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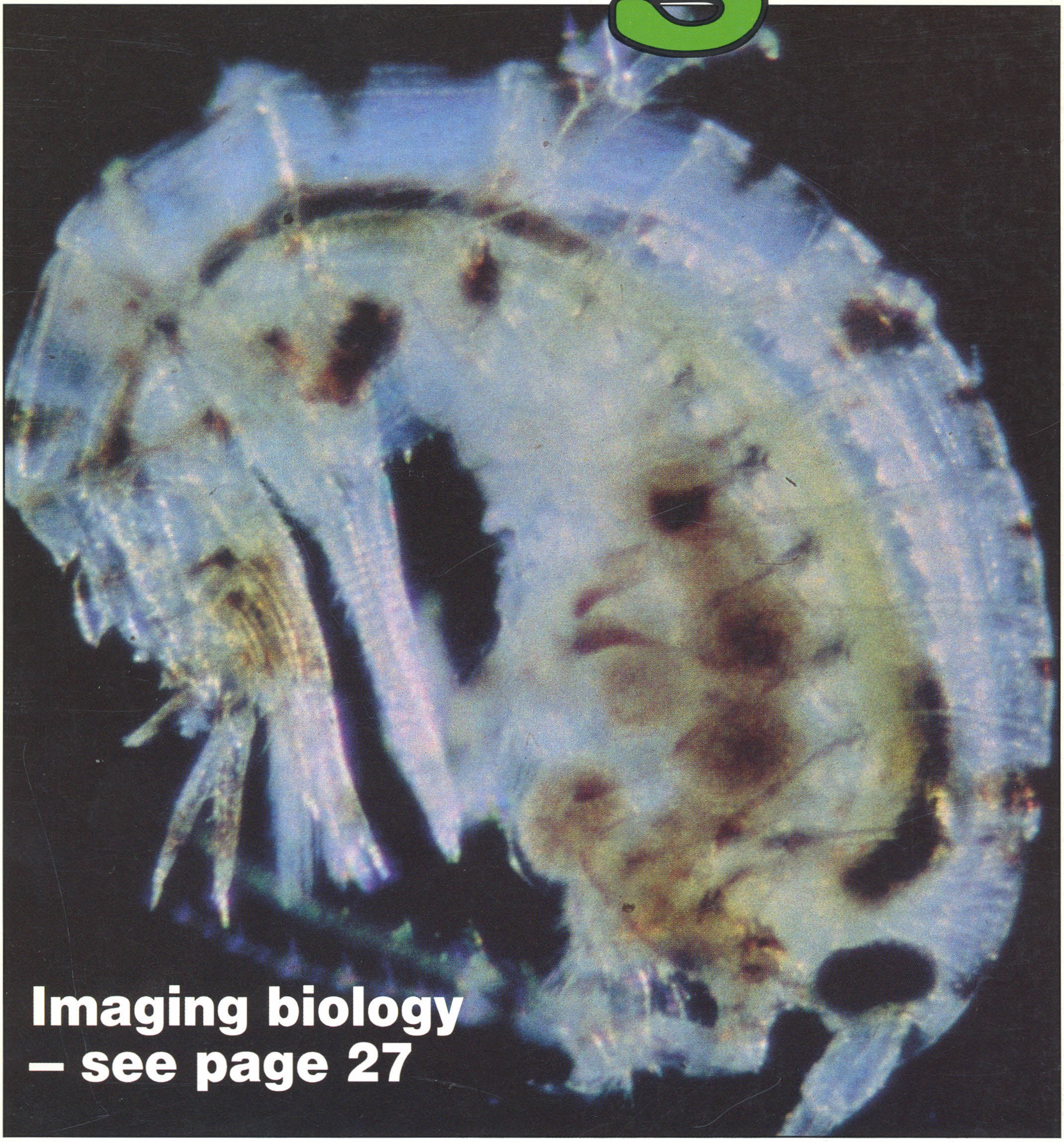

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The possibility of life on other planets

Jack Cohen

Is the planet Earth the only place where life may be found? And if not, what else might we expect to find? Jack Cohen examines the possibilities and takes a look at some of the biological errors made by science fiction pulp writers and film makers

During the years 1959–1981, I gave more than 360 lectures with this title: it had more requests through the local British Association for the Advancement of Science lecture service than any other title ('Science in the detection of crime' was close). Different versions of POLOOP, as it became widely known, were given to prestigious national scientific societies and to science fiction fans, women's groups, sixth forms and supervisors' societies.

The argument I used was very different from the various contemporary arguments for (or indeed against) alien life, and was especially different from those about intelligent aliens. These were based on the concept of chemistry being similar everywhere, the commonness of planets in the universe, and that life will arise and be acted upon by natural selection leading to a highest form of life which develops intelligence. This was a very respectable argument, and had many sophisticated forms – the great biologist Waddington was sure that the highest form of life anywhere would resemble Waddington . . . More philosophical variants, based on the assumed typicality of our situation ('We *can't* be the only ones'), were countered by anthropic variants (for example 'But even the very first intelligent life would say that, and would be *wrong*'). I used an argument which, although it depended crucially on the universality of chemistry and some ubiquity of planets, nevertheless was based solidly in *biological, evolutionary* argument about likelihoods. For that reason, it is limited to 'Life as we know it'. I am happy to make guesses about 'Life as we don't know it', based on different molecules for its chemistries, for example – but not here.

All biology has history, a history *deduced* from fossil evidence and homologies, as an integral part of its arguments and its understanding. So it also has credibility as a test of evolutionary, or other historical scenarios. As an example, consider the question of whether pterodactyls did actually fly. Did they perhaps swim? Climb trees or cliffs, then glide? We use two very different principles in such a credibility test, which I will call 'internal' and 'stochastic'. The internal principle looks to the *mechanism* concerned (makes models of pterodactyls, calculates aspect ratios, density, food sources, heights and density of trees, local palaeoecology and so on – they *could have* flown). The stochastic test of credibility assembles apparently comparable instances (other reptiles flew and became birds, some fish fly, mammals produced large fruit bats, and so on, so flight is *not difficult to believe in*).

For some historical events (the origin of DNA, the origins of life, even the continuing synthesis of amino acids from the primitive reducing atmosphere) we *can* only use internal evidence, because we are presented with only one instance. They must be considered *unique* events, even though they may not have been: DNA may have arisen many times, even by different routes – but we now have only the unique evidence of its presence. The *likelihood* of these, apparently unique, events is assessed by sums involving Earth's early chemistry, routes to sugars, phosphates, bases, catalytic agents like clays or lipid smears. Cairns-Smith (1985), for example, proposed a whole new scenario: clay minerals, which we now know to reproduce in very life-like ways, would have used adsorbed complex carbon compounds to assist their own stability and reproduction. These carbon compounds ultimately 'took over' the genetic mechanisms of the clays themselves. A new suggestion like this changes the likelihood sums. All we know from the evidence of such unique occurrences, really, is that they are *possible*; they happened, so far as we know, once. Likelihood estimates come from outside knowledge – of chemistry, mineralogy, and so on (for example, amino acids were certainly to be found in prebiotic oceans, but nucleotides probably weren't).

The likelihood of the other, stochastic, events is assessed by *how many* other organisms adopted this particular trick: we are not surprised at pterodactyls flying because we know about insects, birds, bats. Indeed, and this is crucial to the argument, we would *expect* flying forms to arise. We know what evolutionary tricks we might expect on another planet with a similar biological history, then, because many Earthly evolutionary lines have adopted a particular trick.

Popular representations of possible alien life-forms are all too often artificial constructs of existing forms on Earth. Evolution on other Worlds is unlikely to reproduce the pentadactyl limb, as portrayed here: different limb structures will evolve. This picture was taken at the last UK-hosted World SF convention in 1987. (Photo, P. Tyers/ Concatenation Pictures.)

We would actually be surprised if similar life forms elsewhere had *not* done so. If you don't find this convincing, think of other-temporal, rather than outer-spatial, examples: if DDT or some other noxium destroyed *all* the flying life on this planet, leaving a varied but depleted land fauna, how long would it be before other flying forms evolved? What would they be? (Dougal Dixon, in his delightful *After Man* scenarios (Dixon, 1981), has a beautiful extended argument deriving the evolutionary radiations of the next 50 million years in this way.) You will agree that flying forms will evolve again, I trust; similarly, I hope you will agree that if there should be a planet with our kind of carbon-based life on it, with land areas, photosynthesis, and cellular eukaryote organisms, then flying forms *will* have evolved on it.

There is a negative side to this argument, too. There are many creatures on this planet (the land vertebrates) which possess variations on the pentadactyl limb. This peculiarity will *not* be found on other planets, however. All the instances on this planet derive from one innovation, probably by a fish (classically *Eusthenopteron*) which invaded Devonian beaches; its descendants – and *only* its descendants – possess pentadactyl limbs. Contrary to the evidence on the front covers of many older science-fantasy novels and magazines, aliens won't have knees and elbows of our kind; they will, however, have limbs, and probably joints too. Our knees and elbows are parochial, found only on Earth (and only in one clade at that); but limbs and joints are probably 'universal', found in nearly all biologies.

On this basis, then, what is the evidence about alien life forms? Are we alone, or is our biology but a tiny fraction of the variety of extensive xenobiologies? Some unique, and some multiple, important events during the evolution of life on *this* planet are listed in table 1, with brief reference to the evidence (on the assumption that most readers have some knowledge of the areas concerned). From this evidence I believe we can argue likelihoods of alien life, and to some extent also say what they will and won't look like. In the POLOOP lectures this was a very useful educational trick to take audiences, usually of sixth-formers but many 'lay' audiences too, through a set of 'shape, form and function' arguments. I do believe, however, that the positive and negative forms of the stochastic argument enable modern professional biologists, also, to assess the credibility of alien – and indeed terrestrial – life forms.

A useful way to make likelihoods public is to set up a credible number of Earth-like planets, then express likelihoods as the proportion which might have a particular evolutionary step. If we are certain that many terrestrial groups have independently invented an evolutionary trick, like flight or parasitism, then 100 per cent of similar biologies will do this too; if the trick is unique in Earthly biology, it probably won't be found elsewhere with the same details, like hands or feathers. We should make some assumptions about main-sequence stars, about just what should count as Earth-like, about the number and kinds of planets stars might be expected to have; then most people who have done this suggest that there could well be as few as 100 000 000 in our Milky Way galaxy (Asimov, 1984), about 1 per 10 000 stars. How many of these have *started* the story of life? If the chemical events which result in replicating RNA, then DNA molecules interacting with a protein matrix, are 'easy' (say, more than one instance per 100 million years on the whole planet's surface) then nearly all may have done so. If a scenario like Cairns-Smith's has general application, then ubiquitous 'primitive' mineral replicators will evolve protean carbon-chemistry tricks to improve competition – and their genetic systems will usually be 'taken over' by their more effective, sophisticated progeny (These may also, of course, be taken over in their turn – much later, soon after the origins of technical intelligence, by their own silicon-based computer inventions; so carbon-based life may only be an interlude in planetary history . . .)

Table 1 Unique or multiple occurrences during the evolution of life on Earth

Event(s)	Unique/ Stochastic	No. of instances	Organisms	No. of planets
Origins of amino acids	unique	one, extended	none arisen yet	10^8
Origins of nucleotides, etc.	unique	probably several, but evidence only of one	none arisen yet	10^8
Clay mineral replications	each unique	many and various	?primitive	10^8
Origin of DNA (or RNA?)	unique	probably several, but evidence only of one	?	10^7
Origin of prokaryotes ('cells')	unique??	probably several, but evidence only of one	archaeo-bacterial progenitors	10^6
Photosynthesis	multiple	at least three	cyanobacteria, plants, violet bacteria, etc.	10^6
'Evolutionary symbiosis' of prokaryotes	multiple	at least three	eukaryotes, actinomycetes, some protists like *Chaos* and *Giardia*	10^6
Life on land	multiple	twenty plus	land plants, molluscs, insects, vertebrates, etc.	10^6
Flight	multiple	ten plus	four fishes (+?) pterodactyls, birds, bats, etc.	10^6
Increase of intelligence	multiple	three plus	cephalopods, *Carnivora*, e.g. dogs, *Cetacea*, e.g. dolphins, primates	10^6
Bone	unique	once	gnathostomes	1
Pentadactyl limb structure	unique	once	land vertebrates	1
Crossing of food/airway	unique	once	land vertebrates	1
Conflation of excretory and reproductive systems	several	four plus?	land vertebrates, some crustacea and arachnids, elasmobranchs (but not teleosts or land gastropods)	?

However, internal evidence about these remote events is always suspect – we simply don't know what we don't know about these systems. Disagreements about our early terrestrial atmosphere suggest that our knowledge of appropriate chemistry/mineralogy/catalysis is still inadequate to provide likelihoods about which prebiotic molecules were available here. Perhaps especially we don't know what chemistry or physics may *prevent* biogenesis. So let us make the pessimistic assumption that 9 out of 10 of our planets never gets the life-start, and that 9 out of 10 of those which do never subsequently progress to a competing-prokaryote stage (with a mass of internalized chemistry, genetically constrained). Then we've still got a million 'local' planets, biologically like our own planet for the first three-quarters of its history. Certainly there will, on each of them, be a variety of chemo-synthetic systems (most probably involving iron and sulphur, as do so many of our ancient bacterial life-lines); there will also be several photosynthetic systems, of which the most effective will split water and release oxygen as a waste product. New rules will apply in the new, highly polluted atmosphere, and most organisms will die out. Others, as on Earth, will seek safety in symbiosis and a variety of 'eukaryotes' will appear, with exo-mitochondria that can deal with the pollutant oxygen to everyone's advantage. Multicellularity will appear many times in plants, saprobionts, and animals, as will colonies, invasion of the land by plants and animals – flying forms will appear, of course, on *all* of these million planets (table 1). (As on this planet, life itself may well have originated several times as a series of 'bioclades', of which one eventually won out, surviving to result in today's life on Earth – but by the rules of my arguments we must treat this as unique; only the multiple originations provide arguments for elsewhere.)

What about intelligence? The same arguments apply. Several terrestrial animal groups have adopted this trick: octopi and squids are much more intelligent than their common ancestor with clams and snails; dolphins are much brighter than the terrestrial pre-cetacean; primates have done creditably too. So, *on this evidence*, we have about a million planets which have produced, or will produce, life and intelligence even in our own local Milky Way galaxy. I haven't room here for the arguments about why we haven't seen them, heard them, been visited – or about whether we have (I personally incline to the Douglas Adams (1979) view, that we wouldn't see advanced intelligent life forms if they didn't want us to). In my lecture I asserted that only carnivores became intelligent ('You don't need much intelligence to creep up on a blade of grass . . .') and I emphasized the short-term competitive nature of our kind of carnivore. Perhaps, I suggested, intelligence does necessarily arise, but then naturally sterilizes the surface of the planet again, as we're about to do. Bolton suggested this, in the early sixties, as an excuse for the failure of SETI (radio-telescopic Search for Extra-Terrestrial Intelligence); many planets *achieved* intelligence, but few if any survived it! This 'Take care of your biology, it's all you've got' message got across to many of those POLOOP audiences, long before Green was so generally fashionable. I have since become more optimistic (Cohen, 1989); I really do believe that our descendants (carbon or silicon-based) . . .) will meet progeny of other biologies.

So what are these million kinds of intelligent life like? They're not like Waddington, for a start. The chances of the really peculiar, once-only adaptations like bone, or like pentadactyl limbs, happening anywhere else seem to me in

The probability of extraterrestrial intelligence

Jonathan Cowie

Contemporary advocates as to the likelihood of alien intelligence include those whose business it is to study the cosmos such as Drake (1960) and Morrison (1974). Other astronomers and physicists, such as Barrow and Tippler (1986), believe that perhaps there is only one biological intelligence capable of a technological civilisation per galaxy, if not the universe. Everyone, though, agrees that the existence of Man as a technological intelligence on Earth proves that the natural evolution of such sentience is at least possible – the question is, how does one attempt to quantify this as a probability?

The most common method used is to attempt to value the component parts of such a probability by employing what is known as the Drake equation:

$$N = R_o f_p n_e f_l f_i f_c L$$

N is the number of intelligences capable of interstellar communication. R_o is the mean rate of star formation per year in the galaxy – this is reasonably well established to be about 10. f_p, conservatively 0.1, is the fraction of stars in the galaxy with planetary systems – for which we can get a lower limit by, for example, seeing if stars near us dim due to an eclipsing planet. n_e is the estimate of the number of planets per system capable of supporting life, and f_l the fraction on which it is thought to appear. f_i is the estimated fraction where intelligence evolves, f_c where the intelligence leads to an interstellar communicating technology, and L the lifetime of that technology.

Estimates vary. One of the most common reasons for this has been the estimate for the lifetime of such a technological civilisation (L): some believe that intelligence destroys itself through war and other negative Malthusian checks. However, if L is large, say hundreds of millions of years, then there could be as many as hundreds of thousands of civilisations in our galaxy today with the capability of radio astronomy (though they may not use that particular technology itself). This may seem a large figure but it is simply a reflection of the large number of stars (10^{11}) in the galaxy and represents a probability of about one in a million that a star system supports intelligence. If this were so, and if intelligent life was evenly distributed through our galaxy, then our nearest technological neighbour would be within a paltry 1000 light years. The question that then arises, one first attributed to Enrico Fermi at a Los Alamos dinner party, is if they are there, then where are they (Hart and Zuckerman, 1982) and why have we not detected them?

The probability of life appearing in a given star system is thought to be extremely small. However, multiplying this by vast numbers of stars in a galaxy could give us a figure greater than 1: if this is the case, then we are not alone. Our galaxy is a spiral galaxy, similar in structure to the one pictured here.

Assuming our alien intelligence has a similar technology to ourselves, then their most powerful transmitter would be a twin of the 1000 ft antenna, used as a planetary radar, at Arecibo, Puerto Rico. It could detect a similar device at a distance of 30 light years, or 300 light years if targetted (Regis, 1985). So even if there were hundreds of alien technologies in our galaxy communicating in the same way as ourselves, we may well be blind to them, and they to us.■

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the highest degree unlikely. They are the opposite of flight, photosynthesis, fur, or copulation; they *won't* happen elsewhere. They wouldn't even happen here again, would they? The peculiar constraints with which *Eusthenopteron* saddled its terrestrial descendants, and which are so characteristic of people, won't be found in the same combination again. Other real oddities will occur (see the bar scene in Star Wars 1), but no alien intelligent organisms will be saddled with our combination of evolutionary oddities. It won't cross its airway through its foodway, use a skeletal girder designed for horizontal pendant weight as a column in compression, *and* mix up its genital and excretory hardware – and therefore cultural software. (Was it Spencer who commented that 'Any Architect who put the playground between the sewers would certainly be sacked!'?) These *Eusthenopteron*-rooted oddities made Waddington, and you and me, the peculiar creatures that we are. Aliens will have other foibles, other evolutionary millstones, but not that combination.

Parallel evolution certainly does occur, at least on different continents of the same planet, but kangaroos are *not* litopterns or deer or antelopes, though the similarities are impressive. However, nearly every literary or cinematic portrayal of an alien life form is unsatisfactory biologically, because there are too many parallels in the trivia like knees and elbows, and not enough in the general biological rules. This is especially true in the older pulp literature, though much modern s-f has got it biologically 'right'. But Spielberg's ET, even, is too much like us; I have the strongest feeling that these cinema images are seeking our brain-circuits for our care for 3-year-old children, as Gould (1980) showed was the case with Mickey Mouse, rather than making intelligent guesses about real aliens (Ewoks are obviously Teddy Bears). Although I am now consulted professionally on the design of aliens in science-fiction stories, the only two I've really put my name to are alternate-Earth-evolved (Harrison, 1984) or are constructs (McCaffrey, 1988), designed for a human purpose. My imagination is not ample enough to design a really *likely* alien – but I wouldn't want this modesty to put off film companies from seeking my services!■

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