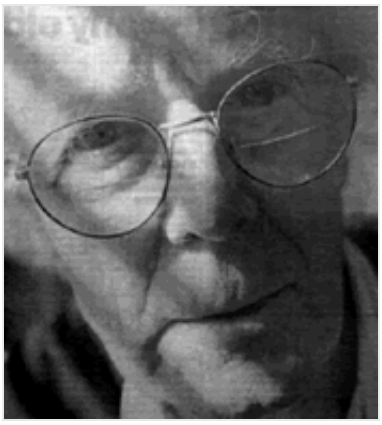
In conversation with John Maynard Smith FRS



John Maynard Smith FRS is one of the most respected evolutionary biologists this century. He is perhaps best known for his application of game theory to biology -- presented in his 1982 book Evolution and the Theory of Games -- which introduced such notions as the 'evolutionarily stable strategy', and paved the way for a more rigourous scientific analysis of interactions among living things. *the evolutionist* talked to him about his new book, *The Origins of Life: From the birth of life to the origin of language*, discussing such perrenial questions as: What is life? What was the first sexual act? and Did the egg really come before the chicken?

the evolutionist: Your new book, *The Origins of Life: From the birth of life to the origin of language*, is a condensed version of your earlier book, *The Major Transitions in Evolution*. What are you attempting to do with this new version?

John Maynard Smith: We are attempting to make the ideas in *Transitions* available to a general readership. *Transitions* would be hard work for someone without a degree in biology. You still have to do a little work for this new book, but you don't need to know any biology to begin with.

the evolutionist: *Origins* discusses seven 'transitions' in the development of life. What is a transition?

JMS: The basic idea was that, in a curious way, a lot of modern biology, most of the biology this century in my view, has really been about information. Genetics is about how information is stored and transmitted between generations. Developmental biology and molecular biology look at how that information is used to build an organism. And evolutionary theory is about how that information got there in the first place. Biologists have done their science surrounded by tape recorders and gramophones and television sets and telegrams and so on, and notions of information have been dominant in the way we've thought about biology. What my friend Eörs Szathmáry and I decided, almost ten years ago now, was that there had been a number of really rather dramatic changes in the way in which information was either stored or transmitted or translated, and each of these transitions made possible further future evolution of complexity. We also thought that there were real analogies between the different transitions and between what happened in the transitions. We wanted to present them all in one book so people could see the parallels between, say, language and the origins of the genetic code.

the evolutionist: Do these analogies arise because of the similar requirements of storing information, whatever the medium?

JMS: Yes. Information imposes certain criteria on how it can be stored.

the evolutionist: So this is not just a scheme that you're imposing on the world; you're carving nature at the joints?

JMS: I really do think we are. An historian might think of events like the origins of agriculture, the origin of writing, the industrial revolution, events of this kind, as having marked a major change in the organisation of human society. We think there are comparable major changes in the history of life.

the evolutionist: What's particularly fascinating about the book was that it provides all the little steps between these transitions, and show how they could have come about.

JMS: There's a lot that happens in evolution for one reason, and it turns out, rather accidentally, just the job for something else. It's constantly happening, something that evolves with one function turns out to be starting point for some completely new revolution.

the evolutionist: Well let's start at the beginning. What is life?

JMS: I think that life has two characteristics. Imagine you get out of a spaceship on the surface of Mars and something walks up towards you on legs. On the front of it there are two disc-like objects, two antennae and a large hole with sharp serrations around the edge of it and so on. I think you'd guess that either this thing is alive or that it was made by something intelligent and alive. Let's forget about the artifact possibility. Living things have parts which are clearly functional; they are there *for* something. In fact they are there for the survival and reproduction of the object they're part of. So one aspect of life is that it's not only complicated, but it's complicated in an adaptive way. Hands and kidneys and livers and noses and eyes and ears and so on -- everything's adapted for something. That's the first feature of life.

The other way you can define it is to say that life is any population of entities which have the properties necessary to evolve this complexity. And those qualities are: they must reproduce; they must vary; and they must have heredity, that is to say like must beget like. If they have those properties then the rest follows. They will evolve complex adaptations.

Very early life was just the replication of molecules that could copy their structure, but didn't code for anything. The idea is that the first life -- what is called RNA world -- was just RNA molecules. The same molecule was the replicator, the thing that got copied, and the thing that did something, i.e. was an enzyme. So there was no division of labour between genes on the one hand and proteins on the other, as there is today. A modern gene codes *for* something. But think I recognize it as life before genes coded for anything. I think I would recognize life when you have complex replicators, whether they're coding for anything or not. Coding comes later.

the evolutionist: Are you happy that biology has got rid of any notion of an "essence", the idea that

life is some magic spark?

JMS: I think it was Laplace who remarked, "I have no need of that hypothesis". He said it to Napoleon I think.

the evolutionist: Another transition people might be interested in is the origin of sex. What was the first sexual act?

JMS: There's a broad and a narrow definition of sex. The broad definition would be any process that results in an organism receiving genetic material, genes if you like, from two different ancestors. That probably goes way back into the past; it is present in bacteria. I nowadays spend my life looking at the evidence of bacteria exchanging genes. That's a kind of sexual process. But most people, when they think of sex, think of it as how we do it. In ourselves -- and all higher organisms -- the new individual starts with the fusion of two gametes, two cells, which contribute more or less equal amounts of information to the individual. And basically when one talks about the evolution of sex it's that fusion of two totally different cells that we think of.

If you have cells swimming around with just a single set of chromosomes, fusing has real advantages because you cover up the deficiencies that may have arisen in one or other copy. It's what I call the 'engine and gearbox' theory of the origins of sex. If you buy two clapped-out Minis, one with no engine and the other with no gearbox, you can make one functional Mini. I have the feeling that sex originated on that principle, two cells, both with deficiencies, fused and they cover up the deficiencies.

But that's not the really complicated part of sex, funnily enough -- you can imagine fairly easily how two cells might fuse. The really complicated part of it is the process whereby an individual with two complete sets of genes produces gametes which have only one of those sets, but neatly shuffled between the two parents -- a process called meiosis. It is a very complex process. Anyone who has learnt A-level biology will recall that it is terribly difficult to remember how meiosis works. It is, I think, inconceivable that all the details would have originated twice, and yet you find them just the same in a plant, in an animal, in a fungus.

the evolutionist: Are the broad and narrow processes connected? Is one antecedent of the other?

JMS: The bacterial method is obviously much older. Many of the enzymes needed for doing it, for cutting and splicing DNA and sticking it together, which you need for both processes are already present in the bacteria; they evolved in the bacteria. But sex as we know it is unique, I think it's one of those unique transitions we talk of, it happened just once. The origins of sex in animals and plants and fungi and so on is common, it goes back to the common ancestor of all those things.

the evolutionist: So cells with a single chromosome (haploid) get together to repair eachother and

then go back to being haploid again. Are organisms just an extension of this bit in the middle, when haploids get together to compare notes?

JMS: Well they're not only that. If you think of a human being, most of the living is done with two chromosomes (diploid), and what was once just a process of getting together on a temporary basis has now come more or less the permanent mode of existence. Some organisms never go back to a single copy -- there are plenty of parthenogens out there which are diploid and female and produce female offspring like themselves and never bother with males. But that's a much later evolution.

the evolutionist: So the chicken *is* just the egg's way of making more eggs... that's not just a joke?

JMS: No, it's true. It captures an important point.

the evolutionist: When these cells go their separate ways again, are we talking about gametes? Sperm and eggs?

JMS: They are doing essentially the same thing. The first sexual organisms there would have been no males and females, the two cells that fused would have been the same size. There are plenty of organisms today that don't have a differentiation between male and female, they just have gametes. They won't fuse with other cells genetically identical to themselves, they have so-called mating types, and you only fuse with the other mating type, but you couldn't tell looking at them which was male and which was female. The origin of femaleness, which means making a large gamete with lots of food reserves in it, or maleness, which means making a small gamete that moves, is a later event. And sexual differentiation has almost certainly evolved many times.

Essentially it's a matter of "division of labour". Division of labour is often an efficient way of doing things, and it turns out to be efficient to use one sex for storing food reserves and the other for doing the motility and making sure that fusion happens. And once that happens the whole process runs away and you get all sorts of ridiculous accessories like peacocks' tails and beards.

the evolutionist: How necessary is sex for the notion of a species? Because presumably before sex, the idea of a population with whom it is possible to breed with loses any meaning.

JMS: That's a much harder question than you think actually. Because it's certainly true that sex does impose speciation on you because there must be a class of individuals which will breed with one another, and then another group of individuals which will breed with one another, but no hybridisation between the two. Otherwise you can't have populations adapting to specific environments -- everything would be half elephant and half camel, and that would be no good at all. So sex certainly imposes speciation upon populations.

It's a much harder question as to whether something like speciation would exist, let us say, in bacteria. Indeed, there are two very closely related bacteria, which I'm interested in -- one causes meningitis and

the other one causes gonorrhea -- and yet if you look at their genetic structure they're very similar and they do exchange genes. They pass genes across, quite a lot. Resistance to antibiotics goes from one to the other. It would be better if it didn't. There you've got kinds of bug defined not so much by the fact that they will only exchange genes within species but kinds of bugs defined by their ecology, what they do. One of them is good at living in the urino-genital tract and the other one is good at living in your throat, and occasionally makes a mistake and gets into your cerebrospinal fluid which does you -- and it -- no good. So you can have kinds of organisms without sex, just adapted to particular ways of life.

the evolutionist: But is it still meaningful to call them a species?

JMS: Ah, that's a much debated issue.

The evolution of sex is the hardest problem in evolutionary biology. When it happened, how it happened, why they did it in the way they did. There are still features of the way they do it that seem very odd to me. The trouble is that we have two basic hypotheses about the evolutionary significance of sex. One is the coping with bad mutation, that sex helps you to eliminate bad mutation, the other is a more positive view of combining good mutations, such as resistance to parasites. Supposing the environment is changing and you need two adaptations to adapt to that but they occur in different individuals. A population with sex can bring them together, but a population without can't. Both these theories are plausible, what we don't know is their relative importance. That's very hard to decide. I'd like to see data on that.

the evolutionist: Another much debated issue has to do with levels of selection. The section of the book dealing with genetic conflict provides several insightful illustrations of what the debate is about, and also what the answer is. What are your favourite examples?

JMS: There are two examples I like, one of which because it is so simple, and another because it is so intimate and personal about human beings. The simple one is the frequent occurrence of male sterility in plants. Plants normally have both male (pollen-producing) organs and female (seed- or ovule-producing) organs. But they can be rendered "male-sterile" and produce no pollen. And that seems crazy because it is not good for the plant. It turns out that it is caused by genes in the mitochondria that are only going to be transmitted in the seeds and not in the pollen. So as far as the mitochondria is concerned, pollen is a waste of time. So there's a conflict between the other genes in the plant, which want to produce pollen because they'll get into it, and the genes in the mitochondrion that don't. Here is a simple case where different genes have different interests because they have different transmission machinery.

The other example I would want to give is David Haig's work on conflict between mother and feotus. This can have disastrous consequences. Eclampsia -- a very dangerous, potentially fatal, problem

related to blood pressure that afflicts pregnant women -- is a consequence of conflicts between genes in the feotus and genes in the mother over the provision of nutrients in the blood supply. That work is beautiful, intellectually beautiful. And it would worry people and interest them because it is actually important in their lives.

the evolutionist: Moving on to social organisation, you refer in the book to analogies that Aristotle made between human society and the hives of social insects. Did he get his biology right?

JMS: Well I think there are real analogies between human societies and a hive, but there is a crucial difference. The division of labour in humans, which is very striking, is based on extensive learning; you learn to be a biologists or a bus driver or whatever, your skills are culturally acquired, they depend on language. You couldn't have human society without language. A learnt language. A bee society has communication, which is quite sophisticated, but it isn't true that there is an extensive division of labour in a bee community based on different individuals learning to do different things.

the evolutionist: So do you think the difference between animal and human society as a difference in kind?

JMS: Well I think it fits in very nicely to our picture of major transitions. The crucial step in the origin of human society is the origin of language. And that is a new way of transmitting information between generations, and of acquiring and storing information. We no longer have to store all the information in our genes. We store a lot of it in books and libraries and myths and stories and we communicate it by word of mouth and by writing and animals don't do that and that's the crucial difference.

the evolutionist: "Social contracts" also play a large part in your account of human society...

JMS: Societies depend on agreed rules. They may be codified in law or they may just be culturally accepted rules of behaviour, but if we had no rules of behaviour there'd be no society. The question is how can such rules originate and what keeps them more or less stable. They obviously change in time, but nevertheless societies are reasonably stable they don't break-up all the time. And I think we came to the conclusion that in order to make a social contract -- or any type of agreement whatsoever -- that works in society, you need language. Suppose you want to come to some agreement that smoking is not going to be allowed in this laboratory; if you don't have words for smoking there's no way you could make any agreement at all.

The other thing you need to make a contract, to talk to eachother, you have to know that the person you're talking to is a being like yourself. A 'theory of mind' is crucial. You have to ascribe to that person feelings and ideas and knowledge similar to your own, otherwise there's no way you can exchange ideas at all. And by and large animals don't do that. I don't say no animals do that, the apes are beginning to, but it is not widespread in the animal kingdom. That and language are the absolutely minimal

requirements for coming to some kind of agreement.

the evolutionist: So you don't think any species other than humans practice reciprocity?

JMS: Oh no there can be reciprocity, but it is genetically determined reciprocity. You get reciprocity between symbiots in a lichen, or between root fungus and a plant, they help one another; the fungi help the plant to fix nitrogen gets something out of the plant and the plant gets something out of them, so it's certainly reciprocation. But nobody is thinking and their behaviour is genetically determined. The point about human beings is that they can come to a reciprocal agreement which is helpful to both parties about something that is not genetically determined, but is something to do with a new cultural invention, like smoking, or driving on the left hand side of the road. These are not genetically laid on, they are conventional agreements.

the evolutionist: And is the bridge between these two that we have genetically specified psychologies that are capable of entertaining these kinds of ideas?

JMS: That's right. I mean we have to have the genotype that makes it possible for us to talk and to have a theory of mind and to foresee the future and so on. If we didn't have that as a genetically laid-on capacity we couldn't do all the other things.

the evolutionist: And that would include things like the evolution of a sense of fairness, moral outrage, the emotions that police social contracts?

JMS: Such things have to be genetically potentiated. It is genetic that you can feel angry, but it is not genetic that you should feel angry with a particular thing.

the evolutionist: And it's the explosion in the number of things we can get angry about that's made the difference?

JMS: That's right.

the evolutionist: If you wanted to bring Aristotle up to date on biology, what would be your reading list for him?

JMS: Well I think top of almost any reading list for someone back then would have to be *The Origin of Species*. He might get something out of Chomsky you know, linguistics, I think he'd find that interesting. I don't know what I'd give him political to read, because most of it is such rubbish. A lot of social science doesn't seem to me to be terribly helpful.

the evolutionist: *Origins* presents an intriguing analogy between language and chemistry. Could you explain this?

JMS: That's an idea that I understand Chomsky and some of the linguists are now playing with, it's not our idea. But the notion is that there are rules according to which chemical compounds are formed; rules concerned with the valence of the individual atoms and other properties that they have which determine that some compounds can be formed and others can't. There are certain kinds of things that you couldn't put together. And there are clearly rules about how you put sentences together. To give you an example, there are some verbs, like "sleep", that have a subject but no object. You can say "Joe is sleeping", but you can't say "Joe is sleeping Mary", it wouldn't make sense. There are other words like "hit" which have a subject and an object. You can say "Mary hit John", but it wouldn't make much sense to say "Mary hit". So the words have valences, which you have to learn, but they do have rules of composition. And I understand that Chomsky and his colleagues are working on the possibility of constructing the rules of grammar, which make some sentences grammatical and others not, in a way analogous to the rules of chemistry. I think it's an attractive idea.

the evolutionist: This gives you a fascinating insight into how the Universal Grammar is actually wired up, neurologically... How this combinatorial system could have evolved bridge by bridge...

JMS: I think one of the tragedies at the moment is that almost nobody is trained both in genetics and in linguistics. To make real progress with the evolution of language, rather than just talking about it, which is neither here nor there, you have to have either real cooperation between groups of people who have these skills and can put them together, or better still some people who actually have both skills to some extent. And that is simply not happening. Partly it's the fault of our whole educational system. Genetics is a branch of science, and linguistics is a branch of the humanities, and never the twain shall meet... and all this nonsense. You've got to bring them together. To make progress in the evolution and development of language we're going to have to put language and genetics together. We need to do some real nuts and bolts genetics, find some genes, find out what they do. And it's perfectly do-able now without interfering with anybody's freedom. If I was a young man, 18 and not 80, I'd be awfully tempted to get myself a training in both those disciplines, in linguistics and genetics. Steve Pinker is an expertly trained linguist and is very aware of Darwinism, but he'd be the first to admit he's not a trained geneticist.

the evolutionist: How did different languages emerge?

JMS: I take it that if groups of humans have rather little social contact, or no social contact, it's a very striking fact that language does change, surprisingly rapidly. In matters of hundreds of years people can come to use different words for things and different grammatical constructions. I find that, even with the mass of television and radio and people travelling around the world, when I go to the United States I will find phrases that I don't understand. An I expect they find the same when they come here, which indicates just how quickly things can change. But if there was no television, no radio, no communication -- if the founding fathers had been isolated from Europe -- I suspect that when we met an American, we wouldn't understand what they were saying. Language changes very fast.

the evolutionist: And what's the mechanism of that change? You mention having the possibility of having new words...

JMS: Clearly you have to invent new words for new machines, but I think there's something else, somebody thinks of a neat phrase and when they first use it other people may not quite understand what they mean. But if the person who invents it is, say, socially influential, other people will try to pick up on what she means by it. "Full of shit" or whatever. Individual creativity produces a lot of the changes in language.

the evolutionist: I wondered if any of the impetus of languages changing were for purposes of deception, or limiting the amount of information. If you look at the origin of some modern languages, cockney rhyming slang, ciphers, they are designed to conceal information from certain others.

JMS: Could be, that's an idea I haven't thought about -- we didn't want the chaps over the hedge to know what we're saying to one another. It is sometimes suspected that professional scientists invent a lot of jargon so that non-scientists can't understand what they're saying to one-another. I don't actually think that's a fair accusation. I think we invent jargon because it saves times talking to one-another. And we forget that we know the meaning of the word because we've used it among ourselves that in fact it does make us incomprehensible to outsiders. But I don't think it has developed *in order* to do that, in that context. But I can imagine contexts in which it might do. We're discovering new things and we need new words for it. What else do I say other than meiosis? To a non-scientist it would take a lot of time explaining. I do think jargon is excusable, but I do think we have to learn to talk to people without using it, and it's not easy. That's partly why we wrote *Origins,* a book about biology that doesn't assume that people know biological, technical terms.

the evolutionist: Thank you.

the evolutionist

(The interview was conducted in John Maynard Smith's office at Sussex University, February 2, 1999.)