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Timeless Near the Lime Trees

Born in 1951 in Calcutta, I studied in the open-air school conceived by the poet Rabindranath Tagore in Santiniketan. While learning the conservation and symmetry principles in Theoretical Physics at the university, I wondered what principles underlie the patterns in nature. For the past eighteen years, I have been working on different aspects of spatiotemporal patterns and dynamics in biological systems at the Centre for Cellular and Molecular Biology at Hyderabad in India. I have been a Fellow of the National and Indian Academy of Sciences, India and Visiting Fellow at the University of Oxford, UK, the National Institutes of Health, USA, and the Santa Fe Institute, USA for extended periods. Along with my interest in basic research, I have also been actively involved in science education in schools and training students in the interdisciplinary area of theoretical biology. I am deeply interested in formulating a common framework for the understanding of the evolution of generic properties of complex systems that encompass both the living and non-living world. – Address: Centre for Cellular and Molecular Biology, Uppal Road, Hyderabad 500 007, Andra Pradesh, India.
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They were only skeletons – the trees – when I flew into a grey Berlin one morning in April. They told me that it was the first day the sun had lifted its cold and misty veil after a long winter. The big, bare, stony Wallotstraße 19 depressed me as I was struggling to pull my suitcase up the stairs from the gate. Things started brightening up when a gentleman (who introduced himself as Wolf Lepenies) came swiftly and helped me to the Reception, and I started meeting one after another wonderful person who made my life for the next four months a memorable period. I thank them all.

Within a very short time I realised that the Wissenschaftskolleg is a very special place for one's brain and being. When did I last talk

science to a non-scientist? How do I explain what I do to a historian or a philosopher? How come the words I use do not mean the same to everybody? I became acutely aware how differently natural scientists and social scientists behave and think in their respective academic pursuit. There were 50 people from all over the world talking in many different languages and discussing all those different things that I stopped hearing once I got busy with my specialised research and technical conferences. By the time I had got the software in my computer, loaded all programmes, known who sits where during the colloquium, matched the photos and the names of Fellows and Staff (an excellent and useful system), I had lost sense of the periodicity of day and night and had a fluidity in my daily life structures. The only point of reference to the outside world was the lunch, trips to the library, and an occasional trip to the grocery stores.

The basement apartment in Villa Jaffé with the attached office made it complete. I would sleep when the dawn has broken through my windows and the days and nights seemed to merge because I was under artificial light (thanks to the prolonged rains and clouds this year!). But that could not stop the trees from filling up with buds and bursting into new leaves and flowers. You could see them waiting eagerly on the branches for the rains to stop. Suddenly everything turned green and I could not see the stone walls of the buildings any more. As I walked down Wallotstraße every day, I could smell and see all the spring in its full glory; the trees were dressed spectacularly for the occasion. But very special was the scent of the lime tree when it bloomed. That will remain as my association with my stay here in Berlin, a strange feeling of happiness tinged with the sadness of the flowers that are left from previous festive nights. I felt that when I saw Unter den Linden for the first time from the top of Bus 100 and then in "Berlin – Ein Tag im Juli '45". It is a sensual experience, a smell and a dream that some day I hope to capture in my dreamcatcher.

Discrete-space, discrete-time spatiotemporal systems are fascinating because they let you put a lot of variation in the local dynamics and types of interactions among the agents. The way those entities self-organise into structures, in spite of their different inherent properties, are suggestive of the role that space and local interactions play in modulating the dynamics in a collective. Starting from the age-old continuous fluid-like description of spatial systems, more and more people are trying to look into semi-coarse grained descriptions, such as lattice models or individual-based models, so that the discrete entities that make up the collection can be assigned relevant

biochemical, ecological, and social properties. When I was invited to be a Fellow for the year 2000/2001 and participate in the working group on Demography and the Evolution of Eusociality, I realised that this was my chance to do something that I have been wanting to do for a long time but put off because of the constant struggle to meet official deadlines. And the Kolleg turned out to be the best place for such an activity. I could not take full advantage of opportunity, since I came only for the last four months, and therefore the longing has remained. But even in this short time, talking to the other Fellows has helped me a great deal in sharpening my arguments and thoughts. I was the poor soul who gave the last colloquium, "Collective Behaviour – a Theoretical Perspective", while competing for slots with the rehearsals for the farewell party, and I faced an already-depleted home-bound Fellow community. But even then my hypothesis was critically analysed and my generalised assumptions questioned by historians, social anthropologists, and neurobiologists. Such is the atmosphere in the Kolleg!

Evolution of the collective from individuals or single entities has been one of the major transitions in the history of life on earth. Many attribute the driving force to the realisation that being together helps survival and/or more efficient functioning than being solitary. It is not clear when an efficiently functioning collection of individuals becomes an organism. And the term collective behaviour is thus used with a wide scope of interpretation in different disciplines. My mathematical and computational work on coupled complex systems with simple abstract models considers agents with certain inherent dynamics interacting with their neighbours where information transfer occurs through diffusion or conduction. We have shown that, starting from a random, unorganized behaviour, the interaction leads to some sort of structure in the dynamics of the agents in space and time. Studies on specific examples of spatiotemporally-interacting systems – a biochemical system (collection of interacting biochemical pathways), a cellular system (pancreatic islets of beta cells), and ecological systems (metapopulation of single and coupled discrete populations) – have shown that units capable of showing a variety of individual behaviour can synchronise to exhibit quite different functional dynamics when they are allowed to interact among themselves.

The emergent dynamics of interacting units not only depends on their inherent dynamics, it is also influenced by the environment and the type of interactions. These results have reinforced the general role of interaction (type, strength, extent), and the underlying

structure (e.g. design or heterogeneity) imposed by the internal and external environment in deciding the emergent dynamic outcome of the collective behaviour. We have also studied the controllability of the spatiotemporal dynamics in these systems as it is useful in restoring normalcy in pathological situations. Much depends on the inherent dynamics of the agents and the type of links among them, and too much chaos is uncontrollable. The notion of localised control and distributed control in suppressing undesirable dynamics have also been looked at.

In an attempt to understand the interplay of organization and dynamics in the evolution of natural and social phenomena, I tried to arrive at a general description of a collective in terms of a set of minimal constituents, such as agents, interactions, and environment. The primary intention was to arrive at a general description of a collective in terms of a set of minimal players and rules and to frame a consensus definition that would be applicable to collective behaviour spanning cells to animals (including humans). Though the task for having a general description of physicochemical and non-human biological systems seemed tractable, the scenario turned out to be quite different when collective behaviour in human societies is considered, because the existing social theories use an anthropomorphic set of rules and images. Can similar concepts and methodology be used to describe the collective behaviour of molecules in a gas, cells in tissues, and a crowd in the football stadium? As a nonlinear dynamicist who is interested in collective behaviour, such questions are not only challenging, they are surely provocative.

The major point against using a similar methodology or approach stemmed from the idea that humans are supposed to have been endowed with intention, and so treating cells and humans on a similar footing in describing emergent collective behaviour seemed to be unacceptable to many social scientists. Notwithstanding the importance given to cultural evolution, natural sciences, unlike social sciences, generally treat humans as a member of the animal kingdom. It seemed to me that the basic structure and assumptions of natural science training differ significantly from the human-centric knowledge bases, such as sociology, anthropology, etc., giving rise to differences in viewpoints, definitions, and terminology. To my mind, one can try to incorporate the so-called intention of individuals by the introduction of bias and noise or randomness in decision-making in the system behaviour that can be a function of the past history of the system. In fact, the role of heterogeneity among the agents' intrinsic properties and the type of interactions and environment in deciding

the emergent collective behaviour are one of the important aspects of our studies. The properties of robustness, resilience, threshold, and synchronization across space and time in a collective as a function of the type of interactions ("links") are of interest for studying the system-wide transfer of localized perturbation or information. Thus, I believe that the generality of the theoretical approach can be useful in studying the evolution and maintenance of social behaviour in a collection of individuals interacting through certain social rules, and I draw inferences about collective behaviour on many levels of organisation. It became obvious that a constant dialogue among seekers of knowledge in all fields of science and humanities is imperative for those who think of unifying several levels of organization from molecules to human behaviour. And the Wissenschaftskolleg provided a very rare and convenient stage for that.

As I saw the stars fade into the light of the rising sun on the last day, I looked back at Wallotstraße 10 and 19 on my way to the airport and bid farewell to a memorable experience.

Then finish the last song and let us leave.
Forget this night when the night is no more.
Whom do I try to clasp in my arms?
Dreams can never be made captive.

(Rabindranath Tagore)