional world should be governed by an inverse cube law of gravitation rather than our inverse square law.

Since I believe it is a contingent truth that there is no fourth dimension, I do not base my conclusion that enantiomorphs are duplicates on the premise that one can *actually* mirror reverse three dimensional objects. I side with those who think that the mere possibility of a fourth dimension is enough to show that two mirror image counterparts are congruent. Actually moving the objects is irrelevant. Consider twins separated by a distance of a thousand light years. The combination of their limited life spans and the vast distance ensures that one twin cannot be actually maneuvered into a region that had been exactly occupied by the other. But so what? What makes them congruent is the appropriate mathematical mapping. (The `appropriate' alludes to the entrenched functions of topologists and excludes perverse mappings that fascinate philosophers commenting on radical translation and rule following.) That mapping will exist if there is some possible space in which they could be made to coincide. As James van Cleve (1987, 218) says, what matters is "fitting there", not "getting there".

Van Cleve's slogan holds even if we relax the assumption that there is a single space. Consider a world in which there are two separate spaces. In a unified world, there is a single space and thus there is always a path connecting any two points. It is always possible to "get there from here". Not so in a two space world. The objects are trapped in their own space. Nevertheless, it is still possible that an object in one of the spaces has the same shape as an object in the other space. (For a classic discussion of how one might acquire evidence of two spaces, see Anthony Quinton's (1962) "Spaces and Times".)

6. Predictable Differences

If Hori's scale eating fish were mirror image variants, then they would be stuck in their orientation. But this no more undermines their status as duplicates than if they were stuck in another way. Consider a field of dandelions. A botanist has determined that the dandelions are genetically uniform and so ideal for testing weed killer. He plans to apply the weed killer to the left half of the field and use the right half as a control group. He always uses the right half of a field as the control group in weed killing experiments. The botanist's scheme systematically darkens the prospects of lefties. The lefties cannot escape by migrating to the right half of the field. They are rooted in their leftward orientation. But the predictably brighter future of the righties does not make them more fit than the lefties.

Many biologically uninteresting properties are relevant to one's reproductive success. Consider luck. Although biologists recognize that luck heavily influences reproductive success, they deny there is any natural selection for luck. Nor is there any selection for the more "heritable" property of having a long line of lucky descendants. If someone has this property, then his children will tend to have it as well. Of course we can only ascertain whether someone has this property with the benefit of hindsight. But heredibility does not entail predictability.

Being lucky is an extrinsic property. One must go outside the nature of the individual itself to assess whether it is lucky. If biological understanding of an organism is confined to its inner nature, then we have a tidy explanation of why luck is biologically uninteresting.

However, natural selection is a comparative process and so must be at least indirectly sensitive to many extrinsic properties. For instance, gazelle A is selected because it is faster than gazelle B. Being faster than gazelle B is an extrinsic property. The difference between being lucky and being faster than gazelle B is that being faster than gazelle B is *grounded* in the intrinsic properties of gazelle A. There are non-relational properties of A and B (their respective bone lengths, muscle mass, lung volume, and so on) that explain the greater speed of A. Gazelle A having greater luck than gazelle B is not a grounded relation because the greater luck must be explained by externalities. Natural selection is sensitive to only those asymmetric relations that rest on the *intrinsic* properties of organisms (more specifically, to genetically grounded differences).

When two organisms have the same intrinsic properties, there are no grounded asymmetric relations between A and B. Thus there is no basis for natural selection of A over B. Unsurprisingly, natural selection is indifferent toward duplicates.

I do not deny that evolutionary theory could be used to *predict* the consequences of a female preference for lefties. The forecasters need only treat mirror image orientation *as if* it is an intrinsic property. But this would be a fictive use of the theory. Evolutionary theory is also used instrumentally to predict the "evolution" of stars and firms. But these fictive predictions do not change the fact that astronomy and economics are outside the scope of evolutionary theory.

7. Pseudo-duplicates

Many biologists would not be assuaged by the concession that evolutionary theorists could predict the phenomena in an instrumentalist manner. They might claim that comprehensive enantiomorphs are pseudo-duplicates like baby alligators and Clifford's cubes. I have claimed that enantiomorphs have the same intrinsic properties on the grounds that they have the same absolute properties and that the relationships of their parts do not differ with respect to angles and distances. This might be challenged. After all, enantiomorphs do differ with respect to direction. John Earman (1971) once suggested that an anti-Kantian could recognize *standing in a left-configuration* and *standing in a right-configuration* as primitive internal relations. These relations would not be reducible to any other relations. Nor would they supervene on relations of distance and angle.

The basic problem with Earman's proposal is that it is mysterious how mere travel through the fourth dimension could (and necessarily would) result in the acquisition of new primitive properties. We know how to turn a left-hand glove into a right-hand glove by disassembly or by pulling it inside out. These violent operations involve changes to the glove's parts and changes in the angles and distances between the parts. According to Earman's proposal, these alterations necessarily suffice to change the glove from having the simple, irreducible, non-supervenient property of being in a left-handed configuration to having the simple, irreducible, non-supervenient relation of being in a right-handed configuration.

When cornered, a metaphysician may attempt to solve a problem by postulating queer properties. Perhaps if the threat is grave enough, such desperate measures are justified. But the problem at hand is only a mild embarrassment for evolutionary theorist. He can pay the small price of conceding that evolutionary theory has a blind spot with respect to comprehensive enantiomorphs. And move on.

8. Can inheritance be ungrounded?

A second disproportionate response is to allow purely extrinsic properties to be heritable. In particular, one might say that I inherit my orientation in space from my parents. After all, if they had been mirror reversed at my conception, then I would have been mirror reversed.

One immediate problem with this proposal is that it opens a floodgate to the biological inheritance of many ungrounded properties. My mother had the ungrounded property of having had an ancestor who crossed the equator. She got this property from her grandmother and I passed the property on to my sons. I can safely predict that all of my descendants will have this property. But it is not the sort of property that obeys Mendel's laws or which appears in genetics textbooks. If we permit orientation in space as a heritable property, how are we to forbid other ungrounded properties?

John McTaggert, Bertrand Russell, and other philosophers affiliated with Cambridge University maintained that an object changes whenever a new statement about it becomes true. One strange consequence of this criterion is that one thing can change another without causally interacting with it. For instance, when the penultimate Pinta tortoise died, "Lonesome George" was made the last of his subspecies (*Geochelone elephantopus abingdoni*). His acquisition of the property of being the last of his subspecies was instantaneous. The event did not require a signal to be sent from the penultimate Pinat tortoise and hence was not constrained by the speed of light.

Peter Geach (1969, 71) scornfully classifies such transitions as "Cambridge changes". According to Geach, objects only change when they gain or lose causal powers. Lonesome George changes when he becomes hot. But Geach denies that Lonesome George is changed by the death of a distant tortoise. Regardless of whether biologists wish to allow some Cambridge events to be genuine changes, they do not take themselves to be ultimately studying these kinds of events. They regard inheritance as a causal relation. To inherit blue eyes from my parents, there must be an appropriate causal chain from their genes to mine.

9. Mirror imagery and complexity

There is no mechanical obstacle to producing mirror reversal. Big animals start from little fertilized eggs. A mirror reversed whale egg should develop into a mirror reversed whale.

To some extent, this kind of mirror reversal has long been in our control. Simply halving fertilized mouse eggs with a fine thread tends to produce some enantiomorphic mice.

Mirror reversal down to the level of organs actually occurs harmlessly in human beings. About 1 in every 8,000 to 25,0000 people have all their internal organs reversed (a condition inconvenienced surgeons call “situs inversus”).

Nevertheless, I doubt that any complicated organism has a *comprehensive* mirror image variant. Consider Alice in Lewis Carroll's Through the Looking Glass. Alice goes through the looking glass into a mirror reversed world (Gardner 1990). Since Alice is not also mirror reversed, she should have trouble digesting looking glass milk. Although 85% of the milk is composed of symmetrical water molecules, the milk also contains asymmetric carbon compounds (fat, lactose, proteins) which would be affected by mirror reversal. Many of Alice’s digestive enzymes are mis-oriented. Carbon compounds are pervasive in the diet of any large animal. Alice might starve if confined to the mirror reversed environment.

Possibly all organisms that now inhabit the earth share Alice's enzyme problem. Bacteria have been forced to complicate their lives in response to shortages and predators. However, organisms at the beginning of life had simpler lives. Natural resources were plentiful. Repacious predators had yet to evolve. Even after life began to become more complicated, some primitive organisms might have subsisted on symmetrical food or be digestively ambidextrous over the limited range of substances upon which they feed. In the case of these early organisms, mirror reversal should be expected. The first reason just parallels the expectation of mirror reversal for inorganic molecules: the forces acting on molecules are symmetric, so a molecule is just as apt to form in one orientation as another.

The second, more intriguing reason, is that mirror reversal may play a role often attributed to sexual reproduction. Although asexual organisms reap the advantage of 100% genetic representation by their offspring, they are vulnerable to predators, parasites, and diseases. Their adversaries become ever more efficient at striking the fixed target. Sexual reproduction regularly alters the target. No longer can your adversaries make cumulative progress. They cannot “home in”.

Scrambling the code comes at price. One must sacrifice 50% of one’s genetic representation. And there is the further loss of order effects. Randomly selecting half the cards from two good poker hands yields a better than average poker hand. But the derived hand is probably not as good as either of the two original hands.

Mirror reversal avoids the above two compromises. The same genetic information can produce reproductively relevant variety. Mirror reversal preserves the elements of an organism and their relationships. Thus, for a simple organism, mirror reversal is a cheap way of achieving diversity. Of course, this kind of diversity is limited and one's adversaries are likely to adapt to the mirror reversal.

The adversary's obvious reply is to produce offspring that also vary in mirror imagery. In addition to countering the prey's defenses, mirror reversal would also serve as a new defense for the predator against *its* predators (and *its* parasites and diseases). Adversaries of one's adversaries will themselves have adversaries. So they should also produce mirror reversed offspring. This will in turn precipitate another round of mirror reversal. This positive feedback loop for mirror reversal should ripple widely. Or to revert to a military metaphor, the arms race of mirror imagery proliferates.

Well, it proliferates less smoothly in the "up" direction. As organisms become more complicated, they have more trouble stocking the expanding arsenal of counter-measures needed to deal with the mirror imagery strategy of their simpler opponents. Eventually, it is best to capitulate. Along a certain frontier between the complex and less complex, the mirror imagery strategy is an unmitigated success.

Below that line, the mirror imagery strategy should have the self-canceling pattern of arms races. Mirror imagery succeeds in the short term but tends to be countered in the long run. The confrontation freezes the adaptations into place. Thus mirror imagery variation should be stable even if there are costs to maintaining enantiomorphic variety. An arms race forces each side to bear the cost of armaments even when each realizes it is no more secure than in the scenario of mutual disarmament. They are stuck in the mutual armament scenario because *unilateral* disarmament would expose each to attack. The two parties are locked in a prisoner's dilemma. Consequently, mirror imagery persists even if both parties would be better off with another solution.

I have made heavy use of thought experiments. But I think that there actually have been comprehensive mirror image variants. I just believe the phenomenon is restricted to very simple organisms. Some of these were the early organisms of earth. Present astronomy gives biologists reason to think that there is much simple life beyond the earth. Thus it is reasonable to conjecture that there are now comprehensive enantiomorphs elsewhere in the universe. And that there are more to come.

* *Ancestors of this paper were presented at the Syracuse University metaphysics conference on August 14, 2000, the University of Sheffield, and at the Australasian Association of Philosophy, in Hobart, Tasmania on July 3, 2001. I have benefitted from the reflections of Michael Dietrich, Denis Walsh, an anonymous referee for this journal, as well as the editor's' suggestions.*

REFERENCES

Clifford, W. K. (1901) "Conditions of Mental Development" in Lectures and Essays ed. Leslie Stephen and Frederick Pollock vol. I (London: Macmillan) 79-119.

Earman, John (1971) "Kant, Incongruous Counterparts, and the Nature of Space and Time" Ratio 1-18. Reprinted in James van Cleve's and Robert Frederick's The Philosophy of Right and Left (Dordrecht: Kluwer Academic Publishers, 1991): 131-149.

Eddington, Arthur (1928) The Nature of the Physical World (Cambridge: Cambridge University Press).

Fisher, R. A. (1930) The Genetical Theory of Natural Selection (London: Oxford University Press).

Gardner, Martin (1989) The Ambidextrous Universe (New York: W. H. Freeman).

Geach, Peter (1969) God and the Soul (Cambridge: Cambridge University Press).

Hori, Michio (1993) "Frequency dependent natural selection in the handedness of scale eating cichlid fish" Science 260: 216-9.

Jammer, Max (1969) Concepts of Space (Harvard University Press) second edition.

Laland, K. N. and F. J. Odling-Smee (2000) "Niche Construction, Ecological Inheritance and Cycles of Contingency" in Cycles of Contingency ed. R. Gray, P. Griffiths and S. Oyama (Cambridge: MIT Press).

Langton, Rae and Lewis, David (1988) “Defining `intrinsic’” Philosophy and Phenomenological Research 58: 333-345.

Quinton, Anthony (1962) "Spaces and Times" Philosophy vol. XXXVII (1962) 130-147.

Smith, John Maynard and Szathmary, Eors (1999) The Origins of Life (Oxford: Oxford University Press).

Van Cleve, James (1987) "Right, Left and the Fourth Dimension" The Philosophical Review 96: 33-68. Reprinted in James van Cleve's and Robert Frederick's The Philosophy of Right and Left (Dordrecht: Kluwer Academic Publishers, 1991): 203-234.