42 TALES FROM LIFE

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RICHARD DAWKINS

42 TALES FROM LIFE

A MODERN BESTIARY



An Apollo Book

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Prologue



Mediaeval bestiaries were compendia of animal illustrations, some mythical, some real, some purportedly real but so fancifully portrayed they might as well have been mythical – and with scant distinction between the three categories. The pictures were accompanied by written descriptions, almost entirely untrue but that wasn't the point. A delightful twelfth-century bestiary in my possession includes (the English is modern because translated from the Latin) such gems as:

> The partridge is a cunning, disgusting bird. The male sometimes mounts the male, and thus the chief sensual appetite forgets the laws of sex. Moreover, it is such a perverted creature that the female will go and steal the eggs of another female… The Devil is an example of this sort of thing. He tries to steal the children of the Eternal Creator…

> When a lioness gives birth to her cubs, she brings them forth dead and lays them up lifeless for three days – until their father, coming on the third day, breathes in their faces and makes them alive. Just so did the Father Omnipotent raise Our Lord Jesus Christ from the dead on the third day.

The point was not natural history but moral or allegorical lessons that could be drawn from the animals. The Darwinian bestiary now before you is, or sincerely aspires to be, factual. But it resembles its mediaeval forebears in two respects. First, I go beyond the facts to draw a lesson or moral from my animal story. Not a moralistic or allegorical moral (heavens, no!), a Darwinian one. Not a lesson for

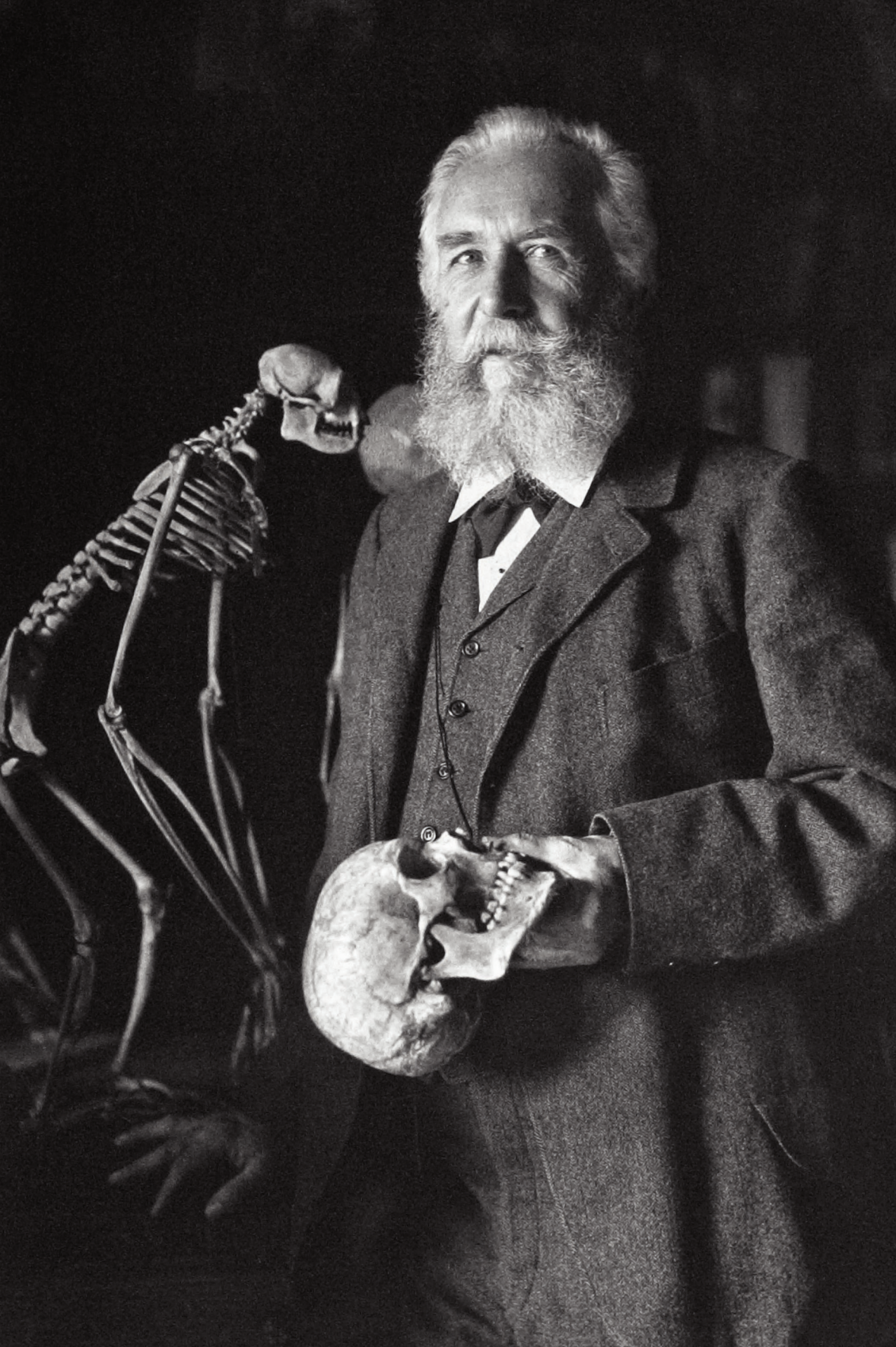
how we ought to live, but a lesson about the science of life generally, which a particular animal happens to teach. Or happens to start a train of thought about. Second, in my choice and treatment of real living creatures, I stray beyond the mundane familiar into a real-life version of the "Here be Dragons" territories that pervaded the old bestiaries. Not unicorns and dragons, not werewolves, gryphons and phoenixes, nothing non-existent, only real animals. But scientific reality, if you know where to look, is way stranger than legend. Reality goes beyond what we can easily imagine, goes far beyond the troubled fantasies of the old bestiaries, challenges science-fiction writers to come up with something ever more alien. My friend Douglas Adams possessed what was rightly described as a world-class imagination. Even he once told me he wanted to go back to university to study zoology. I dissuaded him. But I understand what he meant. I hope that, if you read my 42 Tales, you will too.

My Darwinian bestiary is structured as a series of "Tales". It follows the precedent of an earlier book, and I need to explain this. In *The Ancestor's Tale,* my co-author Yan Wong and I embarked on a Chaucerian pilgrimage, marching backwards into the past. Our starting point was the present; our Canterbury the origin of life. The pilgrims who initially set out were modern humans. As we travelled back in time, we were joined successively by other bands of pilgrims journeying to the same destination from their disparate starting points. First to join, around the 6-million-year rendezvous point, were the chimpanzee and bonobo pilgrims, who had already joined each other. At 8 or 9 million years, we humans, chimps and bonobos were joined by the gorilla pilgrims. Then we African apes joined forces with Asian apes before travelling on through forty (surprisingly few) rendezvous points before reaching the origin of life, perhaps 4 billion years ago. At each rendezvous, one or more of the new joiners regaled the other pilgrims with a Tale, as in Chaucer. In all, there were 59 Tales.

Although nominally told by a pilgrim, each Tale was actually a device for us, the authors, to make a particular point of biological interest, a point that arose from contemplation of the pilgrim concerned. The Grasshopper's Tale, for instance, was an essay on race,

including the vexed matter of human race. Why should the Tale of Race be attributed to the grasshopper? Because there happens to be an especially interesting story of two North American grasshopper species that bears on the question. That is what I meant above by a Darwinian moral. The Marsupial Mole's Tale was an essay on convergent evolution. It is given to the marsupial mole, because the underground "mole" way of life has arisen convergently several times in evolution. The marsupial mole of Australia resembles the Eurasian mole and the African golden mole, not because they are related, they aren't (except in the wider sense that all mammals are related), but because they all have the same way of life. The Tale is about convergent evolution in general, not just about moles.

The point is that each Tale in that previous book only starts with the animal that nominally tells it. Most Tales branch out more widely. And that is what the Tales in this book do too. Most centre on animals and protists, but some plants and fungi are in the mix. In the earlier book, the thread binding the Tales was the pilgrimage to the past. In this book, the binding thread is quite different. And quite different from that of a mediaeval bestiary with its untrue legends and poorly drawn illustrations. Instead, it is the beautiful and meticulous biological art of the celebrated German zoologist and artist Ernst Haeckel (1834–1919). The pictures in a mediaeval bestiary were not drawn from life. They were drawn from legend or from travellers' tall tales or ill-recorded second- or third-hand accounts. Haeckel's pictures are drawn from life. And so are my Tales. Hence the title of this book. Haeckel's microscope revealed wonders to outdo the wildest imagination. If my word-pictures achieve some fraction of the same thing in your mind, I shall be content. Each Tale begins with the Haeckel drawing or painting that inspired it. What then follows may be an account of the biology of the creatures portrayed. More often, as explained above, it is a moral drawn from their contemplation, not a moralistic moral as in a bestiary but, as in *The Ancestor's Tale*, a scientific one. First, I need to introduce Haeckel himself.



Haeckel's Tale



Ernst Haeckel was known as "the German Darwin", although in my opinion August Weismann (1834–1914) vies for the title. Haeckel was perhaps more like the German Huxley, with an admixture of artistic flair. He was Darwinism's most outspoken follower in Germany, indeed continental Europe. "Follower" doesn't capture the zeal with which Haeckel preached and enlarged on his hero's views. Where Darwin was of a retiring disposition, Haeckel, like Huxley, was pugnacious in his cause. The German American geneticist Richard Goldschmidt (1878–1958) said that "Haeckel became one of the best loved and one of the most hated men of his age." If TH Huxley was Darwin's English bulldog, Haeckel was his German rottweiler. Neither Huxley nor Haeckel got their Darwinism as right as Darwin himself, or indeed as right as Weismann, in my hindsighted view. Huxley, wrongly in my opinion, thought Darwin too wedded to gradual change in small steps. Haeckel unfortunately embraced Social Darwinism and theories of racial superiority, and he went overboard for the now largely discredited "biogenetic law" of recapitulation: "ontogeny recapitulates phylogeny" – the developing

embryo "climbs up its own family tree". Worse, Haeckel espoused a version of the Lamarckian notion of the inheritance of acquired characteristics: improvements acquired during life are somehow inserted into the genome (it wasn't called that then) and passed to the next generation. To be fair, Darwin succumbed to a version of the same fallacy in his later writings, notably *The Variation of Animals and Plants Under Domestication* (1868). He was needlessly provoked by criticisms now known to be erroneous, which, incidentally, is one reason I prefer the first edition of *Origin* over the sixth.

In 1866, Haeckel sent Darwin an advance proof copy of his book on *Generelle Morphologie der Organismen*. Darwin's struggle with Haeckel's difficult German was more or less a losing battle, but he was sufficiently impressed to invite Haeckel to lunch at Downe House. The meeting occurred in October 1866, when Haeckel was 32 and Darwin 57. W. Bölsche's 1906 biography of Haeckel tells the story. Haeckel found Darwin to be "tall and venerable…"

> … with the broad shoulders of an Atlas that bore a world of thought: a Jove-like forehead, as we see in Goethe, with a lofty and broad vault, deeply furrowed by the plough of intellectual work. The tender and friendly eyes were overshadowed by the great roof of the prominent brows. The gentle mouth was framed in a long, silvery white beard… I seemed to have before me a venerable sage of ancient Greece, a Socrates or an Aristotle.

Even in translation, it is clear that Haeckel's artistic eye complemented a gift for poetic imagery: "deeply furrowed by the plough of intellectual work" is really rather good.

> Overawed, Haeckel began jabbering in broken English. Darwin said something and found that Haeckel did not understand him either. They stared at each other for a moment and then burst into laughter. Slow speech worked wonders, and over lunch rapport was finally established – until Haeckel became excited again. Waving his arms, he railed against "the stubborn and

> bewigged professors who still held out against the luminous truth of the theory of evolution." No one could make out what he was saying and Emma looked impatient. Darwin just put his hand on Haeckel's broad shoulder, nodded and smiled. To Haeckel it was a benediction. Darwin had "seldom seen a more pleasant, cordial, and frank man." Links were quickly cemented: Lubbock came over from High Elms[1] to meet Haeckel, and Darwin introduced him to Hooker. There was much mutual back-slapping.

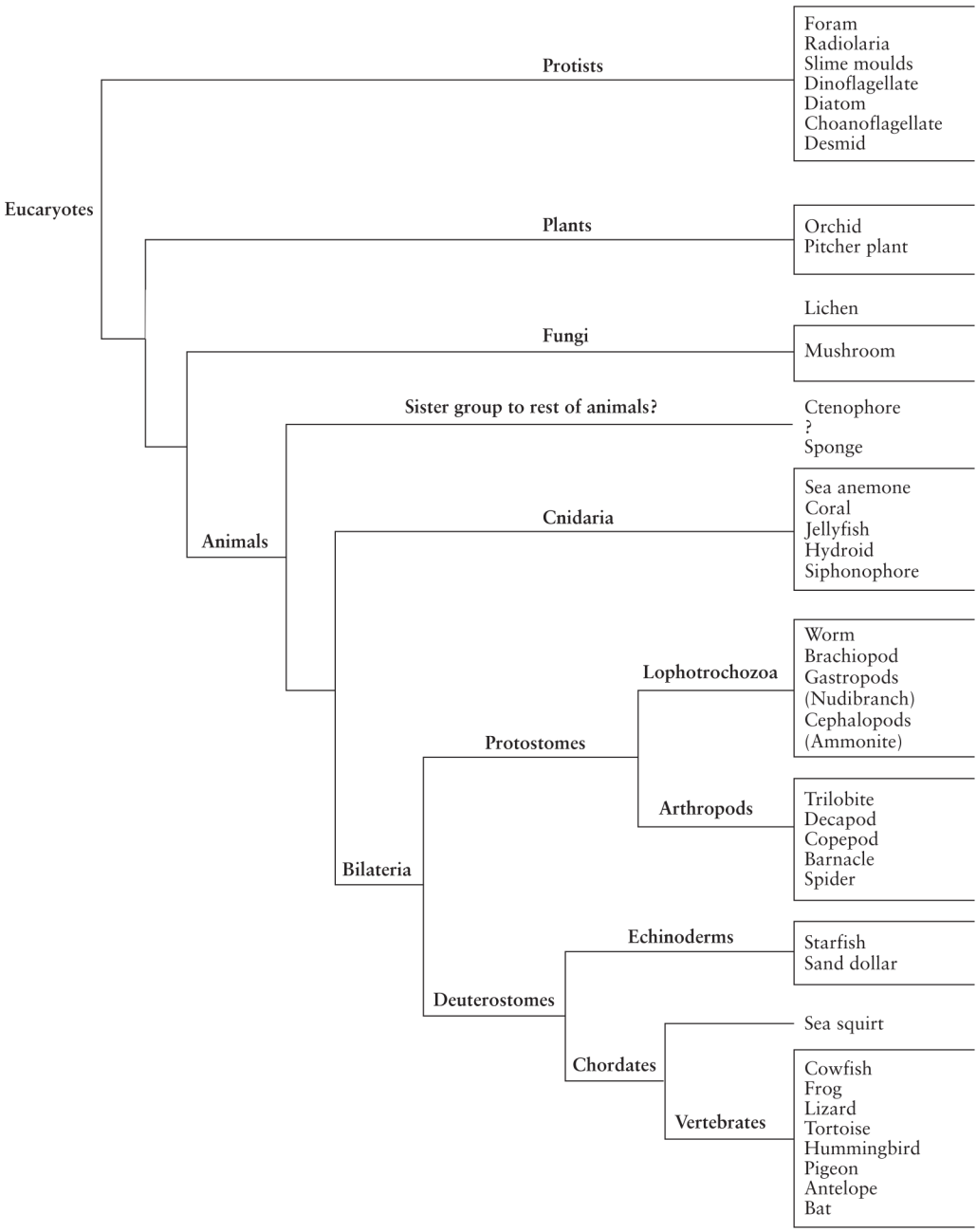
Born in Potsdam in 1834, Haeckel trained as a doctor, like Darwin and with a similar lack of enthusiasm. Unlike Darwin, Haeckel qualified, and even practised briefly, but he cunningly set his consulting hours before 6 a.m., and was seldom troubled by patients. He soon turned to his real love, zoology.

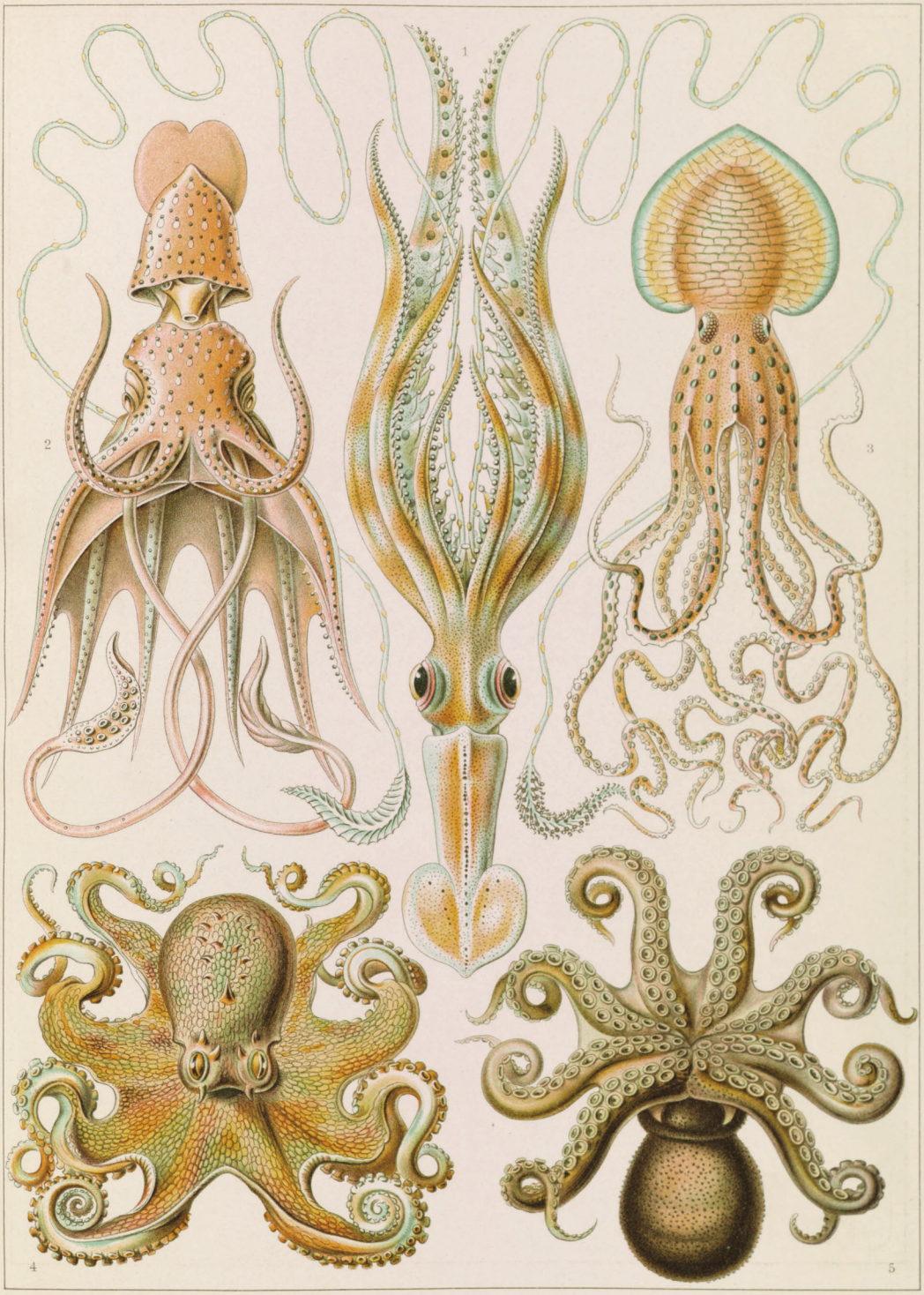
He was an outstanding artist, whose representations of living creatures are said to have influenced painters of the calibre of Gustav Klimt and Edvard Munch. The grand gateway to the Paris World Fair in 1900, designed by René Binet, was inspired by Haeckel's drawings of Radiolaria. Exploiting his talent, Haeckel wrote and illustrated extensive monographs on not only Radiolaria, but other groups of (what we formerly called) Protozoa, then further monographs on jellyfish, hydroids, siphonophores and sponges. In the course of his work on these zoological monographs, he discovered and named an enormous number of new species. At a rough estimate, he published around 3,000 exquisitely detailed drawings of the animals he studied, an astonishing body of high-quality work to pack into one lifetime. Especially when one includes all his other time-consuming accomplishments, as a popular lecturer, author of substantial volumes, and researcher. It comes as no surprise to learn that he typically slept only three to four hours per night.

A hundred of Haeckel's plates were collected under the title *Kunstformen der Natur*, or *Art Forms in Nature*. I have made my own selection from this collection of 100, supplemented by a few others from his various monographs, chosen not only for their beauty but because

they provoked interesting Tales, alluring subjects for my Darwinian bestiary. When I counted these, they really did come to exactly 42.

The pictures in the *Art Forms in Nature* portfolio were presented in something close to random order, certainly not any order that a biological systematist would recognize. My Tales, too, can mostly be read in any order, although I have made some attempt at steering between them, and there are frequent cross-references. Sometimes cross-references are phrased in the form "See The So-and-so's Tale". On other occasions I'll simply put so-and-so in bold type to signify that it has a Tale of its own. I'll also adopt the – I hope not irritating – convention of capitalizing "Tale" when it refers to one of my 42, as opposed to just any old story. Before launching into the first Tale, it might be helpful to see a map of the living kingdoms (technically a cladogram), showing how all 42 subject organisms are related to one another.


Eucaryotes
Protists
Foram
Radiolaria
Slime moulds
Dinoflagellate
Diatom
Choanoflagellate
Desmid
Plants
Orchid
Pitcher plant
Fungi
Lichen
Mushroom
Animals
Sister group to rest of animals?
Ctenophore
?
Sponge
Cnidaria
Sea anemone
Coral
Jellyfish
Hydroid
Siphonophore
Bilateria
Protostomes
Lophotrochozoa
Worm
Brachiopod
Gastropods
(Nudibranch)
Cephalopods
(Ammonite)
Arthropods
Trilobite
Decapod
Copepod
Barnacle
Spider
Deuterostomes
Echinoderms
Starfish
Sand dollar
Chordates
Sea squirt
Vertebrates
Cowfish
Frog
Lizard
Tortoise
Hummingbird
Pigeon
Antelope
Bat



Gamochonia. — Trichterkraken.

The Cephalopod's Tale

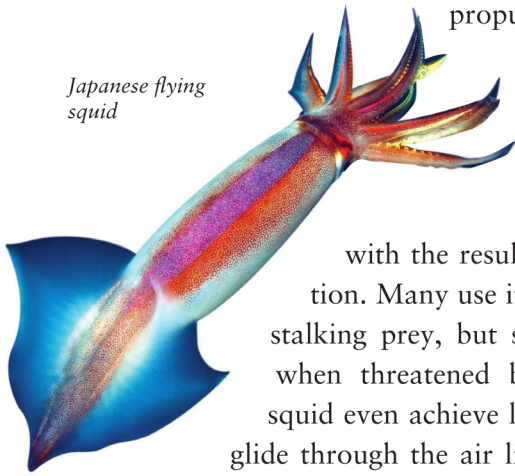


Are these the Martians?

Science-fiction writers strain their imagination to come up with an extraterrestrial creature sufficiently alien, sufficiently outlandish, sufficiently different from familiar earthly life to outflank accusations of terrestrial chauvinism. A colleague from my Berkeley California days, giving a lecture on cephalopods, began with a striking phrase that stuck in memory: "These are the Martians." The Cephalopod's Tale follows Haeckel's picture in extolling the sheer strangeness of octopuses, cuttlefish and squid.

All molluscs have a principal ganglion wrapped, as a ring, around the gut. That doesn't seem especially odd in a snail or a limpet. But in cephalopods the circum-oesophageal ganglion has grown into a large brain, and the idea of passing all your food through the middle of your brain sounds positively, well, Martian.

Almost uniquely in the animal kingdom[2], cephalopods have jet



Japanese flying squid

propulsion, which in squids especially shoots them at high speed through the water. The jet nozzle can be swivelled like that of a VTOL (vertical take-off and landing) aircraft, with the result that they can jet in any direction. Many use it to creep forwards slowly when stalking prey, but shoot backwards at high speed when threatened by a predator. Japanese flying squid even achieve lift-off from the waves, and they glide through the air like flying fish when pursued by predators. The blue "arrowhead" indicates the direction in which the squid is flying, but it is actually at the posterior end of the animal: a large fin that provides aerodynamic lift. And the "fletching" at the back of the arrow is at the anatomical front end of the animal. Hurtling backwards through the air? What could be more Martian?

Flying fish, of course, hurtle forwards, and there are many respects in which squid can be seen as alternative fish, an alien approach to the fish way of life. They live in the same kind of way as fish, and in the same range of places. Like fish, they often go about in schools. Humans catch them in similar ways, in nets or with bait and line.

If squid are Martian fish, octopuses are perhaps more like Martian monkeys. They are intelligent like monkeys, dextrous with their limbs, and they get up to all kinds of monkey tricks, but always in alien, unmonkeylike ways. Octopuses in aquariums are adept at escaping from their tanks, even squeezing their rubbery bodies under the tanks' glass lids. One octopus Houdini, trapped in a glass jar with the lid screwed down, managed to unscrew it from the inside and make its escape. The "coconut octopus", *Amphioctopus marginatus*, is given to bipedal walking briskly across the sea bottom. It strides vigorously along on two of its arms, the other six being held up in a bunch. I think they look like comic characters in a cartoon film.

The spider monkey of New World forests has five long limbs (the prehensile tail functions as a skilled fifth limb). An octopus has eight

limbs, and they are all highly skilled. I mean that literally. Each arm is individually skilled. Where the monkey's skill lies centrally in the brain but manifests in the limbs, the octopus nervous system, and even a part of its intelligence, is distributed over all eight arms. The total number of nerve cells in an octopus is large. But fewer than 30 per cent of them reside in the brain. By way of comparison, our brain holds more than 99 per cent of the body's neurones. The skills of each octopus arm lie largely in the nerves of the arm itself, and it is to the arms and the rest of the body that the octopus distributes the bulk of its nervous system. There's a satellite "brain" at the root of each arm, and the arms can communicate with one another to some extent thanks to a nerve ring that connects them all.

The dexterity of octopus arms is all the more remarkable for containing no hard skeleton. Where the limb muscles of a spider monkey, or of a spider crab or, indeed, a spider, pull on rigid levers, octopus muscles have no hard members to pull against. Like an elephant's trunk, which also has no bone, an octopus arm requires a highly sophisticated network of muscles pulling, in effect, against each other. Its rows of suckers are not only capable of a very strong grip. They are highly sensitive organs of taste, smell and touch.

One could be forgiven for bemoaning the exceptionally short lifespan of cephalopods. One to two years seems scarcely long enough to make use of their high intelligence! They put all their efforts into one "big bang" reproductive event, and then die.[3]

Cephalopods range in size from the 1-centimetre-long idiosepiid squids to the almost never seen giant squid,[4] *Architeuthis dux*, at up to 13 metres, and the shorter, but heavier (about 500 kilograms), and equally elusive, colossal squid, *Mesonychoteuthis hamiltoni*. This has the distinction of possessing the largest eye of any living animal, probably any animal ever. The eye is about the size of a soccer ball. You need a large eye to see anything when it's very dark, and it is very very dark in the deep sea where the colossal squid makes its home.

Haeckel's picture runs to only five species, and cannot possibly do justice to the variety and beauty of cephalopods. There are even semi-transparent "glass octopuses", whose internal organs are visible

through the body wall. Other cephalopods bioluminesce in the dark.

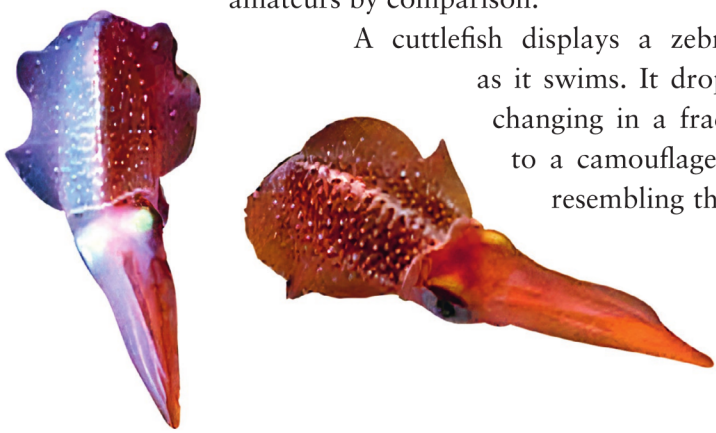
Even if octopuses are a bit too Martian for our aesthetic tastes, the gracefully fletched arrow that is a squid at full tilt cannot fail to stir. And (I deliberately left the best and most Martian feature till last) the fact that a cephalopod's entire outer surface is literally one big colour video screen is… well, it is truly beautiful as well as astonishing.

One of the squids illustrated by Haeckel is *Histioteuthis* (on the upper left in his illustration at the beginning of this Tale), displaying an elegant pointillist pattern of spots. But, unlike the proverbial leopard, a squid can change its spots. Amazingly, it can change them instantaneously, moment by moment. Or abandon spots altogether.

Look, and marvel, at Roger Hanlon's photo of a male squid at the bottom of this page (half white and half brown) courting a brown female. He displays his friendly side to her, resembling her colour and striped pattern. But see his other side. His skin on that side has suddenly changed to white, to intimidate a rival (off picture). If the female moves to the other side, he will instantly switch off the aggressive white display. And I do mean instantly. A cephalopod can totally change colour in a fraction of a second, perhaps the single most "Martian" feature of all. And would you have ever imagined that any animal outside your dreams could at will go half-and-half like that?

Many a squid or cuttlefish can give a peacock a run for its money. Where they score over the peacock is that a split second later they can change to a completely different colour pattern. That might make you think of the proverbial chameleon. But chameleons are amateurs by comparison.

A cuttlefish displays a zebra-striped pattern as it swims. It drops to the bottom, changing in a fraction of a second to a camouflage pattern precisely resembling the particular patch



Male squid with split personality courting balanced female

where it has settled. As a foraging octopus does the rounds of its home range, it too changes its skin colour from moment to moment. I quote from Hanlon, Vecchione and Alcock, to whom I am much indebted in this Tale:

> *Octopus cyanea* on Pacific coral reefs change their appearance more than 150 times per hour while foraging each day! Fast change is needed because cephalopods are mobile and move into different visual scenes constantly when foraging. During their stop-and-go foraging trek, they change their camouflage pattern each time they stop and it is tailored to that particular background. The speed of change is remarkable. By studying video of naturally foraging octopuses and cuttlefishes, it is known that they change in a fraction of a second. That is, they can create patterns in their skin in as little as 200 milliseconds.

The "passing clouds" display of a cuttlefish is mesmerizing. Waves of light and dark chase each other over the body surface. Could it be literally mesmerizing, designed to hypnotize would-be prey?

How do they do it? How does it work, this protean video screen that is a cephalopod's skin? Computer screens and modern television screens have pixels of three different colours: red, blue, and green. The brightness of each pixel is controlled electronically to concoct any desired hue. Red, green and blue are obviously made by brightening the respective pixels; yellow is made by brightening the red and green pixels together; purple the reds and blues; white by turning the gain up on all three colours. Combinations of these three pixels can render any colour our eyes can see. Cephalopods, too, have pixels of three colours (not the same three as our screens). But they don't have light-emitting diodes that they can turn on or off. How, then, do they do it?

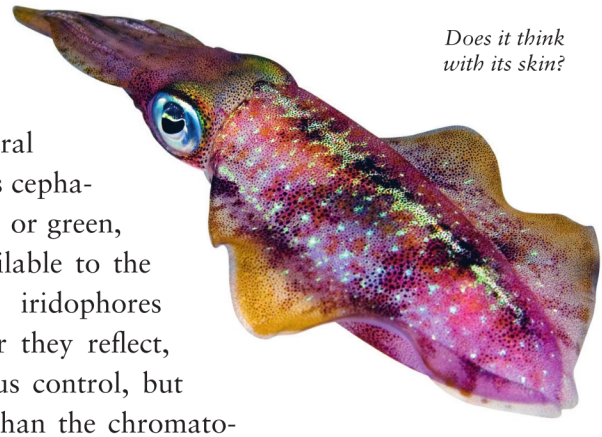
My normal practice when answering a question like that is to list possible alternatives, with pros and cons, before finally divulging nature's answer. In this case, I drew a blank when trying to list alternative solutions to the problem. The only one I could think of was nature's actual solution. And I wouldn't have thought of that

if it didn't already exist, so unexpectedly Martian is it. So I'll jump straight to nature's answer.

Dotted through the skin are "chromatophores", little elastic bags of pigment. As with the computer screen, there are three different colours, not red, blue and green but red, yellow and brown. There are muscles radiating out from each chromatophore like the spokes of a wheel, the bag of dye being the hub. When the muscles are relaxed, the elastic bag is small, and it is not easily visible. But when the muscles pull away from the hub, the bag is stretched into a wide disc, and its colour shows up. This is equivalent to a pixel on a computer or TV screen being turned on. Nerves control the muscles attached to each chromatophore, and nerves are fast. This is why a cephalopod can achieve its remarkably rapid changes of colour and pattern. If you connected the nerves up appropriately to a computer, it is literally true that you could stimulate an octopus's skin to play a skinflick movie all over its surface. That hasn't been done, but here's the next best thing. Roger Hanlon and his lab members connected an iPod to a main nerve leading to a piece of fresh squid skin. Electrical stimulation by the iPod caused the chromatophores to wink in time to the music. If you want to see it, Google "Insane in the Chromatophores".

But cephalopods have more tricks up their tentacled sleeve. Pigments aren't the only way to achieve colour. They work by reflecting light of the appropriate colour, while absorbing light of the rest of the spectrum. But there's a completely different way to produce colour: *structural coloration*. If you see vividly shining colours in an animal, which change when you look from a different angle, you are probably looking at structural coloration. Examples are the glowing blue of a peacock's breast or a morpho butterfly, or the jewel-like flash of a hummingbird. Cepahlopods exploit this too.

The video screen that is the skin of a cephalopod has three layers. The chromatophores occupy the top, or outer, layer. The bottom layer is a vivid white. It acts as a blank canvas for the colour show. Between these two layers, the middle layer contains "iridophores". They get their name from Iris, the Greek goddess of the rainbow. The iridophores are arranged in stacks of reflecting plates, whose spacing is



Does it think with its skin?

cunningly adjusted to produce any colour of the rainbow. It is this structural coloration that enables cephalopods to iridesce blue or green, hues that are not available to the chromatophores. The iridophores can change the colour they reflect, and it is under nervous control, but the change is slower than the chromatophores can achieve: three seconds or so. Recently, to the surprise of workers in the field, it has been discovered that there is some structural coloration associated with the chromatophores in the top layer, and this seems to change at high speed in synch with the chromatophores, but the details are still being worked out.

Curiouser and curiouser, the cephalopod skin has a couple more Martian tricks. First, not only is it a two-dimensional video screen. It rises spectacularly into the third dimension. A cuttlefish can cruise along, its skin bright with changing colour but slippery smooth. Now let it be threatened by an enemy. Not only does the colour change to a sudden fearsome warning. At the same time, and equally suddenly, the skin is thrown up in spikes and ridges called "papillae". Papillae may also be deployed in camouflage, disrupting the outline and enhancing the resemblance of the cuttlefish to the sea bottom on which it rests.

The pigments that cephalopods use to such spectacular effect in their chromatophores are also available, in different form, for another purpose. They have a large ink sac filled with brownish-black ink ("*Sepia*" is actually the Latin name of a common genus of cuttlefish). When evading an attack by a predator, a cephalopod will often void the ink sac, producing a puff of ink in the water. This serves to confuse the predator, perhaps luring it to chase the drifting ink cloud while the real animal makes its cryptic escape.

Cephalopods are so good at mimicking with their skin the background on which they sit, including its colour, their eyes must have

good colour vision. Mustn't they? Actually, no. Let's take a look at that question. As background, we need a digression on how we and other vertebrates see colour.

We see colour with *cone cells* in our retina. They work by means of *opsins*, protein molecules that change shape in response to light, thereby triggering a nerve impulse. We have three kinds of cone, with three different opsins. All respond to light of all colours, but the three have different sensitivity curves. "Red" cones are relatively sensitive to longer wavelengths, "blue" cones to shorter wavelengths and "green" cones are intermediate. The brain knows which nerve impulses come ultimately (via intermediary neurones) from which type of cone. By comparing the relative firing rates of the three kinds of cone, it can reconstruct the colour of an object on the retina.

Birds, and many other reptiles ("other," for birds are dinosaurs), have a similar system, but they have four kinds of cone instead of three. One of them is sensitive to ultraviolet light, of short wavelength that we cannot see. In addition, their retina has tiny coloured oil droplets that act as colour filters. The extinct dinosaurs, too, probably had four types of cone. Before dinosaurs came on the scene, our mammal ancestors may well have had better colour vision than most mammals do today. The danger and competition from dinosaurs drove them to become nocturnal (translation: those individuals with a genetic tendency to become nocturnal survived better than rival individuals who stayed out in the daylight where dinosaurs lurked and pounced, roamed and competed). In the night, mammal eyes specialized in seeing anything at all. Colour had low priority, and they became what we would now call red/green colour blind. After the dinosaurs (except birds) went extinct, some monkeys developed, or rediscovered, a third type of cone, perhaps to help them find coloured fruits. What happened was that the gene making the opsin sensitive to medium-wavelength (green) light duplicated, and one copy moved its sensitivity towards the long-wave, red end of the spectrum. We, along with other apes and Old World monkeys, have inherited this three-colour vision. New World monkeys have a more complicated story. I'd love to tell it but this digression has gone far enough. Before

finally returning to cephalopods, however, I can't resist mentioning the eyes of mantis shrimps, remarkable crustaceans with club-like appendages that can pack a punch powerful enough to break aquarium glass. Mantis shrimps have not three, not four, but sixteen kinds of light-sensitive opsins. Nobody knows what it's like to be a mantis shrimp.

Cephalopods have opsins too. They are held in light-sensitive cells that are rather different from cones – what matters for our purposes is that they all have the same kind of opsin. Unlike our cones. So, that makes them colour blind? Not necessarily. There are other possible ways of seeing colour. An intriguing but unsupported theory suggests that they make use of chromatic aberration, positively exploit it, while we vertebrates, especially designers of cameras, treat chromatic aberration as a nuisance.

Lenses bend light rays. That's what they're for. They bend light in a precise way. In a perfect lens, perfectly in focus, all the light rays from any one source, for example the tip of a leaf on a tree, are bent to a precise spot on the focused image. That's what focus means. Unfortunately, light of different wavelengths is bent through a slightly different angle. So when red light is in focus, blue light is out of focus. And vice versa. Camera designers go to much expensive trouble to reduce chromatic aberration. But – at least according to the theory I am recounting – cephalopods love it. They go out of their way to enhance it. Our bug is their feature. They recruit chromatic aberration into service in their "Martian" system of colour vision.

The suggestion is that they move their lens back and forth, seeking the best focus. Because of chromatic aberration, when the lens is in its most forward position, anything that's sharply in focus must be near the red end of the spectrum. As they move the lens closer to the retina, light rays of shorter wavelength come progressively into focus. Our brain computes colour by comparing the intensity of light *simultaneously* reported by *different* photocells. The cephalopod brain, according to this theory, computes colour by comparing the intensity of light reported by the *same* photocells at different *times*, as the lens shuttles back and forth. It's even been suggested that the strange "W"



"The lone and level sands stretch far away"

shape of a cuttlefish's pupil is a device to increase chromatic aberration. I must stress again that this whole theory of making a virtue of chromatic aberration is a speculation supported by no direct evidence. I thought it interesting enough to be worth a mention.

We're not yet done with the strangeness of cephalopod vision. As we've come to expect by now in this Tale, as well as with their eyes they probably detect light with their skin! Embedded all over the skin are opsins. No lenses, so the skin can't focus an image. But a piece of detached octopus skin will respond to light, especially blue-green light, by changing its display. Some of the opsins are closely associated with chromatophores, so it's possible they initiate a change in their own local chromatophore. Could skin vision have something to do with a cephalopod's ability to mimic the background on which it sits?

As we saw above, the majority of a cephalopod's nerve cells are not in the brain but distributed all around the body. Their skin is one big data screen with more than 200 pixels per square millimetre, winking

on and off like a huge population of light-emitting diodes. The great physiologist Charles Sherrington (1857–1952) likened man's cerebral cortex, the "topmost sheet" of the brain, to:

> a sparkling field of rhythmic flashing points with trains of travelling sparks hurrying hither and thither. The brain is waking and with it the mind is returning. It is as if the Milky Way entered upon some cosmic dance. Swiftly the head mass becomes an enchanted loom where millions of flashing shuttles weave a dissolving pattern, always a meaningful pattern though never an abiding one; a shifting harmony of subpatterns.

He could almost have been describing a cephalopod's skin. Am I going too far when I wonder whether, perhaps, an octopus thinks with its skin?