

cess may be thought of as a coulombic, through-space interaction in which the excited chromophore acts as a transmitting radio antenna, and the acceptor chromophore as a receiver. The Dexter mechanism, on the other hand, requires overlap of the molecular orbitals of each pigment. It is basically a simultaneous two-electron exchange, and thus has much in common with electron transfer. Both types of energy transfer have been observed in photosynthesis and many other natural and synthetic systems.

In spite of the 20 Å distance between the metal centres in **2**, the energy transfer rate constant is one thousand times larger than that for related chromophores separated over 17 Å by a rigid but nonconjugated bridge. The rate is substantially faster than predicted by the Förster theory, so it seems the energy transfer must follow the Dexter mechanism, with electronic coupling through the polyphenylene spacer. Perturbations in the absorption spectra and electrochemical properties of the complexes back this up, again indicating that there is electronic interaction between the widely separated metal centres.

Molecular 'girders' of the polyphenylene type can strictly control the spacing (but not the angle) between groups linked to either end. The use of pyridine moieties at each end of the polyphenylene bridge allows ready attachment to metal centres. In principle, these terminal ligands could be 2,2'-bipyridine, as in **1**. But the use of substituted bipyridine ligands in complex optoelectronic molecular devices can lead to a plethora of unwanted stereoisomers, due in part to the chiral nature of the *tris*-bipyridyl complex. This problem does not arise with the tridentate terpyridine-type ligands in **2**, which form achiral complexes. Such ligands are likely to prove valuable for the preparation of many other molecular-scale devices.

Although convenient and functional molecular wires and girders are not yet routinely available, their development continues apace, and the recent results are encouraging. As the allusions to photosynthesis illustrate, biological systems have already discovered many of the principles now being exploited for molecular electronic applications. They could do much to guide the evolution of the field. □

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## Symmetry without fear

Mark Kirkpatrick and Gil G. Rosenthal

WHY does nature love symmetry? The answer proposed by Enquist and Arak<sup>1</sup> on page 169 and Johnstone<sup>2</sup> on page 172 of this issue implicates a conspiracy between geometry and neural architecture that makes symmetrical visual patterns preferable to asymmetrical ones. Their idea provides a new explanation for why females of some animals favour mating

has the ability to recognize.

The new papers use this model to make an interesting point. Once trained, networks respond most strongly to the more symmetrical variants among the target set of images. Johnstone selected a neural network to distinguish images of an abstracted bird tail from random images. The images were not uniform: the tails varied with respect to their symmetry. After the network evolved to recognize them, Johnstone found that the most symmetrical tail elicited the network's strongest response even though the selection process gave no advantage to that image over the asymmetrical variants.

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### IMAGE UNAVAILABLE FOR COPYRIGHT REASONS

Symmetrical show — a male Temminck's tragopan on display.

with symmetrical males rather than their lopsided competitors. Although the results may not explain the fearful symmetry of William Blake's tyger, they have sundry implications for the evolution of animal communication.

The kernel of the new result is that artificial neural networks selected to recognize images tend to develop biases or preferences for symmetrical patterns. In these digital simulations of a visual system, the ability to recognize is acquired by a process that explicitly mimics biological evolution and that is also a model for learning<sup>3</sup>. Several networks that vary slightly are challenged with a set of target images to be recognized (say a bird's tail) and alternatives to be rejected (random patterns). The network that is most successful is retained and the others deleted. This step is analogous to natural selection: individuals that don't identify and mate with their own species leave no offspring. The surviving network is then used as a template for the next generation of networks. Random variations are added to these progeny, however, in analogy with genetic mutation. The cycle of selection and mutation is repeated many times, and a network ultimately evolves that

Both studies are motivated by results showing that females have mating preferences for symmetrical males<sup>4,5</sup>. The interpretation attached to those findings was that preference for symmetry evolves to identify males of high genetic quality. Symmetry is an indicator of good development and hence good genes, the argument goes, and females benefit evolutionarily by mating with these males and passing the good genes on. The twin pillars of this argument are venerable but not yet proven. Minor variation in symmetry (known as a 'fluctuating asymmetry') has been discussed for over 30 years (reviewed in ref. 6), but its genetic, developmental and evolutionary significance remains obscure. Its relevance to sexual selection is a recent and controversial suggestion. The view that

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