micropterous females and its consequence for the survival of the foundresses certainly implies cooperative brood care and there is some level of reproductive caste differentiation or at least subfertility on the part of the micropterous adults. Notice however that, unlike in the Hymenoptera, the soldiers (workers) can be of either sex.

As Crespi[11] remarks "Australian gall thrips provide remarkable new opportunities for analysing the causes of the evolution of eusociality". A particularly fascinating aspect of Crespi's discovery of eusociality in yet another order of insect is that Thysanoptera are also haplodiploid. The evolution of eusociality in diploid aphids, naked mole-rats and termites is thought to be linked to their living and feeding inside a "highly valuable, persistent habitat that they have created" and which is "defensible primarily by individuals specialized with weaponry and behaviour for heroic acts[11,14]". On the other hand eusociality in the Hymenoptera is usually thought to be linked to the genetic asymmetries created by haplodiploidy and the ability of mothers to produce female-biased sex-ratios due to parthenogenesis[2,15-19]. The gall thrips have both sets of conditions. Nevertheless, unless future research proves otherwise, eusociality in gall thrips, like in the Hymenoptera, Aphids and naked mole-rats, appears to be restricted to a just a few species while the vast majority of related species apparently endowed with the same set of adaptations have failed to evolve eusociality. The plot thickens!

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COMMENTARY

An encounter with genes

G. Baskaran

This summer, while glancing through one of the latest issues of *Physical Review Letters*, an article[1] entitled 'Evolution of long-range fractal correlations and $1/f$ noise in DNA base sequence' caught my attention. Even to a theoretical physicist like me with minimal experience in molecular biology of genes, the long range fractal correlation looked strange and consequential. I took a mental note of this and decided to study this paper further at some future time. About a month later, a write-up by John Maddox[2] in the News and Views column of *Nature*, about the same and related articles confirmed my feeling of the importance of this finding. The notion of scale invariance or power law fractal correlation has a particular appeal to theoretical physicists, who have developed some insights and intuition about them in examples like critical point phenomena, conformal field theory, self-organized criticality, $1/f$ noise and so on. I am writing this short comment to briefly explain the observation of fractal correlation in DNA as well as the captivating and hypnotizing influence that molecular biology of genes is having on me in the last one month or so, while I am having an aerial view[3] of the subject with occasional detailed study. Even this short encounter leaves me awestruck at the amazingly rich variety of complex phenomena, each one being an invitation (or a trap!) to the world of genes. When one realizes that physicists like Schrödinger, Gamow, Crick and others have contributed in a fundamental way to the molecular biology of genes, one feels like peeping into the gene forest, of course, with all humility, and caution.

DNAs are long molecules with the four nucleic acids adenine, thymine, guanine and cytosine, abbreviated respectively as A, T, G and C, forming a one-dimensional sequence. The length of this sequence is as large as 10^{11} for certain flowering plants and of the order of 10^9 for mammals. The information content of this one-dimensional sequence is very basic to any living organism. Different regions of the DNA code for different proteins. This is where the central dogma of molecular biology operates. (Proteins are in turn involved in the myriads of operations doing enzyme catalytic action, providing channels for ion conduction across the cell membrane, repairing mutations, etc.) To me it was news that a major fraction of the one-dimensional sequence of a given DNA does not code for any protein. These regions are called introns (intervening sequences). For example, in some eukaryotes (cells of organisms such as plants and mammals) 95 per cent of the nucleotide sequences are introns. In this one-dimensional sea of introns, coding regions known as exons occur sparsely. They have varying lengths. Various contiguous sequences of exons code for various proteins.

From the articles[1] it is clear that Li was one of the first to suspect the presence of long range fractal correlation in nucleotide sequence in DNA, even though the work by Li and Kaneko does not prove this in a convincing way. The Boston group and later Voss from IBM, Yorktown Heights have done very detailed statistical analysis by taking enormous data from the GenBank (this Bank compiles all the known DNA sequences in a scientific and accessible fashion using computers). The correlation function can be defined in several ways. One way which is adopted by Voss is the following. Imagine a function $F_A(i)$ which takes the value of 1 if the site i contains the amino acid adenine, for example, and zero otherwise. Then define the following averaged quantity $\langle F_A(i) F_A(j) \rangle$. Here, the average is performed along the entire DNA sequence by keeping the distance i–j constant. Further averaging over several DNAs among the same species has also been performed. We say that there is scale invariance if the above average exhibits power law behaviour such as $\approx const + A/|i-j|^{\alpha}$ for large separation of i and j. Fourier transformation of the above function with respect to the variable i–j will give the spectral function. The remarkable finding is that the exponent α changes only from species to species! The above power law behaviour has been verified over 5 orders in the variable (i–j) in the numerical studies.

It is clear from the above works that the power law correlation arises primarily from the intron sequences. A quick look into some of the recent books on genes[3] reveals that the statistical properties of introns are different from those of exons. There are repetitive patterns in the introns of varying lengths. If this repetitive pattern occurs with arbitrary sizes, it will naturally induce power law correlation. It was gratifying to see that this is what Li and Kaneko have suspected and they have also suggested some other possibilities. Intriguing similarity to fractal correlation occuring in music and the self-organized criticality problem have been pointed out by the authors.

The symptom, namely the fractal correlation, perhaps is not that important. The causes seem to be very important having a bearing on the process of mutation, gene multiplication, evolution, etc. In my opinion the occurrence of long range fractal correlation in DNA is a kind and inviting smile from nature to theoretical physicists. It is a small window to the field of molecular biology of the genes. Nature seems to have innumerable challenges to offer and secrets to reveal. In any fertile field of science this is what happens. You start thinking about a particular phenomenon that attracts you at that moment. And once you are inside, it is a new and rich world. The processes that occur involving genes, starting from the chemistry and physics of replication involving the DNA polymerase, mRNA formation, the splicing of introns in mRNA, the way the ribosomes produce proteins from the mRNA blueprint with the help of tRNAs, etc., are all short of miracles. Perhaps it is true and certain, as has been emphasized by molecular biologists, that there are no phenomena which cannot be explained by the fundamental laws of physics and chemistry that we are familiar with. But the fact is they are all awaiting explanation.

Biologists have been doing the commendable job of finding out what exactly happens by their evolving sophisticated experiments, and occasionally postulating this is how it should happen. Why and how do they happen? From the basic laws of physics, equilibrium and non-equilibrium statistical mechanics, new and just emerging paradigms of science of complexity such as the spin glass ideas, self-organized criticality idea, etc., how do we attempt to explain these phenomena? There are quantum phenomena, electron transfers, semi-quantum phenomena and phenomena at every length and time scales.

Not just mathematical modelling, but new notions, insights and concepts are perhaps necessary. Mathematics will follow once our understanding is clear and, of course, it will take us far, make things quantitative and give us more physical insights and so on. There are both old and new physics at every stage —the packing of DNA with nucleosomes in the chromotids, the ever-winding 'random walk' like pattern of DNA when it is freed from the protein scaffold around the cell division times, the collective and coherent way in which one ribosome follows another (like robots) along the mRNA to produce proteins, even while the mRNAs are being produced from the DNA templates. Look at the problem of *regulation of gene expression* (gene expression refers to the process by which information encoded in DNA is read out into RNA and protein products). Every cell produces only certain types of proteins, depending on whether it is a blood cell or the cell in the bone tissue and also depending on the need, environment and time. The regulation of gene expression seems to be a sophisticated regulatory network involving hierarchies and cascades. It is this which directs the development of zygote (the cell that results from the union of sperm and egg) along an orderly path in space and time creating an end product such as a butterfly or a blue whale! There is physics and complexity in abundance. When I look at an atom it is not alive. A molecule like benzene is not alive. But what is going on in and around DNAs seems to be completely alive with robot-like orderly regulated motion! The length scale has changed from about 5 angstrom to the order of hundred of angstrom units from benzene to an RNA or a ribosome. This is not a big change. However, the time scale has changed by several orders of magnitude. From atomic or molecular time scales of the order of 10^{-12}, 10^{-11} sec we have gone to 10^{2} sec (the time taken to produce one protein is of the order of minutes). Given enough time *and environment, nature performs miracles!* If only we could comprehend the science behind these complex and beautifully regulated processes...

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We publish below a commentary which is 'written in some anger'—a rejoinder to an earlier article which summarized the feelings of a number of young mathematicians as to how to improve mathematics education. The present article is associated with many mathematicians who have given much thought to improving teaching methods of mathematics in schools and colleges. The message is that, like in most fields, mathematicians too are divided; (The readers will be familiar with the controversy we are having between classical and modern biology); It is not desirable to characterize different aspects of mathematics—however much each devotee is partial to his own; What is really important is to nurture the 'natural flair' in a young student whenever and wherever it is found.

—Editor

Mathematics education—some remedies

M. S. Rangachari

The commentary 'Can we do something about our mathematics education?' by V. S. Sunder (*Curr. Sci.*, 1992, 62, 658–659) overlooks the real cause for the sad state of mathematics education and advocates remedies based on vested interest. The signatories to the present commentary who are perhaps to be described as 'senior' mathematicians according to Sunder's commentary and who are perhaps not mathematicians of 'non-trivial' standing from such institutions as listed by Sunder, have, however, been involved in programmes relating to school mathematics, college mathematics and 'research' mathematics in the past four decades and have been invested, by the grace of Providence, with a concern for the students who take to study of mathematics besides mathematics itself.

The main points overlooked by Sunder's commentary are:

(i) Most of the Indian children have a great potential for mathematical thinking right at the start of schooling and even outside the school system irrespective of caste, creed, religion and region.

(ii) Mathematics is made difficult and uninteresting to children even at the primary level since it is mostly taught by a teacher with no aptitude for mathematical thinking, along with other subjects, much less with no capacity to make mathematics interesting.

(iii) Only one in thousand or even less master the techniques of mathematics taught at school (mostly computational) and equip themselves with a refinement of the skill of computation at the school-end level to face competitive examinations, where performance in mathematics matters very much, so as to get into professions which could provide them better career than that of a mathematician. The rest take to mathematics as a bugbear and are proud of declaring later in life after getting into positions that they treated the subject so.

(iv) Those who are destined to graduate or post-graduate in mathematics, take to these ventures left with no other better option and that too within a system of lecturing-learning for which no concern is shown by the lecturer, the syllabus or curriculum framer and the authorities who institute the system. In the name of updating of the syllabus, mathematics at post-graduate level h· been made memory-oriented theorem-proof subject, killing the remnant capacity for computation left during graduation.

(v) So-called mathematicians of 'non-trivial standing' do not show any concern for the ills of the system either singly or as a group. Having defined 'non-triviality' by themselves, they show interest in declaring others who come up in spite of the system as 'trivial' or 'non-trivial' with the sole aim of multiplying their species with the least regard for the country's needs and its potential. We are aware that most of the mathematicians of 'non-trivial' standing consider it against the interest of their own original work to take interest in making moves to make the existing system meaningful or to evolve a new system to serve even their 'non-trivialities'.

Let us elaborate a little on the above issues:

(a) Some of us are involved in a project conducted by the Association of Mathematics Teachers of India and sponsored by the Ministry of Human Resource Development, Government of India, on identifying innovative teaching-learning methods for the improvement of school mathematics. This project is done through workshops at the levels of primary, middle, high, higher secondary school in the several regions of the country with participation of both teachers and the taught. Two of the workshops at the first two levels have revealed to us that a majority of children enjoy learning mathematics whether it is computational or conceptual provided it is presented in terms of practical experience. They are able to think also by themselves on the issues presented and make their own inference. There is some resistance of teachers to these innovations (in which P. K. Srinivasan has done pioneering work). To hint at a few of them, dotted sheets could be used to illustrate g.c.d. of numbers, fractions and operations on them can be illustrated by paper folding. Learning mathematics through experience and practicals instills confidence for self-study and to take up small projects in