The 'basic' vs the 'evolved'

Quark and Jaguar. M. Gel-Mann. Little Brown and Co., London. 1994. 392 pp. Price: £ 18.99.

That Murray Gell-Mann's latest book gives the pride of place to the quark as the most basic building block of matter will presumably not be contested by its less dramatic partner, the lepton, since it must be 'aware' of the 'creator', in company with another genius[1], of this bizarre yet most concrete of all objects, especially after the announcement of the last and most elusive member[2] of the series. However, the corresponding privilege for the jaguar to qualify as a prototype for the most complex adaptive system on earth is more a matter of personal taste. (The choice could well have fallen on, say, the giraffe[3] if it were a different author). In any case one cannot but feel a sense of admiration for the poet (Arthur Sze) who had both the words (the quark and the jaguar) in his poetic dictionary and thus captured the literary fancy of the great physicist. This is somewhat reminiscent of an earlier occasion (three decades ago) when James Joyce, through his *Finnegans Wake*[4], had (inadvertently?) supplied the 'name' of the first member of this book.

While the title of a book is largely the prerogative of the author, the more relevant issue is the subject matter and the language in which it is intended to be conveyed. The general tone and the tenor of the book seems to be in keeping with the trend set by some of the author's distinguished contemporaries (Feynman and Dyson) to write personal glimpses on physics in an 'autobiographical' style, but since the author himself disclaims any autobiographical intentions, one must look for other, say educational, motivations designed to convey to the lay reader the significance of major discoveries in a frontline field in a sufficiently nontechnical language without too much sacrifice of rigour. Even such ventures are no longer considered novel, since after the debut of the *Tao of Physics*[5] nearly two decades ago, many impressive literary pieces dealing with abstract concepts in physical and mathematical sciences in a nontechnical manner by professional scientists of great distinction have appeared on the scene[6,7]. And now Gell-Mann has joined this select club with his own 'coup de grace'. In view of the great stature of the author, this book is bound to attract a good deal of attention, as well as an *inter-se* comparison with some of the classics[6,7] on cosmology on the one hand and other equally authoritative treatises[8] on a major aspect (chaos) of its theme on the other. Without presuming to pass a hasty judgement on the book, the issue of immediate concern is its 'thrust', together with the nature of the emphasis that the book wishes to convey.

What is the main thrust of the book? Fortunately, the distinguished author has himself provided enough summary on his own (at both ends of the book) to obviate any need on the reader's part to make an independent inference in this regard. The book is written in an intensely personal style and is studded with examples taken from the author's own experiences from family and friends alike. The entire setting is centred around the Santa Fe Institute (SFI) of Interdisciplinary Studies, which the author founded about a decade ago (after taking an early retirement from his home institution – Caltech) and which now represents his principal scientific base. Shorn of such personal details, the book is presented in four parts, in an obvious attempt to address a whole gamut of information, from 'the simple: a quark inside an atom' to 'the complex: a jaguar prowling its jungle territory in the night', together with the innumerable interrelationships among the various components that make up the whole and are continually showing dynamical manifestations in an ever-growing evolutionary scenario.

The first part of the book is an attempt to describe the relationships between the concepts of simplicity and complexity, especially of *complex adaptive systems* (CAS) – child learning a language, bacteria developing resistance against antibiotics, human scientific enterprise, and so on. The role of theory in science is discussed, 'as well as the issue of which sciences are more fundamental than others', along with the related question of reductionism. The second part deals with the fundamental laws of physics, those governing the cosmos and the elementary particles, out of which all matter in the universe is composed. Here the quark comes into its own (as does its creator), so do superstrings, which the author believes 'for the first time in history' to 'offer the serious possibility of a unified theory of all particles and forces of nature'. The third part is devoted to the various selection pressures operating in complex adaptive systems, 'especially in biological evolution, human creative thinking, critical and superstitious thinking' (which he strongly condemns), and some aspects (including economic ones) of the behaviour of human societies. Many *ad hoc* concepts, such as fitness and fitness landscapes are introduced along the way. The fourth and final part is concerned with policy matters (not science) and 'with advocacy'. (This reviewer hopes that the last phrase does not imply that the author considers science to be so objective as to be above policy and advocacy, since science does seem often to exhibit a high degree of subjectivity at the *operational* level)[9,10].

Now to some essential details concerning the different parts of the book. The most serious discussion (understandably) concerns the *second* part, which bears the characteristic imprint of the author's seminal contributions to elementary particle physics during the fifties and sixties (including the quark proposal among other things), as well as some fresh 'hard physics' on the foundations of quantum mechanics (carried out at his SFI). Since this topic dealing with the deeper issues of 'measurement' and 'paradoxes' is relatively new and still confined to the pages of technical journals, its wider appeal to the scientific community at large warrants some elaboration in this review (see below). However, the other, more familiar topics of the second part, as well as some from the first part, are treated rather briefly (within the limited space available), while Parts 3 and 4 are too 'righteous' (and personalized) for a cogent review.

Complex adaptive systems

Much of the discussion in Part 1 is taken up with a discursive analysis of complex adaptive systems (CAS), their patterns of evolution by acquiring information about their respective environments through their own interactions with the latter, identifying regularities in the information, condensing the (abstracted) regularities into a kind of schema or model, and acting in the real world on the basis of that schema. Their capacity to learn from experience is itself a product of biological evolution, which in turn gives rise to other new types of CAS (e.g. immune system in mammals). Indeed, a CAS generally has a tendency to generate other such systems in turn. They are, of course, subject to the laws of nature, which themselves rest on the fundamental physical laws of matter and the universe. And (over and above the quantum-mechanical (q.m.) effects) indeterminacies arise, even in classical motion, partly due to an *approximate* knowledge of the initial conditions and partly due to *measurement imperfections*. The latter give rise to CHAOS[5], which tends to amplify the resultant indeterminacies (whether from q.m. effects and/or from measurement imperfections) to macroscopic levels. The entire discussion is studded with a rich vocabulary of terms with subtle distinctions in their meaning, depending upon the context of their use. Different types of complexity, along with several associated concepts (conciseness, crudity, algorithmic information content, information, compression, randomness, effective complexity, direct adaption vs CAS) abound in the text.

In Gell-Mann's view, the concept of CAS is well illustrated by the human scientific enterprise. The schemata are theories, and what takes place in the real world is the confrontation between theory and observations. This is strongly reminiscent of Holton's[11] definition of themata along with the associated concept of the contingent plane, which Holton had developed very systematically in the early seventies. (A summary of the main ideas involved may be found in ref. 10). In this regard Gell-Mann strongly endorses the dictum of philosopher Karl Popper concerning the falsifiability (by experimentation) of scientific theories. His views on the scientific enterprise as a self-correcting process (despite occasional abuses) as well as his endorsement of the themes of simplicity and unification in physical theories are quite standard, but his joining the issue, on grounds of semantics, with a distinguished contemporary thinker, Thomas Kuhn on his seminal theme of paradigm shifts[9] does not seem to carry the same degree of conviction.

Gell-Mann goes into great lengths in analysing the powers of theory at successively deeper levels of operation, stressing in the process its unifying role in bringing together apparently unrelated phenomena under a more transparent pattern which reveals their relationships, thus facilitating a more 'compressed' (compact?) description. He illustrates the idea with the simple example of how a relatively empirical model like Zipf's law has *eventually evolved in the hands of* deep thinkers (like Mandelbrot) into something quite profound: fractal behaviour and scale independence. (One may add in parentheses that it already has the germs of renormalization group theory). In this context he introduces several related terms like depth and crypticity as a sort of figure of merit for theorizing.

The quantum universe

Coming to the fundamental laws of matter and the universe, the distinguished physicist is at last on his own territory where he has every reason to look back with satisfaction at the culmination of his quark proposal[14] into the standard model of today. For good reasons he does not obviously believe in the finality of the so-called grand unified theories. He also does not have good words to say about Einstein's mental faculties during his twilight years of research on a unified field theory, pointing out several specific flaws in his approach due to the neglect of fields (weak and strong) other than the gravitational and electromagnetic as well as fermion fields, and, most importantly, the need to construct a unified theory within the framework of quantum mechanics. On the other hand, he seems to believe that Einstein's dream may at last have been realized with the superstring theory, which in his view has the right ingredients to accomplish the unification, since it predicts in a natural way the existence of the graviton within its broad framework. In particular, the heterotic superstring theory, which realizes this crucial quantum in a (conceptually) convincing fashion seems to fit the bill quite well without running into the perennial problems of infinities. Reasons? (i) It explains the great multiplicity of particles discovered and yet to be discovered in the laboratory. (ii) It does not contain any arbitrary particles or forces. (iii) It emerges from a simple and beautiful principle of self-consistency (which dates back to the bootstrap idea of the sixties just preceding the quark model).

Even if the superstring turns out to be eventually 'correct', its claims to TOE (theory of everything) is still beset with other problems. For, the actual evolution of the universe depends not only on the physical laws but also on the initial conditions plus the unknown effects of quantum fluctuations, which in turn are closely *linked with the 'arrow of time'* (On this topic, a nontechnical yet highly readable description may be found in ref. 6). Regarding the initial conditions, Gell-Mann recognizes that a good candidate is one already suggested by the Hawking–Hartle theory[6], viz. the no-boundary condition, which, along with the (weak) anthropic principle, is apparently able to account for the arrow of time[6]. On the other hand, Gell-Mann himself believes that since the laws of physics are quantum-mechanical (not deterministic) and permit only the calculation of probabilities of various alternative histories of the universe that describe different ways events could play themselves out (given the initial conditions), information about which of those sequences of events is actually occurring can be gathered only from observation and is supplementary to the basic laws themselves. And further, each alternative history of the universe depends on the results of an inconceivably large number of accidents. The chance outcomes of the latter (*á la* quantum mechanics) have 'determined' almost every aspect of evolution – from the universe in general to the various biological species on earth. Thus, the algorithmic information content of each alternative history of the universe merely gets a tiny contribution from the 'simple' basic laws, but a gigantic contribution from all the 'quantum accidents' that arise along the way!

A modern view of quantum mechanics

Some well-known paradoxes in quantum mechanics – the Schrodinger cat and the EPRB paradox in particular – have generated much controversy and learned discourse in the recent literature. In this book a new perspective is offered on these and related issues on the basis of Hugh Everett's theory of wave function of the entire universe, which has since been explored by many authors, including the famous Hawking–Hartle formulation with the same title. Gell-Mann and Hartle have since investigated the foundations of quantum mechanics on these lines with a view to clarifying the working of the latter in the quasiclassical domain. Briefly, the picture which makes free use of the notion that *a given system can have different possible histories, each with its own probability*, is as follows: Suppose a set of alternative histories of the universe is specified, and that these histories are exhaustive and mutually exclusive. Rather paradoxically, quantum mechanics *does not always* assign a probability to each one. For a pair of such histories a necessary condition for a meaningful assignment of their respective probabilities is that they *do not interfere* with each other.

What is the condition of noninterference? The more fine-grained the history is, the more are the chances of interference. Therefore, in order to have actual probabilities it is necessary to consider histories that are sufficiently *coarse-grained*, since coarse-graining can wash out interference terms. In particular, if the interference term between each pair of coarse-grained histories is zero to a very good approximation, then all the coarse-grained histories are said to *decohere*, and one gets true probabilities.

But why does decoherence occur? It is the 'entanglement' of what is followed in the coarse-grained histories with 'what is ignored or summed over' that holds the key to the said mechanism. This does not give anything effectively new in the classical or quasi-classical domains, but helps solve several standard puzzles where quantum effects are apparently important. Thus, in the famous example of the Schrödinger cat, the alleged quantum interference between the live and dead cat scenarios can be explained away by the fact that there is plenty of opportunity for decoherence between the coarse-grained histories in which the cat lives and the corresponding histories in which the cat dies. Thus, the *live and dead cat scenarios decohere*, hence no interference.

By and large a very similar mechanism is involved in the Einstein–Podolsky Rosen–Bohm (EPRB) experiment concerning the decay of a spinless particle at rest into two photons wherein the state of polarization (circular or plane) of one is supposed to 'determine' that of the other. Now quantum mechanics says that both linear and circular polarizations cannot be simultaneously specified (these alternatives 'sit' on different branches of history, and cannot be considered together), while Einstein's 'completeness' would imply simultaneous assignments for both, perhaps through some 'hidden variable' mechanism. To distinguish between these two possibilities, Bell[12] had found some testable inequalities for the correlation function of the two photon polarizations wherein the latter could attain values in quantum mechanics that are not allowed in a classical hidden variable theory.

Subsequent experimentation (by Allan Aspect) confirmed the quantum-mechanical result, but led to a flurry of speculations about quantum mechanics showing bizarre properties, the implication being that measuring the polarization (circular or plane) of one photon somehow affects the other photon. On the other hand, there is nothing mysterious in all this according to the logic of decoherence given above, since the measurement process *does not* cause any physical effect to propagate from one photon to the other. Thus, if on a particular branch of history, the plane of polarization of the one photon is measured (and thereby specified with certainty), then on the *same branch* of history the plane polarization of the other photon is also specified with certainty. On a different branch of history, the circular polarization of one of the photons may be measured, in which case again the circular polarization of the other photon is also specified with certainty. This *does not* imply any *signal* from one photon to the other in the actual experiment; hence, no action at a distance is involved despite the seemingly instantaneous effect, implying faster-than-light propagation. Indeed, the physicist in the author comes down heavily on such distortions in the literature.

Summary and conclusion

As for the third and fourth parts of the book, no attempt is made at further abstraction, except to draw some conclusions from the author's own 'afterword' (Chapter 23): The book is *not* a treatise, but a running commentary on the various multidisciplinary researches in progress at the SFI. Running through the entire text is an essential 'interplay' between the fundamental laws of nature and the operation of chance, since the fundamental laws are quantum-mechanical, and quantum mechanics supplies only probabilities for alternative coarse-grained histories of the universe. This often results in their branching, with related probabilities. On certain branches and at certain times and places in the universe the conditions are ripe for the evolution of CASs which function best in a regime intermediate between order and disorder. They exploit the regularities provided by the approximate determinism of the quasiclassical domain, and at the same time they profit from the indeterminacies in their quest for 'better' schemata.

A CAS discovers 'regularities' in its incoming data stream by noticing features in common with its own, and emerges with a higher form of complexity through self-organization. When a CAS gives to a new kind of CAS, whether by aggregation or otherwise, the same can be considered a *gateway event*, e.g. the evolution of the mammalian immune system. And finally, many such features of biological evolution are found in other CASs such as human thought, social evolution and adaptive computing. All these systems keep exploring possibilities, opening up new paths, discovering gateways, and occasionally giving rise to new types of CAS. And the process goes on and on.

Looking back on this broad-spectrum book, one wonders as to what kind of clientele it is intended for, since, apart from the contents of Part 2, the rest of the book, by the very nature of its scope, is too full of definitions and *ad hoc* concepts to do 'coherent justice' to the vast canvas of material that the author has taken upon himself to present to the readership. This is certainly an unenviable task, for its theme is much more diffuse and tentative (many of the conclusions, in the author's own phrase, are the results of ongoing activities which are not yet firmly established) than e.g. the themes of other such books[6,7], which are more focused and based on firmer investigations. On the other hand, since the book is written in a nontechnical style, it must be assumed that it is meant for the widest possible audience, captive or otherwise. While the captive audience may be already aware of its contents along with the various jargons employed, one is not so sure if the general reader will find it equally enjoyable, despite the absence of technicalities. Moreover, the repeated emphasis on SFI and frequent references to the work of only a few personally known to the author (irrespective of the depth of their investigations) does not quite make for a smooth reading from an educative angle, unless the reader were warned in advance that he was reading an autobiography.

Gell-Mann has long been my hero in physics, perhaps next only to Feynman and Dyson. I had richer expectations from the entire book but was only partially rewarded with Part 2 of it.

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Functional Dynamics of Phytophagous Insects. T. N. Ananthakrishnan, ed. Oxford & IBH, 66, Janpath, New Delhi 110 001. 1994. viii + 304 pp. Price: Rs 550.

One-third of a million insect species are known to be phytophagous and constitute one-quarter of all living beings[1]. The number of recorded lepidopteran species alone, which are mostly phytophagous, is one order of magnitude greater than all species of birds and mammals put together – a staggering diversity which continues to overwhelm entomologists. The obvious success of phytophagy as a mode of life for insects testifies to their triumph in the evolutionary battle against plants. But plants have not been silent victims of insect onslaught either. They have waged their own evolutionary battle and what one sees today is a dynamic equilibrium in a continuing race. Interactions between insects and their host plants were first put into a comprehensive evolutionary perspective by Ehrlich and Raven's[2] classic paper, which triggered off an intense flurry of research activity. So strong has been its influence that almost all of plant morphology and plant secondary chemistry have since been attributed to selective pressure exerted by phytophagous insects. The book under review, coming close on the heels of another landmark publication in this area[3], is a laudable attempt at summarizing the mind-boggling literature on ecological and evolutionary aspects of insect–plant interactions.

Is geographic variation in plant allelochemicals of any significance to insect herbivores? In their chapter Johnson and Scriber address this question with examples from nonagricultural systems by dissecting out the ecogeographic variation in plant chemistry into historical, genetic, altitudinal and latitudinal factors. And how do phytochemicals alter insect behaviour? The chapter by Norris gives a brief overview of the major classes of chemical messengers, which is followed by a detailed discussion on the mechanism by which insects respond to chemicals. The idea that many common chemical messengers are both elicited and perceived by sulphydryl/disulphide-dependent mechanism of the receptors is convincingly argued. His call for detailed investigations of chemical communication at electrochemical level for a better understanding of cell–cell and environment–cell exchange of chemically based energy would hopefully attract more chemists to biology. The chapter on the physiological basis of feeding and oviposition behaviour in moths by Ramaswamy is an excellent review of the current knowledge on the role of proximate factors in host finding in moths. At the simplest level, host recognition and acceptance involves integration of inputs from several sensory modalities such as vision, mechanoreception and chemoreception. The internal metabolic state of the insect, the ontogenetic and phylogenetic influences on the mechanism of host selection add several levels of complexity to the dynamics of insect–plant interactions.

Do plants possess chemicals that provide both positive and negative stimuli and influence host selection? Dethier[4] had suggested that a balance of positive and negative stimuli could be present in the plants and the ultimate behavioural response of the insect depends on the balance between internal state of the insect as regards motivation and degree of satiety and external stimuli. This was further elaborated by Miller and Strickler[5], who proposed a 'rolling fulcrum model' wherein the internal excitatory/depressor factors could tip the balance in favour of host acceptance or rejection. This issue is examined by Renewick and Huang in the chapter on chemical stimuli mediating oviposition by lepidoptera. The authors review their work with the *Pieris–Crucifer* system, wherein the host plants have chemicals that are both oviposition stimulants and deterrents. Their results show quite convincingly that final rejection or acceptance of a host depends on the insect's assessment of the balance of stimulants and deterrents.

Ananthakrishnan, Venkatesan and Sridhar examine the effect of relative levels of nutrients and other chemicals like phenols, fatty acids and flavonoids in different plant parts on feeding and reproduction in the lepidopteran pest complex of cotton. The authors argue that this information can be of much use in managing insect pests of cotton by manipulating plant chemistry. Uthamasamy reviews the behavioural processes involved in host selection by the bollworm complex on different varieties of cotton. The emphasis here, however, is more on the effect of plant morphology on host acceptance by bollworms.

'Your enemy's enemy is your best friend.' That even plants believe in this is convincingly shown by Whitman and Nordlund in the seventh chapter. While reviewing the tritrophic interactions between plants, herbivores and their natural enemies, the authors present evidence to show that plants actually 'communicate' with natural enemies of their enemies, i.e. with the enemies of herbivores. Damage by herbivores induces the plants to produce chemicals that not only attract but actually serve as road maps to the natural enemies of herbivores. The chapter ends with a tempting speculation that these chemical beacons, 'kairomones' as they are called, hold great potential for solving pest problems.

Whitaker, Blum and Slansky Jr. attempt to trace the possible evolutionary path of