some of the recent advances in cosmology. The rate at which acceleration in the universe is taking place is surprising; galaxies are moving apart and the rate is increasing with time. Though the gravitation force (universally attractive) should make them come near, it is propounded that dark energy may play a role in the acceleration of galaxies drifting away. 'Peering beyond standard cosmology' was the theme of Tarun Souradeep (Inter-University Centre for Astronomy and Astrophysics, Pune). Discussing the role of Cosmic Microwave Background (CMB) data, Souradeep focused on primordial power spectrum and the bipolar representation of CMB sky that can be used to measure deviations from rotational symmetry in the universe.

Neutrinos are the second most abundant particles in the universe, the lightest massive and the most weakly interacting particles. Many atmospheric neutrinos are lost while passing through the earth. They have different masses and mix with each other. Mismatch between the number of neutrinos from sun and that from earth's core is a mystery yet. Amol Dighe (TIFR, Mumbai) talked about the particle astrophysics of neutrinos specifying that supernova neutrinos can indicate a supernova hours before its light arrives. A talk on 'Spacetime, structure and the large Hadron Collider' by Raman Sundrum (Johns Hopkins University, Baltimore) centred upon the hierarchy problems of multiple universes, new spacetime dimensions, particle compositeness and supersymmetry.

Jaikumar Radhakrishnan (TIFR, Mumbai) gave an example of the colloquium organizer's problem – the number of cookies eaten by each delegate – about computation with limited memory to illustrate the role of randomness and error in computation. S. R. S. Varadhan (Courant Institute, New York) in his talk on 'Random walk in a random environment: a survey', mentioned that a random walk in a random environment is the same as partial differential equation with random coefficients.

Ajay K. Sood (IISc, Bangalore) discussed 'Non-equilibrium fluctuations in driven soft matter'. The viscosity of soft matter fluctuates and becomes negative too. Sriram Shastry (University of California, Santa Cruz) talked about extremely correlated quantum liquids, and Ashvin Vishwanath (University of California, Berkeley) deliberated upon 'Beyond Landau: topology in quantum solids'.

2D graphene is the 'mother of all graphite forms' namely 0D bucky balls, 1D nanotubes and 3D graphite. C. N. R. Rao (JNCASR, Bangalore) discussed his fascination with nanocarbons, particularly graphene, the synthesis of which remains a challenge. Raman spectroscopy is an essential tool to characterize carbon nanotubes. Single-walled carbon nanotubes are highly sensitive and interact with electron donor and electron acceptor molecules and their interaction spectra can be used to study the properties of nanotubes.

The spectrum and the arithmetic of Reimannian locally symmetric spaces mutually determining each other, was questioned by C. S. Rajan (TIFR, Mumbai). Siva Athreya (Indian Statistical Institute, Bangalore) discussed the 'model of contact process' – a simple model for the spread of infection in a population – wherein each member in a population is either healthy or infected.

Two panel discussions were held, one on 'Interdisciplinary Science' (panel members – K. Sreenivasan, Sriram Ramaswamy, Eitan Tadmor, Mukund Thattai and Subir Sachdev) and other on 'Physics and Consilience' (panel members – Edouard Brezin, Avichai Wigderson, Naama Barkai, Anirvan Sengupta, Govindan Rangarajan and Albert Libchaber). The points brought out were: new ways of linking science have to be defined ('consilience'); benefits of interdisciplinary science are evident in genome sequencing; physics has invaded many fields, being used in climatology, quantum science, geophysics, biology, but researchers in these fields are not called 'physicists'; physicists have a different approach in biology as they provide better insights into research; a significant number of physicists work in biology but a concern is publication of this biology–physics interface work in physics journals eventually leading to lack of communication of research to biologists; science needs to be pursued as a whole and not as fragments. Some examples of interdisciplinary work (such as flocks of bacteria, model of chemotaxis and networking) were also described; and it was concluded that interdisciplinary science cannot be achieved at the expense of specialization in the respective disciplines.

Richa Malhotra

MEETING REPORT

Evolution of complex systems*

The International Centre for Theoretical Sciences (ICTS) organized a three-day satellite event following the inaugural event of the centre in Bangalore. The theme of the event was the evolution of complex systems with an emphasis on problem-solving in a variety of systems, from the life sciences, economic and social systems, and geophysics, through statistical approach, mathematical modelling and computer simulations. Speakers were drawn from institutes in India and abroad to provide a wide perspective, also to accomplish the aim of the ICTS – that of a multidisciplinary approach towards research. Spenta Wadia (ICTS) presented an overview of the activities of ICTS in the welcome note.

The conference had sessions covering dynamical evolution in systems at many length scales from cellular to geological, paying particular attention to the behaviour of complex interacting networks. Upinder Bhalla (National Centre for Biological Sciences (NCBS), Bangalore)

*A report on the three-day satellite event of the International Centre for Theoretical Sciences, Tata Institute of Fundamental Research. The event titled 'Evolution of Complex Systems' was conducted at the Indian Institute of Science, Bangalore during 13–15 January 2010.

discussed how 'Multiple cellular states emerge from simple chemistry and cellular traffic'. He highlighted the observation that cellular organelles maintain their molecular identity in spite of changing cellular conditions. He asked how different stable states can be maintained to give rise to different organelle types and different cellular states. These multiple states were studied using simulations and were found to arise from the interaction between chemical signalling and molecular traffic. This capability to generate multiple states and molecular identities may result in evolution of more complex systems.

Sriram Ramaswamy (Indian Institute of Science (IISc), Bangalore) discussed the complex dynamics of self-driven particles, examples of which are collection of birds, bacteria, fish and cytoskeleton filaments in the presence of molecular motors and ATP. He explained why flocks must have giant density fluctuations. He then introduced the notion of a 'headless flocker', that is, self-driven particles without a head–tail distinction, and showed that flocks of such particles should also have big density fluctuations. He discussed experiments confirming predictions from his work that microorganisms swimming through a medium can lower or raise its viscosity, depending on the swimming mechanism. Because self-driven particles are in general elongated, one can imagine states in which the system has a macroscopic alignment. Ramaswamy showed that such states are dynamically unstable as a result of the propulsive stresses carried by each particle: collections of bacteria cannot swim in a straight line.

In his talk 'The evolution of cooperation in social amoebae', V. Nanjundiah (IISc, Bangalore) discussed the development and evolution of so-called altruistic traits in the cellular slime moulds (CSMs) or social amoebae within the neo-Darwinian picture of evolution. When starved, separate amoebae aggregate to form an integrated multicellular group resembling a metazoan embryo. This change from a solitary to social mode of life is accompanied by the apparent self-sacrifice of some cells. Such behaviour appears counter-intuitive and had for long been a puzzle to evolutionary biologists. Based on the observation that naturally occurring CSM groups often were genetically heterogeneous, he proposed that the curious CSM life cycle could have evolved as a trade-off between different fitness-related traits among the amoebae that made up a group. Further, unlike what one had tended to assume, the extent of genetic relatedness within groups was not a significant factor. Anindita Bhadra (IISc, Bangalore), in her talk 'The links and hubs of power in a wasp society', underscored the role of insect colonies in serving as models for understanding the evolution of cooperation in the living world. Having discussed a set of interesting experiments and observations conducted on primitively eusocial wasp *Ropalidia marginata*, Bhadra concluded that these wasps, though categorized as 'primitive' due to the lack of a morphologically distinct queen, have evolved towards a more complex or highly eusocial organization, with a docile queen who uses pheromones rather than physical aggression to maintain reproductive monopoly.

A look into crises in the financial markets, social infrastructures and political violence was offered by Didier Sornette (ETH, Zurich). His group studies links between nature and biological hazards such as earthquakes, critical illnesses and landslides. He referred to these crises as 'Dragon Kings', unlike his contemporaries who refer to exogenous and unpredictable, unknown and unknowable events as 'Black Swans'. Within a framework known as self-organized criticality, earthquakes cannot be predicted (Black Swans) because they start no differently from small events. In the light of the Dragon King story, such events can be predicted to some extent and quantified as well. He illustrated six examples of Dragons including brain medicine, hydrodynamics, financial economics, population geography, materials science and geophysics. He concluded that the financial market is not going up or recovering but is rather being pulled up.

A statistical solution to the 'Kolkata Paise Restaurant (KPR) Problem' was provided by Bikas K. Chakrabarti (Indian Statistical Institute, Kolkata). Kolkata had 'Paise Restaurants' that served food to a very limited number of its several customers, usually daily-wage labourers. Based on an analysis of the possible strategies customers might follow in such a situation, the KPR problem is a repeated game played between a large number of agents N having no interaction among them and choosing from among N restaurants, each preparing one plate each evening. A trivial, though dictatorial, solution offered by him was that agents form a queue, go to the respective ranked restaurants on the first evening and shift by one rank (with periodic boundary conditions) on successive evenings. The solution may provide answers for solving other such problems.

'New directions in Indian dance' by Sunil Kothari (Jawaharlal Nehru University, Delhi) revolved around the complex structure and synchronization in Indian classical dance forms such as Kathakali and Kathak. The dance forms have a structure that evolves and is never static. He played dance clippings dating back to the time India gained independence and of current dance forms as well, depicting an evolution in this complex form of art.

'Darwin's daemon and a mechanistic approach to evolution dynamics' was the topic of the talk by Stefan Thurner (Medical University of Vienna, Austria). His basic explanation of evolution is a three-step process – a new thing 'endogenously' comes into an environment; it interacts with this environment; if it survives this 'interaction' it gets 'selected' and thus becomes part of the environment. To demonstrate the problem of predictability and falsifiability of traditional evolutionary theory, he introduced a thought experiment where a hypothetical being – called 'Darwin's daemon', knowing all species and the fitness landscape – still can predict basically nothing. One has to understand how species and their fitness landscapes co-construct each other, said Thurner. He identified a problem with traditional evolutionary thinking and proposed a model to solve it.

The 'entangled bank' concept (of the interdependence of species) of Darwin does not clearly indicate how loss of a species affects abundance of other species. Neo Martinez (Pacific Ecoinformatics and Computational Ecology Lab, Berkeley) spoke on 'Structure, stability and robustness of complex ecological networks', and proposed a 'niche model' wherein every species in a food web is assigned a random 'feeding range'. This model has several advantages over others and is also applicable to palaeowebs. From modelling of food webs, he concluded that vegetarians are good for ecosystems. The model also has implications in studying the effects of species loss and biological invasions. Priya Iyer (Indian Institute of Science Education and

Research, Pune) discussed evolution of the sexes, its historical overview, empirical evidence and models for the origin of sexes. She described the evolution of biparental care and coordination among parents in taking care of their offspring. She also discussed a model of anisogamy concluding that eggs benefit from small sperm size.

Vijay Srinivasan (Krasnow Institute for Advanced Study, Fairfax) discussed hierarchy of complexity in autotrophic metabolism. From study of metabolic pathways, he proposed generalizations – C, H, N, S and P are the universal atomic constituents of pathways; all pathways are anabolic and when a pathway involves splitting a molecule, both parts enter anabolic pathways, thus reutilized; all core molecules of a metabolic pathway consist of a carboxylic acid or phosphoric acid moiety. Alain Pumir (École Normale Supérieure de Lyon, Lyon), through a newly developed model of invertebrate (*Drosophila*) phototransduction (a typical model of signalling), described the interaction between components of a biological system. Talking about the 'Consequences of sudden species loss in an evolutionary model', Vikram Soni (Jamia Millia Islamia, New Delhi) mentioned that nothing in a natural system goes a waste, everything gets recycled. On an evolutionary scale, there has been a sudden loss of species due to extinction. He explained species diversity in a model of evolutionary networks.

Very few forest studies take into consideration an important aspect – the change in forest conditions. Harini Nagendra (Ashoka Trust for Research in Ecology and Environment, Bangalore) discussed the role institutions play in comparing the indicators of climate change. The International Forestry Resources and Institutions research initiative that records these changes at regular intervals was discussed. She tagged forests as 'social–ecological systems' rather than ecological zones.

Sumantra Chattarji (NCBS, Bangalore) described auditory fear conditioning as a model for understanding the neural basis for learning. He discussed a set of experiments conducted on rats that showed a condition called 'freezing' when re-exposure to a conditioned stimulus was done, after exposure to both conditioned and unconditioned stimuli. G. Rangarajan (IISc, Bangalore) discussed an approach to compute Granger causality between point processes that can be used to detect functional relationship in neuronal networks including the default mode network.

M. Madan Babu (MRC Laboratory of Molecular Biology, Cambridge) discussed the structure, evolution, hierarchy and the node dynamics of translational network in cells. Translational networks are made up of motifs which may be either feed-forward or single input. Translational networks have scale-free structures which confer robustness (ability to maintain function). He also discussed yeast as an example of evolution and stated that 90% of the translational network has evolved by duplication followed by inheritance, loss and gain of interaction. Networks tend to change under stress, sporulation and DNA damage.

Synchronization of networks in chaotic systems was discussed by R. E. Amritkar (Physical Research Laboratory, Ahmedabad), who proposed spatial synchronization as a possible answer to why species die everywhere and do not survive in some locations. He mentioned absence of the 'rescue effect' which refers to a population surviving extinction in a particular area, though in other areas it is not. He reminded the audience of the past five massive extinctions (KT, PT, Late Devonian, End Triassic and Ordovician–Silurian) and proposed two ways of saving existing populations of species from extinction – variation in population and variation in the external threat. His studies on behaviour of a network have suggested that species show spatial synchronization of populations before extinction.

Sanjay Jain (University of Delhi, Delhi) in his talk entitled 'Formalizing the notion of "innovation" in an evolutionary model' explored the idea of innovation in evolutionary events. Innovations are a major driving force in the evolution of complex adaptive systems. These innovations are called big or small depending on the consequences. The new relationships formed as a consequence of the innovative event can be mathematically characterized in a model. Neelima Gupta (IIT Madras, Chennai) discussed communication network models, particularly Waxman network, airport traffic network, and access of websites at the institute campus. Complexity of some well-known problems was discussed by Manindra Agrawal (IIT, Kanpur). He introduced the notions of time and space complexity of problems and the relationship between them.

Richa Malhotra (*S. Ramaseshan Fellow*), H. No. 10, Jaladarshini Layout, Off New BEL Road, Mathikere, Bangalore 560 054, India.
e-mail: rchmalhotra@gmail.com