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Hints of beauty in social cognition: Broken symmetries in mental dynamics

John Bolender*

Department of Philosophy, Middle East Technical University, Ankara 06531, Turkey

Abstract

It is a widely held assumption that social cognition is wholly the result of natural selection and learning, debates arising over how much was naturally selected versus how much is learned. I argue here, however, for there being a third factor, namely physics, specifically symmetries and symmetry breakings in neural dynamics. These symmetries manifest themselves in social judgments in a fairly direct way as descending chains of subgroup types in mental social schemata. These schemata are the four models of Alan Page Fiske's relational-models typology. Descending chains of subgroup types are a phenomenon widely observed in nature; their presence in social cognition is consistent with there being a relevant neural network, the activity of which can undergo symmetry breakings. This would be analogous to the neural activity that has been computer modeled in an attempt to explain animal locomotion. This should encourage work towards specifying the particular symmetry groups in social cognition as a step towards devising computer models of the relevant neural mechanism. Approaches to animal locomotion suggest at least the broad outlines of how to proceed. Evidence of symmetry groups in social schemata also supports the view that the innate aspects of social cognition are at least partly structured by dynamics without being encoded in genes, just as the shape of the protective shell of some viruses results from dynamics without being genetically encoded.

Keywords: Cognitive dynamics; Nativism; Reductionism; Relational models; Social cognition; Symmetry; Symmetry breaking; Ultra-Darwinism

There are hints of beauty in social cognition. As physicists use the term, *beauty* is a "sense of inevitability" resulting from simplicity and principles of symmetry (Weinberg, 1994, pp. 135–136). It is surprising to find hints of beauty in social cognition. Why? A

*Tel.: +90 312 210 5337.
E-mail address: bolender@metu.edu.tr.

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common assumption in the sciences is that thought is biological; in fact, the biological nature of mind is a working assumption of this article. However, the assumption that social cognition is biological is usually taken to mean that it can be explained wholly in Darwinian terms with no appeal to physics. This is often a tacit assumption (e.g., Katz, 2001; Whiten & Byrne, 1997), but it can also sometimes be a point of conviction (e.g., Dennett, 1995). Although there have been Darwinian attempts to explain visible beauty, e.g., the symmetry of facial features as an indicator of resistance to parasites in a potential mate (Grammer & Thornhill, 1994), Darwinian biology does not contain the same high expectation of symmetry for less tangible manifestations of beauty, such as symmetries in mental representations. Symmetry is simply not a core assumption of Darwinian biology. By contrast, physicists anticipate symmetries virtually everywhere they look. That core features of social intelligence are beautiful means that such intelligence is in some important ways more like something inorganic, such as a crystal or the spiral form of a whirlpool or of a galaxy, than what one typically thinks of as a product of Darwinian tinkering.

1. Symmetry and its undoing

A symmetry is a kind of transformation, a transformation being a rule for moving things around, e.g., a rule for rotating a figure about its central point, or for switching the values of variables in an equation. Such a rule is a mapping from original to image, a symmetry being a transformation in which original and image are the same in whatever respects are deemed relevant. A square, for example, has four rotational symmetries, since a rotation of 90° or 180° or 270° or 360° would result in an image indistinguishable from the original. The square also possesses various mirror symmetries, i.e., symmetries of reflection. So too the switching of values in an equation is a symmetry if the solution remains unchanged, e.g., $x^2 = 4$ is symmetrical insofar as the value of x can be either 2 or -2. Physicists expect equations in true theories to be highly symmetrical. The great symmetries of its equations explains much of the scientific appeal of string theory (Figs. 1 and 2).

Loss of symmetry in a system is known as symmetry breaking. When symmetries are broken, it is virtually never the case that all symmetries are lost, however. Ripples on a pond are an illustration. Initially, every part of the pond is identical to every other part: a high degree of symmetry. The pond surface with a pattern of ripples, by contrast, has less symmetry. It lacks the translational symmetries of the initial state of the pond. It also lacks some of the original rotational and mirror symmetries if the ripples originate from a point that is away from the pond's center. But not all symmetries are lost; any given ripple has infinitely many mirror and rotational symmetries insofar as it approximates a perfect circle.

In an unstable system, a tiny perturbation can result in a dramatic loss of symmetry (Cohen & Stewart, 1997, p. 171). This is known as spontaneous symmetry breaking, and it is the sort of symmetry breaking at issue here. The surrounding environment of the system does not explain the intricacy of the resulting pattern. Consider a chain standing perfectly straight up, each link resting squarely on the link right under it. Intuitively, one knows that this is a highly unstable system and would collapse virtually at once. How so? Suppose that there is a tiny perturbation to the system, such as a fly passing by on one side or something even less noticeable. This is an asymmetry that, thanks to the system's instability, will

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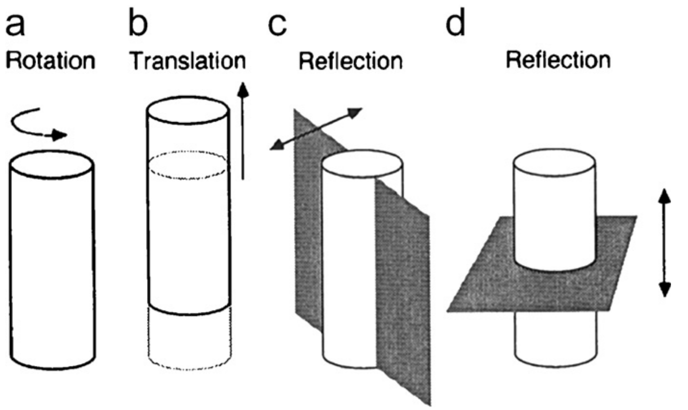

Fig. 1. Types of symmetry: Rotational symmetry is symmetry around an axis of rotation, e.g., the cylinder pictured has a continuum of rotational symmetries since it will look the same no matter how many degrees it is rotated. In mirror symmetry, reflection is a transformation that leaves the object indistinguishable from its initial orientation. A reflection is not the same as a rotation, because, in the case of a three-dimensional object, reflection means turning the object 180° through the fourth dimension. For a discussion of translation, see the next illustration (illustration from Stewart & Golubitsky, 1992, p. 18).

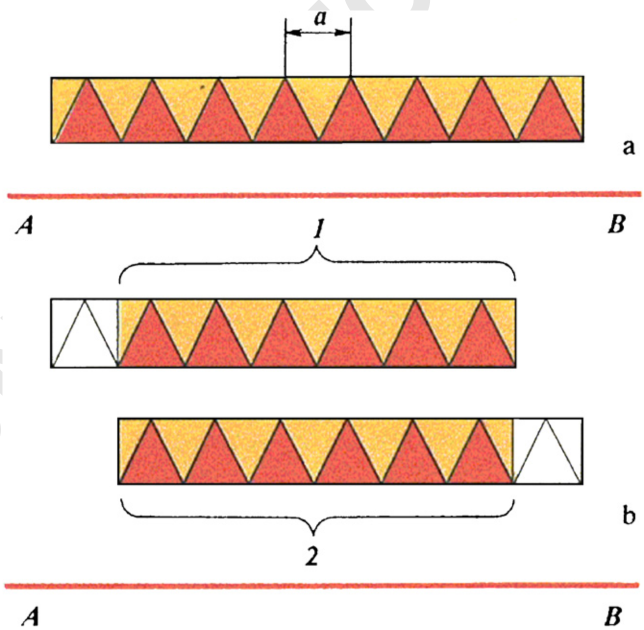

Fig. 2. Translational symmetry: A translation is a movement of parts all in the same direction. The figure on the top will appear partly unchanged if it is translated along axis AB precisely the distance *a* (one period) or a multiple of *a*. Regions 1 and 2 illustrate invariance after translation (illustration from Tarasov, 1986, p. 24).

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iterate. In other words, a vanishingly small asymmetry results in a dramatic decrease of symmetry in the standing chain, which thereby collapses into a heap.

There are also temporal symmetries. Planetary motion is a good illustration. If a planet takes 365 days to orbit the sun, then a translation in time forward or backwards 365 days will produce an image indistinguishable from the original, i.e., the planet will just be in the same place. Hence a 365-day translation is a symmetry for this system. The highest degree of temporal symmetry is found in a system, which remains in a steady state, each moment being just like any other moment. When a system changes from being in a steady-state to exhibiting oscillations, this is a breaking of temporal symmetry. Once the system starts oscillating, it is no longer true that any moment is just like any other. But not all symmetries are lost; the oscillations themselves may exhibit temporal symmetries.

Group theory is the mathematics of symmetry. The *symmetry group* for some system is a set containing all transformations of that system that are closed under symmetry, i.e., any two transformations in the group can be combined to yield a new transformation which is also a symmetry. All the symmetries of a system are members of its corresponding group. If a system undergoes a sequence of symmetry breakings, with no restoration of symmetry, then the corresponding series of groups is a descending chain of subgroups. Descending subgroup chains are important to keep in mind, since we will find the same phenomenon in social cognition, specifically in the relational-models typology.

Spontaneous symmetry breaking is recognizable in biology (Stewart & Golubitsky, 1992, p. 153). Consider morphogenesis, the development of organismic form. The zygote approximates a sphere, the most symmetrical of any three-dimensional shape. The cleavage of the zygote into two cells breaks this symmetry, and symmetry continues to break as the cells continue to divide. Once the organism has developed into a blastula, a hollow ball of cells, strictly speaking no symmetry remains, at least if one considers the relative position of each cell. But symmetry is only wholly lost if one focuses on the most fine-grained level. Looking at the organism as a whole, from a distance as it were, it has managed once again to approximate the shape of a sphere, albeit a larger sphere than the zygote. The blastula develops into a gastrula, a tube-like shape resulting from the partial collapse of the blastula in upon itself. In the case of many animals, such as the human, the only remaining symmetry at the end of gestation is bilateral. And even this symmetry is partially broken by certain off-center internal organs (Fig. 3).

Symmetry breaking is dynamical, not genetic or Darwinian.[1,2] Given that so many biological structures are symmetrical, this raises the question of how much of morphology

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[1]The word "dynamic" is sometimes used metaphorically in psychological literature, e.g., "psychodynamic." Here, however, the term is meant literally: the branch of mechanics, which studies the motions of bodies under the action of forces.

[2]An anonymous referee has asked whether the current work agrees with the dynamicist position of Tim van Gelder. The simple answer is no. The nuanced answer is that it depends. The approach of this paper is meant to be along the lines of "biolinguistics" (Chomsky, 2006; Jenkins, 2000), the innovation here being to extend biolinguistic insights to include social cognition and not merely language. Biolinguists see dynamical properties, not as replacing computational properties, but as underlying and explaining them. Van Gelder (1995), by contrast, recognizes a sharp dichotomy between computational versus dynamical approaches. However, the position of this paper would be compatible with van Gelder's dynamicism if one were to follow *both* a suggestion of Chris Eliasmith (1997, p. 540) in interpreting van Gelder's dynamicism as the view that connectionists should pay more heed to dynamics, *as well as* the view of Gary Marcus that connectionist networks are plausibly seen as implementing symbol-manipulation systems (1999). But if van Gelder rejects this re-interpretation of his work, and continues to eschew symbol manipulation, then my position is not compatible with his, since there are serious

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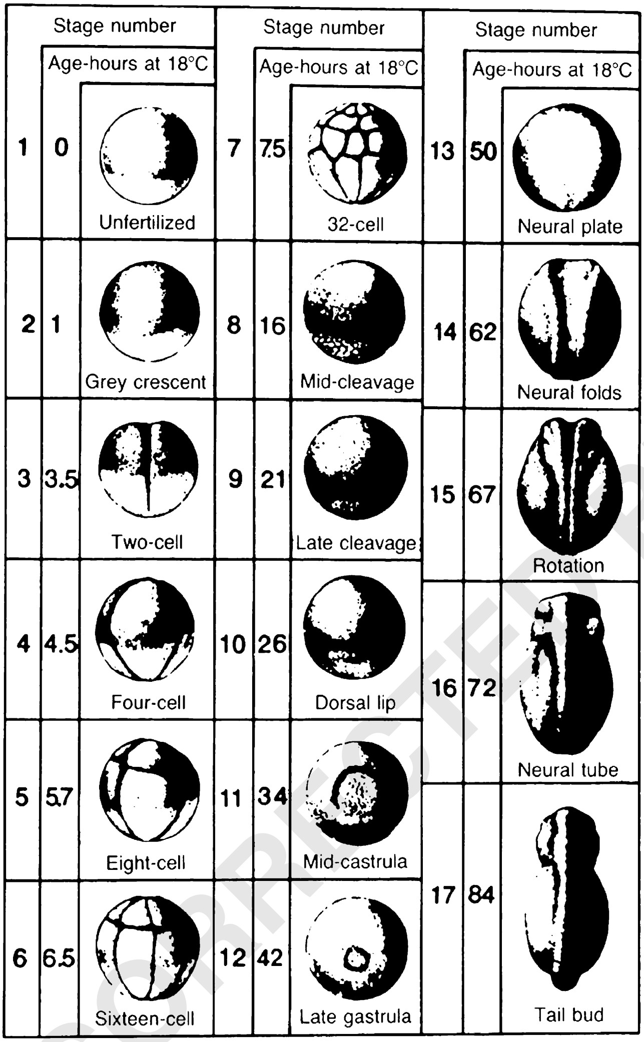

Fig. 3. Morphogenesis of a frog, from Stewart and Golubitsky (1992, p. 153).

needs to be explained genetically. To quote Stewart and Golubitsky (1992, p. 158), "DNA can be seen as a kind of computer program, which specifies the structure of the developing embryo. … [but] there is little reason why a program should follow the natural mathematical pattern for changes of symmetry in dynamical systems. A program can contain a pretty arbitrary set of instructions, it doesn't have to mimic dynamics", the implication being that if it did mimic dynamics that would be astronomically improbable given all the other possibilities open to it. "DNA has a significant role in organizing the development of an organism, but [] very little information about the form of the organism

(*footnote continued*)
problems with rejecting the symbol-manipulation view (Marcus, 1999). The challenge is to connect dynamics with symbol manipulation; not to portray one as excluding the other.

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and its developmental path can be 'read off' from its DNA sequence. Genetics acts in concert with dynamical physical and chemical processes'' (Golubitsky, Langford, & Stewart, 2003). Consider viruses, in some viruses such as HIV and the West Nile virus, genes manufacture proteins but give no instructions for assembling them into a shell. The proteins self-assemble to form a shell (Berger, Shor, Tucker-Kellogg, & King, 1994), meaning that the proper explanation lies at the level of physics. The result is that the protein shell is icosahedral, the icosahedron being one of the two equally most symmetrical of the regular solids.[3]

2. Broken symmetries in animal locomotion

One clue as to when a dynamical approach to cognition might be fruitful lies in qualitative changes (Kelso, 2003, pp. 49–50), specifically cognitive processes which look like phase transitions, such as the change from liquid to solid, or which look like bifurcations. In searching for a dynamics of thought, the advice to look for qualitative changes is more a matter of method than of principle, since linear dynamics could account for quantitative changes. But since a qualitative change clearly distinguishes one pattern from another, it often makes it easier to isolate the responsible variable.

Gait analysis illustrates how qualitative changes can be useful in isolating pertinent dynamical variables. A gait is a periodic pattern of leg movement. As long as there are no obstacles and no change of speed, the animal will repeat the same rhythm over and over, thus exhibiting temporal symmetry. There are both temporal and spatial symmetries in the patterns of leg movement in horses, for example. Furthermore, some gaits are more symmetrical than others (Hildebrand, 1965). Since animal locomotion exhibits a clear group structure with descending sequences of subgroups as found in broken symmetries, and since it is directly under the control of the central nervous system, it provides important clues as to the symmetries and symmetry breakings likely to occur in the CNS. In other words, we plausibly have a window here onto the symmetries of neural activity, including that of the spinal cord. A neuron is an oscillator. Simple networks of oscillators have been shown to produce patterns similar to those found in animal gaits, suggesting that gaits provide a window onto the organization and activities of some neural circuits (Collins & Stewart, 1993).

Plausibly, some symmetries in neural activity are due to entrainment, the tendency of coupled oscillators to oscillate together. Biologically, this is common. Fireflies flash synchronously, horses running together tend to synchronize their gaits, birds in a flock tend to flap their wings together, crickets chirp together. Neurons in a network evidently entrain one another. Hypothetically, there is either a single neuron or a pool of neurons which fires thus resulting in a footfall. Entrainment of neurons results in patterns of neural activation. Patterns of activation result in a pattern of footfalls, a gait.

[3]An anonymous referee has suggested that whether or not a trait is encoded in genes or whether it results from physics is a false dichotomy. ''Without suitable genes, the proteins produced would not be able to form a shell with a specific shape.'' But there must be some sort of dichotomy here. The shapes of snowflakes, crystals, and galaxies are due to broken symmetries, and there are no genes involved in those cases. Hence, when there is symmetry breaking, one can speak of a non-genetic contribution. The matter is perhaps best understood in terms of Dennett's (1987) distinction between different explanatory stances and which stance is most suitable for each case at issue. In other words, the dichotomy concerns when it is best to assume the physical stance versus some other stance. More on Dennett below.

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The roboticist DaeEun Kim notes similarities between firefly entrainment and neural firings:

- A flash of light from a firefly corresponds to one neuron spike. The membrane potential increases to a threshold level and then the neuron emits a spike or light message.
- The flashing rhythm or frequency is controlled by interactions with neighbor fireflies, as a spiking neuron can adjust its spike time depending on inhibitory or excitatory connections with neighbor neurons.
- A firefly has a neural delay time from the brain to the light organ, as a spiking neuron has its own transmission delay to communicate with other neurons.
- The membrane potential for flashing is decreased to the basal level and then it increases again, as a spiking neuron has a decay (refractory) period and an integrating period.
- A firefly flash triggers flashes of other fireflies and the entrainment model of a group of fireflies can be seen as a neuronal model of all excitatory or all inhibitory connections among multiple neurons (2004, pp. 7–8).

Kim proceeds to propose his own dynamical model of both firefly and neural synchronies.[4]

By oscillating together, the neurons in a network form a temporal symmetry, which can spontaneously break resulting in out-of-phase oscillations. Spatial relations between neurons in a network can constitute spatial symmetries, which may be reflected in spatial symmetries of limb movements. Such neural symmetries may explain the degrees of symmetry observed in animal gaits. The symmetry of each gait is expressed in terms of the relative phase of each foot. Relative phase is determined relative to a reference foot that has, by definition, the value 0. The relative phase of a foot is the fraction of the gait cycle between the reference foot hitting the ground and the foot concerned hitting the ground. When a human walks normally, if the left foot is the reference foot, then the right foot has the relative phase 0.5 (Fig. 4).

Roughly speaking, faster gaits are more asymmetrical than slower ones, with stand being the most symmetrical of all.[5] A standing animal is, roughly speaking, a system in a steady state; any moment in time is the same as any other. But when the animal begins to walk, this symmetry is broken in favor of periodic movement. Some translational temporal symmetries remain, but one can no longer say that each moment is indistinguishable from any other moment.

Central pattern generators (CPGs), primitive neural nets, set up the basic rhythms of locomotion. Although not fully established, there is strong evidence for their existence. Collins and Stewart have shown that there are many symmetry types of CPG such that each exhibits a natural hierarchy of symmetry-breaking oscillation patterns, i.e., a descending sequence of subgroups. Many of these hierarchies correspond to gaits observed in various species. "The movements of an individual limb are governed by a single oscillator, which may be a single motoneuron or a pool of motoneurons. The coordinated movements of the limbs result from the coupling between the generators/oscillators, which could be established by interneurons" (Collins & Stewart, 1992, p. 831).

[4]Several scientists have proposed other such models. See references in Kim (2004).

[5]Canter is an exception, being less symmetrical than gallop but also slightly slower. Canter is also exceptional in that horses must be trained to do it.

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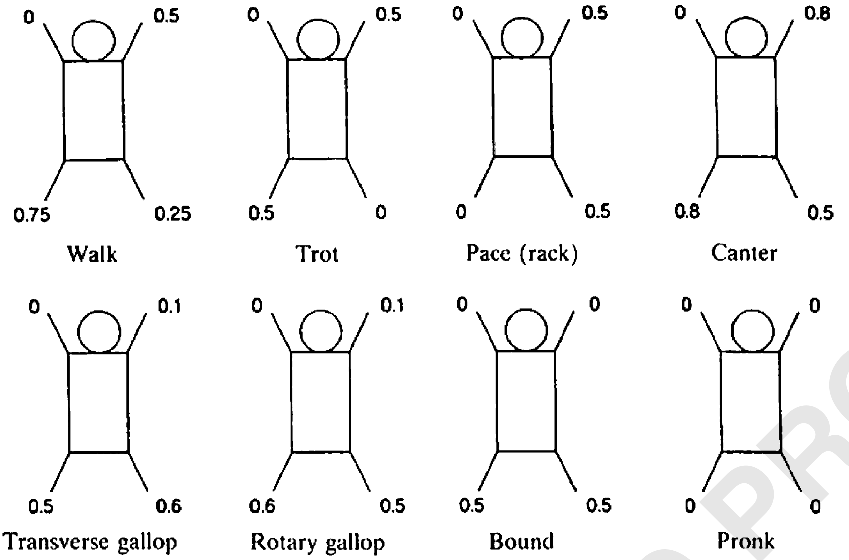

Fig. 4. Relative phase relations of footfall patterns in non-primate mammals as viewed from above. Note that pronk is a kind of simultaneous springing on all fours sometimes observed in baby deer (from Collins & Stewart, 1993, p. 357).

Modulating between different degrees of symmetry could perhaps be understood in terms of phase transitions. However, most work on animal locomotion explains such modulations through bifurcations. In a dynamical system, as a parameter varies, qualitative changes may occur at isolated values of that parameter. Such a sudden qualitative change is a *bifurcation*. In gait analysis, the coupling strengths between oscillators are the bifurcating parameters: "we show that by varying only coupling strengths between cells [in our model], the network can produce all primary gaits, except pronk, by Hopf bifurcation" (Buono & Golubitsky, 2001, p. 292). The search for symmetries and symmetry breakings can be extended into more paradigmatically cognitive domains. Language serves as an example.

Language prosody resembles animal locomotion in being rhythmic. The plausibility of computer models in specifying broken symmetries in animal locomotion is a good reason to attempt to model CPGs for similar behavior in humans, and that would include prosody. The baby, so long as its lungs permit, emits a continuous cry. This approximates a steady state. But the older child, while never losing the ability and occasional inclination to emit a continuous cry, also acquires the ability to emit sound in a more discontinuous form, namely to pronounce syllables. Unless the mechanism behind crying and the mechanism behind prosody are disjoint, this looks as much like temporal symmetry breaking as does the transition from stand to walk in gait analysis.

Different spoken languages exhibit different rhythms, e.g., French is rhythmically more symmetrical than English (Patel & Daniele, 2003). French exhibits equal duration between syllable onsets. English, by contrast, exhibits equal duration between stressed syllables, resulting in greater variability of vowel duration and consonant duration as a means of keeping the stressed syllables equally spaced while allowing room for varying numbers of

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unstressed ones. Given that the symmetry groups for rhythms can be readily identified, this suggests a relatively straightforward research program for exploring symmetries in speech.

With the discussion of animal locomotion and prosody in language, we begin to consider features, which are at least marginally cognitive. We enter more unambiguously cognitive terrain when we consider syntax in language, and here Noam Chomsky has suggested that some features of syntax may be biologically innate, not because of genes or genes alone, but because of principles of physics:

> [A factor in language design], which is much harder to study [than genetics and environment], but it's coming into view in the study of language and in the study of biology also, are just general principles of nature which enter into how organisms grow and develop in every aspect. We know that in some cases. Everyone knows that, say, cell division is into spheres not cubes, but not because there is a gene that tells the cell "Become a sphere but not a cube." That's because of physical principles. And no one knows exactly how far that goes, but undoubtedly just the general principles of nature play a major role in determining how an organism gets to its successive states of maturation and development. And the same is true of evolution. There must be fixed principles of nature which determine the kind of channel in which natural selection can make a few choices. … The same is true of language. [Language] is basically a computational system, so you would expect that principles of efficient computation, that don't have anything in particular to do with language, should enter into the way the language grows in the mind of the child, no matter what language it is (2006; see also Jenkins, 2000).

Even partial success in explaining syntax in terms of physics would show that even the most paradigmatically cognitive operations can be linked to physics in at least some cases. Naturally, this should encourage the attempt to find links between social cognition and physics, even though success in one area does not guarantee success in the other.

3. The relational-models framework

Gait analysis aids the study of social cognition in several ways. There is evidence for descending sequences of subgroups in social cognition. So the biophysics of social cognition and gait analysis both start with similar evidence, and it is in both cases presumably the central nervous system, which exhibits these symmetries. Furthermore, one finds qualitative differences among the schemata used in social cognition just as one finds qualitative differences among animal gaits. Hence, it is rational to apply the same general approach, which has proven fruitful in gait analysis to social cognition. As we will see, progress has been made in specifying the symmetry groups in social intelligence. But more works need to be done. The next step would be to devise models of neural circuits, similar to CPGs, whose activity has a similar mathematical structure to the symmetry groups found in social cognition. The step after that, probably the most difficult, would be to find the neural mechanisms.

Social cognition did not show any hints of underlying group structure until the work of Fiske (1991, 1992). Fiske first proposed his relational-models typology as an inference to the best explanation meant to make sense of a large range of anthropological facts from many different cultures. In this section, Fiske's thesis will be discussed in general terms. In the following section, we turn to its mathematical properties, namely its symmetries. On

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Fiske's relational-models framework, there are four mental models accounting for the construction, interpretation, and evaluation of social relations. The four mental models are as follows:

> **Communal Sharing** (CS) is a relationship in which people treat some dyad or group as equivalent and undifferentiated with respect to the social domain in question. Examples are people using a commons (CS with respect to utilization of the particular resource), people intensely in love (CS with respect to their social selves), people who "ask not for whom the bell tolls, for it tolls for thee" (CS with respect to shared suffering and common well-being), or people who kill any member of an enemy group indiscriminately in retaliation for an attack (CS with respect to collective responsibility). In **Authority Ranking** (AR) people have asymmetric positions in a linear hierarchy in which subordinates defer, respect, and (perhaps) obey, while superiors take precedence and take pastoral responsibility for subordinates. Examples are military hierarchies (AR in decisions, control, and many other matters), ancestor worship (AR in offerings of filial piety and expectations of protection and enforcement of norms), monotheistic religious moralities (AR for the definition of right and wrong by commandments or will of God), social status systems such as class or ethnic rankings (AR with respect to social value of identities), and rankings such as sports team standings (AR with respect to prestige). AR relationships are based on perceptions of legitimate asymmetries, not coercive power; they are not inherently exploitative (although they may involve power or cause harm). In **Equality Matching** (EM) relationships people keep track of the balance or difference among participants and know what would be required to restore balance. Common manifestations are turn-taking, one-person one-vote elections, equal share distributions, and vengeance based on an-eye-for-an-eye, a-tooth-for-a-tooth. Examples include sports and games (EM with respect to the rules, procedures, equipment and terrain), baby-sitting coops (EM with respect to the exchange of child care), and restitution in-kind (EM with respect to righting a wrong). **Market Pricing** (MP) relationships are oriented to socially meaningful ratios or rates such as prices, wages, interest, rents, tithes, or cost-benefit analyses. Money need not be the medium, and MP relationships need not be selfish, competitive, maximizing, or materialistic ... MP relationships are not necessarily individualistic; a family may be the CS or AR unit running a business that operates in an MP mode with respect to other enterprises. Examples are property that can be bought, sold, or treated as investment capital (land or objects as MP), marriages organized contractually or implicitly in terms of costs and benefits to the partners, prostitution (sex as MP), bureaucratic cost-effectiveness standards (resource allocation as MP), utilitarian judgments about the greatest good for the greatest number, or standards of equity in judging entitlements in proportion to contributions (two forms of morality as MP), considerations of "spending time" efficiently, and estimates of expected kill ratios (aggression as MP) (Fiske, n.d.).

For Fiske, these models are innate. What is not innate is which model is to be implemented in a given situation and the form of that implementation. For Fiske, this learned element explains diversity in social judgments and norms. A social situation can be divided into parts such that different models structure those different parts, e.g., people may vote on a law (Equality Matching—EM) while the decision as to how to apply that law is the responsibility of officials (Authority Ranking—AR); or an instance of a model can be recursively nested in another instance of the same model, e.g., a social ranking within a social ranking. "By combining the elementary forms in various concatenations and nested hierarchies, people produce complex social forms" (Fiske, Haslam, & Fiske, 1991, p. 658).

To test his framework, Fiske performed studies some of which examined involuntarily referring to someone by the wrong name (Fiske et al., 1991). The assumption was that such mistakes reveal the basic cognitive typology used in social relations. Fiske et al. were concerned to show that the relational models better predict such mistakes than do other ways of categorizing people, such as personality, ethnicity, and age. So, for example, Fiske et al. would predict that if you say "Bob" instead of "Jeff", it is likely that Bob and Jeff stand in the same relation to you according to the fourfold relational-models typology. That Bob and Jeff are of similar personality, age, or ethnicity is less likely to predict such mistakes. The studies showed that, with the exception of gender, the relational-models typology was the strongest predictor.

They also studied person memory errors in which one incorrectly remembers with whom one did something and misdirected actions in which one performs an action with a person other than the one intended. They predicted that the relational models would tend to predict the mistakes made (Fiske, 1993; Fiske et al., 1991). In order to avoid for effects of culture, four of the nine studies were performed on non-Westerners: Koreans, Liberians, Bengalis, and Chinese (Fiske, 1993). Fiske and his colleagues found that, with the exception of gender, the four relational models were better predictors of such errors than were other perceived characteristics. Fiske also tested deliberate substitutions, e.g., changing one's mind about the person with whom one would perform an activity (Fiske & Haslam, 1997). The results of this study also supported the relational models approach.

Haslam and Fiske (1992) conducted another study to test the relational-models thesis in comparison with other sociological and psychological hypotheses for how people cognize social relations. Subjects were asked to list at least 40 people, by name or by description, with whom they had had any sort of social relationship at any point in their lives. From this list, two lists of 20 were created by random selection. For one 20-name list, subjects were asked to assign a number to each pair of names indicating the degree of similarity in interpersonal relationship to the subject. A subject who feels that s/he has a very similar relationship with both parents, for example, would place a high number next to the pair of his or her parents' names. For the other list, subjects were asked to sort names into groups according to similarity of relationship. Each subject was required to sort names into groups of six, and then into groups of four, and finally into just two groups. A week later, subjects were apprised of the various relationship categories being tested, and then sorted all 40 names according to these categories. The results from the second session were used to predict how well the various theoretical classifications predict subjects' classifications in the first session. Overall, the relational-models typology was found to be a better predictor of sortings than other sociological and psychological hypotheses.

Another study testing the relational-models framework in relation to other sociological and psychological accounts also showed the former to be the best predictor (Fiske, 1995). The same study also showed the relational models to be better as a predictor than non-social characteristics of people. Specifically, when subjects are asked to recall those with whom they interacted recently, say in the past month, they recall individuals in runs, which cluster according to the relational models.

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4. Broken symmetries in social cognition

With the relational-models framework, we can begin to make sense of the notion of symmetries in social cognition. Each relational model, considered in isolation, is a mental schema, a network of empty place-holders. When a model enters into thought processes about some social situation, the result (cognitively speaking) is a system of mental objects representing relations between social agents or classes of such agents. Fiske (1991, p. 207) notes that ‘‘Formal statements of the structures of the four models will help us to formulate explicitly the social dimensions people take account of and those they ignore; that is, what empirical differences make a social difference in each kind of social relationship’’. In other words, there are some transformations in such a system of mental representations that would make a social difference (asymmetries) and some which would not (symmetries).

A relational model is a mental faculty or state of some faculty, the social faculty. When the faculty receives input concerning some specific social situation, the incoming representations of relations among (classes, groups of) persons bear properties. A difference in such properties is a transformation. Transformations which make no difference to the output of the social faculty are symmetries. But other transformations do cause the social faculty to give a different output. If King Henry, who has done nothing to lose his title, is represented as bowing down before a serf, as opposed to the other way around, this would make a difference to the social faculty. That faculty would deliver CONDEMN or ABHOR as output rather than APPROVE. Such transformations are asymmetries.

Each relational model takes the form of one of the four measurement scales (Fiske, 1991), and symmetries in social cognition correspond to symmetries found in measurement scales. Communal Sharing (CS) takes the form of a nominal scale, AR an ordinal scale, EM an interval scale, and Market Pricing (MP) a ratio scale. Each scale exhibits symmetries and hence corresponds to a type of symmetry group (Stevens, 1946). In fact, the four scales correspond to a descending sequence of subgroups, the group for the nominal scale containing the group for the ordinal scale, the group for the ordinal scale containing the group for the interval scale, and the group for the interval scale containing the group for the ratio scale. In other words, the symmetries which are members of the set corresponding to the ratio scale are also members of the set corresponding to the interval scale although the latter contains additional symmetries as well, and so on, the set corresponding to the nominal scale having the greatest number of symmetries as members. Descending chains of subgroups are also what one finds in systems, which undergo a sequence of symmetry breakings. When a drop of water turns into a snowflake, for example, the group corresponding to the snowflake is contained in the group corresponding to the drop.

As noted, CS is nominal. In a nominal scale, items are sorted into classes with no quantitative information conveyed. Numbers may be used in a nominal scale, but they are only used to indicate group membership, e.g., the numbers on the jerseys of players on a soccer team. Numerals can also be used to distinguish one group from another. One could assign the numeral 1 to all players on one team and the number 2 to all players on the other team, for example. Having the members of a single team exchange jerseys, so that each wears a different number than before, would be a permutation that would make no difference to the information conveyed. In other words, the assignment of numbers is arbitrary. Here the high degree of symmetry in nominal scaling is clear. Consider the following case of CS: People at a party are drinking from a punch bowl. One thirsty person may drink three cups, another may drink only one. But if the numbers had been reversed, it would have made no social difference. This is a symmetry.

As a form of measurement, the nominal scale only serves to distinguish things on the scale from things that are not on it. Due to its high degree of symmetry, it conveys little information and is hence the weakest form of measurement. By way of illustration, pass/fail in grading conveys much less information about student performance than assigning a percentile. This mathematical property explains why, in a CS relation, the identity of one member of the group is socially the same as the identity of any other. This can be found in intense romantic love. Equivalence also appears in the negative side of CS, e.g. in racist ideology members of a race are somehow all the same; and in CS-structured vengeance: In revenge for an insult to one's community, one can kill anyone from the enemy's community.

If I am applying the CS model to three people, call them A, B and C, then there are corresponding mental representations: A′, B′ and C′. A, B and C might be sitting around a dinner table sharing a meal. Let us suppose that A and B exchange plates so that A gets what would have been B's meal and vice versa. Even if the amount or quality of food on the two plates is very different, this does not matter in CS. In CS, one takes whatever one needs or desires, and one gives whatever one can. Let us also suppose that C notices that A and B have switched plates. This means that the relation between the mental representations A′, B′ and C′ has also changed. But the social significance of the affair for C does not change. This means that the change in relation between A′, B′ and C′ has not caused any neural change which is relevant to how C sees the social dimension of the matter. This is an invariance in the brain, a symmetry of activity in nervous tissue. It is like rotating a square 180° and ending up with a figure that is indistinguishable from the one you started with.

I want to address a possible objection to my claim that these are actual symmetries in the brain structuring social cognition. One might be tempted to say that if A and B exchange plates, this does matter to C's judgments and hence is not a symmetry within C's brain activity. Let us suppose that A and B change plates by switching seats. The conversation C conducted with A might differ from the one C conducted with B; C must either change the topic of conversation or continue the old conversation by directing attention toward another place in space, e.g., turning the head a little and refocusing the eyes. This involves some difference in mental representation. Hence, at least according to the objection, there is no symmetry here.

This objection forces us to specify which relations bind together representations of the members of the specified CS group and which do not. It need not be just one relation. It can be a cluster, a congruence. Nor need it be all relations that link the representations of those who belong to the CS group. "Moose [an ethnic group in Burkina Faso] who eat the daily meal together also cultivate a collective field together, harvest together, share a granary, and are all protected by a particular altar to which they sacrifice together" (Fiske, 1991, p. 212). This cluster of properties is the congruence for this CS relation. There is a corresponding cluster of relations among relevant representations, a mental congruence.

To reply to the objection: The symmetrical relations within the (mental representation of the) relevant CS group constitute the congruence. But they need not constitute all the relations that may pertain. The representation of A's eating with B and C would belong to

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the congruence, but the representation of the specific conversation amongst them might not. In other words, C's inability or unwillingness to continue that same conversation with A, instead of B, may not be directly relevant to the CS relation. Instead of partly constituting the CS relation, the conversation may have occurred only because the CS relation provided an opportunity for it.

Also note the relevance of faculty psychology. There may be different token mental objects all of which represent, say, A. Because these tokens may occur in different mental faculties, one object representing A may stand in some given relation to some distinct object or other, while another object, also representing A, does not, perhaps standing in some other relation (s) (to some distinct object or other) instead. In the case of CS, one may find perfect symmetry among the objects representing A, B and C within a faculty dedicated to social cognition. At the same time, one may find important asymmetries among objects representing A, B and C in some other non-social faculty. And that other faculty is, let us suppose, the place where the above-mentioned conversation is represented. If this is the case, then (representations of) relations outside the congruence do not even link the same token representations as do those within the congruence.

When the agent shifts from CS to AR, some symmetries disappear. This is because AR takes the form of an ordinal scale, which is less symmetrical than a nominal scale. AR can be used as an illustration of preserving order in an ordinal scale: The king outranks the prince, and the prince outranks the duke. This ranking can be implemented in the following way: The king must be served more pancakes than the prince, and the prince must be served more pancakes than the duke. But as long as order is preserved, there is no social significance in varying the number of pancakes served to each. The king may be served six, the prince four, and the duke one pancake; but it would make no social difference if the duke were to be served two extra pancakes (while the others are served the same amounts), or the prince one extra, or the king 20 extra. Hence, there are symmetries here as well, transformations which would make no social difference. According to measurement theory, "Since any 'order preserving' transformation will leave the scale form invariant, this [ordinal] scale has the structure of what may be called the … order preserving group" (Stevens, 1946, p. 279). But there is less symmetry here then in CS, since some transformations that would not socially matter in AR do matter in CS. For example, serving more pancakes to the prince than to the king would be forbidden, or it would indicate a change in status. "Consider making all sergeants into generals and all generals into sergeants: the AR relationships among the people would be transformed. Such one-to-one mappings of groups distort AR relations but not CS relations" (Fiske, 1991, p. 208).

An implementation of EM resembles an interval scale, and a transition from ordinal to interval amounts to a reduction of symmetries. On an interval scale, one unit represents the same magnitude as any other. The centigrade scale is an example. One degree centigrade is warmer than 0 °C degrees to the same extent as 2 °C is warmer than 1 °C. "Equality Matching relationships resemble an interval scale in that people can not only specify who owes what to whom, but also how much they owe" (Fiske, 1991, p. 209). Bear in mind that in EM, people keep track of imbalances or differences between each other and try to maintain balance. Turn-taking, strict reciprocity, and eye-for-an-eye justice are the norms. Examples are voting, games that involve equal turn-taking, and so on. There is less symmetry here than in the case of AR. Why? In EM, one must make sure that everyone has the same thing, however, sameness is defined. This degree of precision is lacking in AR. In AR, the higher precedes the lower, but that is not very precise. The king sits down before

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the prince sits down, but one does not need a stopwatch to measure the length of time between the two sittings. The only measurement is a measurement of things exhibiting a certain order. There is greater precision when it comes to EM, since one must now notice how much each individual receives or contributes. For example, the important thing is that each person at the table receives precisely three pancakes. But there is also some symmetry in EM too, e.g., the scale remains invariant when a constant is added. There is no harm done if everyone receives four pancakes each. Nutritionally, being served four pancakes instead of three may make a difference. But it makes no social difference for EM.

MP resembles a ratio scale. A ratio scale is exactly like an interval scale, except that it has an absolute 0 point, e.g., the Kelvin temperature scale. Ten degrees centigrade is not twice as hot as 5 °C, but 10 °K is twice as hot as 5 °K. In MP, people order their interactions according to a system of ratios and proportions such as wages, rents, tithes, taxes, etc. All pertinent aspects of a situation are made commensurate by being reduced to a single metric of value. This allows each individual or group of like-minded folks to decide how to act and evaluate actions according to cost-benefit analyses. Examples are the capitalist market place, calculating how efficiently people spend their time in relation to each other, and even the libertine's attempt to maximize his amorous conquests.

In MP, we no longer have invariance when a constant is added, so MP is less symmetrical than EM. Performing a $+1$ operation on the libertine's romantic conquests would get a positive response from the libertine, while performing a -1 operation would get a negative response. The important thing is that it would matter. Returning to the issue of pancakes: Suppose there is a kitchen that produces them. Suppose that each cook in the kitchen is making three pancakes every 5 min. If the relevant model were EM, then it would be indifferent if each cook were to make four pancakes in that period of time or just two, so long as everyone was producing the same amount as everyone else. But in MP, it would matter if everyone were producing four per 5-min period versus only three per that period, e.g., the kitchen might be trying to maximize its pancake output. Hence, MP is even less symmetrical than EM.

As noted above, each measurement scale, and hence each relational model, has a corresponding type of symmetry group. Furthermore, particular instances of this series of group types form a chain. On the relational-models framework, the transition to a subgroup does occur and hence there is symmetry breaking. If I apply CS to a group of people and then apply AR to the very same group of people, then a symmetry breaking has occurred in my brain. There is a change of relation among A′, B′ and C′, for example. But what if I apply CS to one group of people and then apply AR to some other non-overlapping group of people? The simplest hypothesis is that here too there has been a breaking of symmetry. It is simpler to suppose that the schema used in one application of CS is the same schema as that used in another, with only a difference in how the place-holders in that schema are labeled. It would be less elegant to posit different schemata. But, even so, our confidence that symmetry breaking has occurred in this sort of case should be a bit weaker.

5. Hints of beauty in social cognition

For the physicist, beauty is symmetry (Kaku & Thompson, 1995, p. 99). If one is convinced by the evidence supporting the relational-models framework, then one will also be convinced that social cognition is beautiful in the physicist's sense. After all, each model

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has a corresponding type of symmetry group. Beauty, however, does not consist ultimately of the symmetries found in systems but the more fundamental symmetries found in laws. With regard to social cognition, we are nowhere near that stage since we have not yet even isolated the relevant neural mechanisms. Hence, it is more appropriate at this stage to speak of hints of beauty in social cognition.

Scientists expect to find beauty in fundamental phenomena, the phenomena that serve to explain everything else. Copernicus thought that the orbits of the planets had to be perfectly circular, because planets are fundamental features of the cosmos. Or at least he thought they were. Today we are not surprised that planetary orbits are elliptical, and hence that they are not perfectly beautiful, because we think of planets as accidents. But the expectation of symmetry remains high in studies of what we take to be fundamental, e.g., the equations in string theory. If the notion of beauty in social cognition does not sit well with some readers, this may be because it sounds too anthropocentric, too much like saying that the human mind is a fundamental phenomenon in nature. But it is not anthropocentric. While there is much evidence showing that searching for beauty among fundamental phenomena is a good research strategy, that does not mean that expecting only ugliness among accidents is also a good strategy. Accidents are often beautiful too, as seen in the symmetries of crystals and phyllotaxis.[6] This is because fundamental principles of nature often manifest themselves in accidents. Then why are not the planetary orbits perfectly circular? Because there is no guarantee that accidents will be beautiful. Sometimes they are, and sometimes they are not. But if an accident shows signs of symmetry, and if that accident is of any scientific interest, as I take social cognition to be, then it is a good idea not to ignore those signs but to use them as clues in the search for symmetrical equations.

6. How much Darwin?

It is this latter point which ultra-Darwinians miss: The principles of physics sometimes directly enter into the best explanations in biology. The point can be made by focusing on Dennett's (1987) three strategies for explaining the behavior of a system; where I take "system" to include parts or aspects of organisms as well as whole organisms, and "behavior" to include form. One strategy is the *intentional stance*, meaning that one ascribes beliefs and desires to the system. For example, I predict my chess opponent's next move or overall strategy by thinking of him as an agent with certain beliefs and goals concerning our game. Another reasonable means of explanation is the *design stance* in which one makes assumptions as to how the system was built to perform. My alarm clock is designed to ring at a certain time according to how it is set, so I predict with fair reliability that it will ring at the time it is set to ring. Finally, there is the *physical stance* in which one uses one's knowledge of physics to predict outcomes. For example, I predict that the tree branch will break because it is so heavy with snow. For Dennett, it is very often a pragmatic matter as to which stance to take, the choice often depending upon how complex the system is and how easily one can isolate crucial factors. Plausibly, the physical stance is always possible in principle although not always practical. Furthermore, exclusive use of the physical stance will result in one overlooking interesting higher-level patterns.

[6] Regarding phyllotaxis, see Douady and Couder (1992).

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Dennett (1995, p. 237f) characterizes what he calls "adaptationism," what I here call "ultra-Darwinism," as taking the intentional stance toward natural selection itself as a means for taking the design stance toward the organism. One ascribes beliefs and desires to natural selection, albeit only pretend or "as-if" beliefs and desires, as a means of inferring how natural selection "designed" the organism or organ in question. For example, scientists inferred that there must be morphine-like chemicals in the brain on the grounds that there are morphine receptors in the brain, and natural selection would not have *desired* to build such receptors unless she *believed* that they would serve to reduce pain and psychological stress by receiving the appropriate chemical. Given these beliefs and desires, one infers that natural selection *designed* the receptors to receive an endogenously produced morphine-like substance; bearing in mind that "desire," "belief," and "design" are here being used in degenerate and ersatz senses which do not imply literal agency. Dennett (1995, pp. 233–234) points out that this sort of reasoning led to the discovery of endorphins; scientists knew what to look for. Ultra-Darwinism is the view that this combination of the intentional stance and the design stance is virtually always the right approach to devising explanations and predictions in biology.

What this leaves out is the physical stance, which is reserved for extraordinary cases, according to Dennett. Organisms are just too complex for the physical stance to be practical in most cases. This is even more obvious, on Dennett's view, with regard to an organ as complex as the brain. Even a computer is far simpler, and taking the physical stance toward a computer is not general practice. "One seldom adopts the physical stance in dealing with a computer just because the number of critical variables in the physical constitution of a computer would overwhelm the most prodigious human calculator. Significantly, the physical stance is generally reserved for instances of breakdown, where the condition preventing normal operation is generalized and easily locatable, e.g., 'Nothing will happen when you type in your question, because it isn't plugged in' …" (Dennett, 1973, p. 154).

In discussing which stance it is appropriate to take in biology, Dennett also emphasizes the alleged complexity of the relevant physics. But it is noteworthy that he makes his point through an artificial example, namely a computer game with its own contrived laws of nature, rather than nature itself (1995, pp. 166f, 235f). In this computer game, the "Game of Life," various macro patterns are best described and predicted by ignoring the laws governing micro elements, even though the latter are fundamental. It turns out that it is far more feasible in the game to predict and explain macro patterns by appealing to macro regularities. Dennett, so far as I can understand his point here, is generalizing from this fact about the Game of Life to actual biology, arguing that since lower-level explanation is only very rarely appropriate in the Game of Life, then the physical stance is only very rarely appropriate in biology. But to generalize from a computer game to the natural world, in which the fundamental laws are different, is absurd. The biologist is not trying to predict or explain phenomena in Dennett's computer game. It remains an undefended assumption that the general superiority of higher-level stances in contemplating the Game of Life shows that ultra-Darwinism is the proper strategy in the life sciences.

A similar mistake is made by Steven Pinker who also defends ultra-Darwinism. Pinker argues that symmetry in organisms is best explained in terms of natural selection because symmetry is mathematically improbable: "If you were to fill in the squares of an 8×8 checkerboard at random, the odds are less than one in a billion that the pattern would be bilaterally symmetrical" (1994, pp. 302–303), ignoring the fact that symmetry is ubiquitous

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throughout the known cosmos (Tarasov, 1986) and hence far from improbable. Pinker's argument has only the semblance of plausibility if one ignores the fact that there are laws of nature. Mathematically all patterns may be equal, but physically they are not.

Pinker (1994, p. 302) also notes that "The molecules of life are asymmetrical, as are most plants and many animals". Molecules and plants are not self-moving. For Pinker, this provides a clue as to what symmetry is an adaptation for: "the species with bilaterally symmetrical body plans are the ones that are designed to move in straight lines. The reasons are obvious. A creature with an asymmetrical body would veer off in circles, and a creature with asymmetrical sense organs would eccentrically monitor one side of its body even though equally interesting things can happen on either side" (1994, p. 303).

None of this explains the symmetries found in the relational-models typology. But, apart from that, note that Pinker's empirical premise is questionable, namely the claim that organic molecules and plants exhibit little symmetry. One can see that plants exhibit many symmetries as soon as one allows for close approximations to symmetry to count as symmetry. A tree approximates a cone. This is perhaps most easily visible in the pine, but virtually all trees approximate the cone to some extent. The cone is a shape exhibiting rotational symmetry, a form of symmetry not found in animals. Hence, trees are more symmetrical than animals, not less. Flowers and fruit typically exhibit rotational symmetries, leaves bilateral symmetries, and leaved branches either bilateral or translational symmetries depending on the species. Douady and Couder (1992) have argued that the clockwise and counterclockwise spirals of florets in the sunflower can be explained in terms of a series of broken symmetries. At the very least, they have reproduced such patterns in a non-biological system through symmetry breakings. It has already been noted that many viruses have icosahedral shapes. Pinker may be able to think of adaptationist explanations for these symmetries—adaptationist explanations are easily devised—but clearly he cannot appeal to locomotion and sensory organs in such cases. Pinker has not ruled out the validity of the physical stance in explaining many organic symmetries.

As for organic molecules, there are symmetries in the genetic code, known by the unlovely term "degeneracies." The standard genetic code codes for 20 amino acids that are used to construct the body's proteins. The four nucleotide DNA bases, thymine (T) guanine (G) cytosine (C) and adenine (A), are arranged in triplets, i.e., codons, with very nearly each codon specifying one of those 20 amino acids. (I say "very nearly" because three of the codons do not code for any amino acid but serve to terminate the transcription process.) Given that there are 61 possible codons coding for 20 amino acids plus three coding for "stop," the codons stand in a many-to-one relation to the amino acids, as well as to "stop." For example, the codon GAT specifies leucine, but GAA also codes for leucine. This is a degeneracy, i.e., it is a genetic symmetry, since replacing the T in GAT with A would make no difference to the resulting amino acid just as rotating a perfect square ninety degrees makes no discernable difference. It is generally accepted that there was an evolution from a primordial code that was even more degenerate and hence specified relatively few amino acids.

The mathematicians Hornos and Hornos (1993) noted that this evolution is consistent with the current code being a product of a sequence of five symmetry breakings starting from a primordial genetic code that specified only six amino acids.[7]

> [T]he by now generally accepted picture of a primordial evolution of the genetic code, accompanied and characterized by a stepwise inclusion of more and more amino acids into the machinery of protein synthesis, is completely consistent with the picture of stepwise symmetry breaking, starting out from a large primordial symmetry which is broken in a sequence of steps until reaching a final state of strongly reduced symmetry (Hornos, Braggion, Magini, & Forger, 2004, pp. 125–126).

Hornos and Hornos' quest for the primordial code led them to seek a mathematical group for a 64 dimensional codon space. There are eight such groups. As noted earlier, successive broken symmetries in a system correspond to a chain, i.e., a descending sequence, of subgroups. Hornos and Hornos sought a descending sequence leading from any of these initial eight groups to a close approximation of the group for the current genetic code. There are seven sequences leading to the degree of asymmetry in the current code, and only one leads to a close approximation of the actual code. The first group in this sequence, the symplectic group in six dimensions, Sp(6), commonly used in mechanics, would code for six amino acids, hence the inference that the primordial code only specified for that number of them.

Arriving at the exact genetic code is partly empirical since it does not correspond to a subgroup for the final breakage, suggesting that the fifth symmetry breaking was partially incomplete or "frozen." If it had been complete, the code would specify 27 amino acids. The empirical element may for some raise a doubt as to whether the code really is the result of a chain of broken symmetries, but this would overlook the fact that even arriving at a approximation of the actual code as close as this is mathematically improbable. "Starting with the 64 codons and arranging different ways of distributing them among the 20 [amino acids] and one termination code, Bertman and Jungck estimated that at least 10^{71}–10^{84} different genetic codes like our contemporary one are possible" (Hornos and Hornos, 1993, p. 4402). "[Hornos and Hornos'] method is not so adaptable that it could fit any pattern, which deflects the most obvious criticism" (Stewart, 1994, p. 16). There is, furthermore, evidence of symmetry restoration in the mitochondrial DNA of some species, "the evolution of the mitochondrial codes can be viewed as a retrogression from the standard code to an earlier code, a higher degree of symmetry" (Hornos et al., 2004, p. 129).

In sum, my criticism of Dennett and Pinker is that their defense of ultra-Darwinism is too a priori. Pinker relies on a notion of probability, which ignores laws of nature, as though the relevant sort of probability belonged to pure mathematics, rather than a more appropriate physical conception of probability. Similarly, Dennett's case for the general inappropriateness of the physical stance is based on a mathematical contrivance, a computer game, rather than nature itself. And Pinker's denial of symmetries in plants and organic molecules is just not in agreement with the facts. Dennett's distinction of explanation/prediction into three stances is extremely useful, but his skepticism toward the

[7]For relatively non-technical overviews, see Stewart (1994) and Jenkins (2000, pp. 159–161). For a slightly more technical and up-to-date overview, see Hornos et al. (2004).

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physical stance in biology is too dogmatic. I submit that the question of when and whether the physical stance is appropriate is itself an empirical question. One tries the physical stance in biology and sees how far one can get with it.

Note, in addition, that Dennett (1987) acknowledges that the physical stance is appropriate when the other two stances fail. Hence, failed attempts to explain why social cognition uses just these four models in adaptive terms should lead us, even on Dennett's own view, to the physical stance. Evolutionary work on the models has consisted primarily of showing that other primate species use at least three of them. But there has been very little, if any, progress toward specifying for which adaptive problems each model is a solution (Haslam, 1997). Hence, Dennett should concede that exploring physical approaches to the four models is at least an option, perhaps even the preferred option at this time.

Given that physics gives us symmetry and symmetry breaking for free, a Darwinian or genetic explanation of symmetry breaking in cognition would be superfluous. However, it would be a mistake to say that genes and natural selection play no role at all in explaining the four models. Fiske has discovered a very rich semantic content in all four of them. To take just one example among many, the four models correspond to different attitudes toward time. In CS, "relationships are idealized as eternal," in AR, "sequential precedence marks status by serial ordering of action or attention according to rank," in EM, there is "oscillation of turns, of hosting," and MP features a "concern with efficient use of time, spending it effectively" (Fiske, 1992, p. 695). The models also correspond to four different attitudes with regard to objects, motivation, social identity, and so on. With this much semantic complexity, it would be foolish to suggest that genes and natural selection nowhere play a role.

What this illustrates is that one must distinguish the underlying mathematical structures, essentially the four measurement scales, from the semantic complexity which overlays them. The four measurement scales constitute a relatively non-semantic and beautiful core of social intelligence. It is plausible that this core can be explained in physical terms as four self-organizing states of a single system. In contrast, the semantic richness of the four models, the ways in which they enter into different conceptualizations of time for example, can be understood as interaction effects, i.e., results of interfaces of these four relatively abstract structures with other mental faculties. But to say that symmetry in this essential core of social cognition can be explained directly in terms of physics is not to say that the core as such lacks a Darwinian or genetic explanation. The matter should become plain enough when one reflects on self-assembling viruses. Genes produce the proteins that make up the shell, but there are no genetic instructions for the shell's assembly. Therefore, dynamics takes over, and the proteins self assemble into an icosahedron. These genes were naturally selected, because the virus would not last long enough to replicate unless it were protected in some way. So the fact that there is a shell has a Darwinian/genetic explanation. But its shape does not. Likewise, the beauty of CS should be explainable in terms of physics. But the fact that some model or other is used to structure social relations, e.g., between mother and infant, is surely due to natural selection. Stone-Age hominids who used no model at all would have been at a disadvantage especially in infancy. But the mathematical structure of the models is so beautiful that it suggests a more direct role for physics.

7. Conclusion

There is evidence of descending chains of subgroup types in social cognition. This is consistent with there being a neural network crucially entering into social cognition that can undergo a series of temporal symmetry breakings analogous to the behavior of a CPG in animal locomotion. This should encourage work towards devising computer models of the relevant neural mechanisms, which exhibit activity corresponding to the relevant groups. Gait analysis gives at least the broad outlines of how to proceed.

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