Hindus had expert knowledge in dyes, cosmetics and perfumery; in the preparation of fast dyes for textile fabric by treatment of natural dyes like *manjishtha* with alum.

In the tantric period (AD 1100–1300), chemistry was exploited in magic and in witch-craft. Charms, sorcery, exorcism of diseases by means of amulets were used. Mercury preparations were key tantric medicines. Palming of alloys of base metals, which possess bright yellow lustre, for gold was also prevalent. This according to Ray, has been there in all ages and in all climes.

Hindus reigned supreme in the field of medicine. The popularity of *ayurveda*, the Hindu system of medicine, continues from the days of the *Atharva Veda* to the present. Ray establishes convincingly that before the birth of Hippocrates, the Hindus had elaborated a system of medicine based upon humoral pathology. Some of the legendary names in the Hindu medical field are Charaka, Susruta, Vagbhata, Madhava, Sarngadhara, Vrinda and Chakrapani. *Rasaratnasamuchchaya* was a systematic and comprehensive treatise in materia medica, pharmacy and medicine. The medical works of Vagbhata (2nd Century BC) and Nidhana were translated by the order of the Caliphs of Baghdad in the 8th Century.

I would mention here an interesting medical preparation, an iron tonic. The preparation is interesting because it would suggest to a modern chemist that some metal complexes had been formed to which could be attributed the medicinal property. The procedure is as follows. A thin iron plate is to be made red-hot and plunged into a decoction of the myrobalan, cow's urine, a solution of 'the salts', a solution of the alkalies extracted from the ash of *Butea frondosa* (one of the above liquids at a time). When the iron becomes black like collyrium, it is to be powdered.

The development of chemistry (materials science) in ancient India, perforce, was empirical; by trial and error methods, presumably, monitored for specific performance. The preparation procedures for a drug had strict regimens. Serendipity must have played its role in the discoveries. No characterization of the compounds responsible for an activity, was attempted. It would not have been possible in those days. Perhaps, the very concept of associating a single medicinal property with a single compound was not there. In later years, the Hindus did not persist with their experimentation on the materials science. Their bent of mind was more towards spiritual quest; perhaps, on the realization that material prosperity led nowhere to inner peace.

Ray's book has extensive Sanskrit texts on chemical and medicinal literature, which must have been gathered painstakingly*. His work is indeed a labour of love, love for India's hoary past. Ray, quite often, digresses on the philosophy of the Hindus.

The book includes two articles, by B. N. Seal; one on the mechanical, physical and chemical theories and the other on the scientific methods of the Hindus.

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Editorial note:* See *Resonance*, 2001, **6, 97 also available at http:// www.ias.ac.in/resonance/Jan 2001/pdf/Jan 2001 p95-98.pdf

Imitation in Animals and Artifacts. K. Dautenhahn and C. L. Nehaniv (eds). The MIT Press, 5 Cambridge Center, Cambridge, MA 02142-1407, USA. 2002. 607 pp. Price not mentioned.

Imitation – the ability to recognize and reproduce others' action – is one of the most important mechanisms whereby knowledge is transferred between individual agents, whether they be animals (including humans), or computational agents and robotic autonomous systems (collectively referred to here as artifacts). Although traditionally, imitation, as a behavioural phenomenon and cognitive process, was largely studied by ethologists interested in animal behaviour, imitation has, of late, been attracting the attention of computer scientists and engineers typically interested in artificial intelligence (AI). Today, spurred on its way by current trends in multidisciplinary research, it is likely to be of interest to psychologists, ethologists, philosophers, linguists, cognitive scientists, computer scientists, mathematicians, biologists, anthropologists and roboticists.

The reason for this paradigm shift is not too difficult to find. Imitation, apparently a simple process when viewed outwardly, involves the interaction of perception, memory and motor control – subsystems that typically utilize very different representations and that must interact to produce and learn novel behaviour patterns. Gaining insight into the mechanisms of imitation thus becomes compelling from the standpoint of AI and the behavioural sciences. Moreover, the propensity to imitate appears to be innate and the mechanism is phylogenetically ancient, although its true and complete form, it is largely believed, is very rare in nature. From the practical standpoint, imitation, even in its simple forms, is a faster and more efficient form of acquiring new behaviours than are traditional classical conditioning and reinforcement learning; in humans, particularly, imitation is critical during development and remains an important aspect of social interaction and adaptation throughout life.

It is precisely for these reasons that this book provides fascinating material for behavioural and computational scientists and some chapters for interested laymen as well. Born out of the 'Imitation in Animals and Artifacts' Symposium, organized by the editors at Edinburgh, Scotland in April 1999, this impressive collection of papers spans a great diversity of subjects and is likely to be of interest to researchers working in the areas of computer science, robotics, software engineering, comparative psychology, neuroscience, primatology and linguistics. In fact, in my opinion, a self-stated function of the book is likely to succeed admirably – it will bring together this diverse group of people and allow them glimpses into why the other roads not taken are equally fascinating and, perhaps more important, contain signposts they can each learn from.

One strategy that the book thus adopts while presenting an integrated interdisciplinary approach to imitation is that it

desists from grouping its twenty-two chapters into the two obvious categories of 'animals' and 'artifacts'. Instead, it provides a framework that allows a unified approach to the problem of imitation as displayed by possibly apparently-dissimilar agents – referred to as the correspondence problem by the authors. In an initial chapter itself, they clarify what it means for the imitative behaviours of different agents to match with each other and what could be the most appropriate measures that such matching could be subjected to.

In general, imitation is believed to be among the least common and most complex forms of animal learning. It is usually found in highly social species which show, from a human observer point of view, 'intelligent' behaviour and traits supporting the evolution of traditions and culture. In its most complex manifestations, imitation may provide fundamental capacities for social cognition – the recognition of conspecifics, attributing intentionality to others and the ability to deceive and manipulate the mental states of other individuals. There is now strong evidence for imitation in certain primates (humans and chimpanzees), cetaceans (whales and dolphins) and specific birds (grey parrots), although for a long time, some sceptics were of the firm opinion that true imitation exists only in human beings, all that is seen in animals being mere social facilitation. The chapters in this book that explicitly deal with the problem of animal imitation are those on imitation of self and others by bottlenosed dolphins (Herman), interspecies correspondence in vocal imitation by grey parrots (Pepperberg), the cognitive basis of social learning among birds, particularly ravens (Fritz and Kotrschal), imitation during object manipulation by chimpanzees and human infants (Whiten), kinaesthetic-visual matching in primates and other animals (Mitchell), and finally, an excellent review of social learning paradigms and the *lack* of true imitation in certain neotropical monkeys (Visalberghi and Fragaszy).

One important theme that emerges from some of these reviews is the issue of enculturation which apparently plays an important role in animal imitation – apes raised by humans in a typically human social and cultural environment are more likely to demonstrate imitative abilities than their mother-reared counterparts, as are bottlenosed dolphins that have had extensive contact with humans. The way that enculturation could act to increase the potential of animals to imitate could be by influencing the development of attention mechanisms so that these individuals focus on different sources of information in the environment, particularly the behaviour of the individual to be imitated (Call and Carpenter). It is in this way that imitation becomes a specialized form of social learning and this points to the need for extensive comparative studies across species to discern subtle differences in the ontogeny of different types of social learning. These discussions also suggest that future research on animal and human imitation should consider social and cultural influences, including social relationships and networks, on the ontogeny of imitation during the lifetime of an individual. Since controlling for these parameters may well be impossible in experimental studies on imitation, an intriguing alternative possibility is that of studies on advanced artifacts – robots that can engage in social interactions with humans and build up relationships with them (Breazeal and Scassellati).

Artifacts might also provide interesting tools in order to investigate the problem of 'other minds'. Recently, therefore, imitation has begun to be studied in domains dealing with such non-natural agents as robots, as a tool for easing the programming of complex tasks, or for endowing groups of robotic agents with the ability to share skills without the intervention of a programmer. It is believed that robots will soon become a part of our everyday lives. Anticipating the need for machines that interact naturally with people, scientists have thus recently begun research on humanoid robots that have the potential to assist the elderly and disabled, to aid in rehabilitation and athletic training, and to act as educational toys. Most humanoid robots constructed so far, however, have primitive control mechanisms and limited perceptual abilities. Also, due to constraints in computational power, controlling humanoid robots is usually extremely difficult. Vision-based systems, which many researchers believe are necessary for comprehensive robot perception, currently have trouble even identifying objects and are far away from being able to perceive complex activities such as human movement. These problems make programming humanoid robots an immense task – and this is where imitation-based learning can perhaps step in and make life a little easier for roboticists.

Imitation is a natural method for teaching a robot how to perform a certain task, and thus ease the process of programming or otherwise controlling a robot. For example, a human could teach a robot how to perform a skill by imitation rather than directly controlling it (usually with much difficulty) through remote operation, as is usually the case. Imitation learning, however, still has several open problems that must be resolved. The first significant problem is that of interpreting and understanding the observed behaviour and the second, that of integrating the visual perception and movement control systems to reconstruct what was observed in the first instance. There could be several potential approaches to solve these problems. One of these employs the concept of sensory-motor primitives (outlined by Matariæ), derived from mechanisms of movement perception in humans and the neurobiological basis of motor control. These primitives have been used as the basis for a particular design perspective – one that involves building up different artifacts – including a simulated humanoid and different kinds of mobile robots – all with potentially extensive imitation capabilities.

A different approach to the construction of robot control architectures (described by Demiris and Hayes) draws inspiration from the now-famous mirror-neuron system and the developmental psychology of imitation in primates, including human infants. Briefly, the mirror-neuron system (particularly for grasping) in monkeys refers to one particular region in the monkey brain in which neurons are active when the monkey executes a specific hand action and are also active when the monkey observes another primate (human or otherwise) carry out the same action. This primate imitation model has been tested with a simulated robot that imitates particular movements – sign language 'words' in this case – by first internally generating movements of the kind shown by the demonstrator and then selecting for those that predict the demonstrator's behaviour best. Remarkably, this is perhaps the first experimentally tested robot control architecture for imitation based on the mirror-neuron system and one that holds tremendous hope for the future, not only in terms of its potential for the de-

sign of more complex imitative robotic systems, but also in furthering our understanding of primate imitation mechanisms.

Three other interesting chapters draw inspiration directly from language and its underlying mechanisms, and indirectly from the mirror-neuron system. For example, Arbib argues that the ability to imitate was the key innovation in the evolutionary path that finally culminated in the development of full-blown language in humans, and he specifically relates this to the primate mirror-neuron system, the human homologue of which is Broca's area, a crucial speech centre in humans. Moving from humans to robots, Billard addresses the role of imitation as a means to enhance the learning of communication skills in autonomous robots. He describes a series of experiments in which mobile robots learn a synthetic protolanguage by replicating a teacher's movements, thus sharing a set of perceptual contexts with the teacher. This, in turn, creates a meaningful social context in which language – a common means of symbolic communication – can effectively develop. Philosophically, this work follows a particular approach to language development that stresses the importance of social cues such as coordinated behaviour and imitation (again possibly mediated by the mirror-neuron system) as a precursor to language ontogeny in human infants. Finally, Oliphant, in a provocative chapter, points out that the most basic feature that separates human language from other forms of non-human animal communication lies not in syntax, as most linguists have argued, but in its symbolic reference – the mapping between different lexical elements and their arbitrary conventional meanings that learners must acquire by being exposed to its use in the community. He goes on to argue that such a system of learned symbolic communication could be transmitted most effectively in humans rather than in other animals – leading to the evolution of language ability. Although not explicitly stated, does this imply that the roots of such transmission efficiency could lie in the superior imitation skills of the human species, tempered perhaps by the ability of each individual to reflect on its own thoughts and actions as well as on the thoughts and actions of others?

The final section of the book explores several aspects of the proximate psychological mechanisms underlying human imitation. An extremely lucid chapter by Heyes, for example, contrasts transformational theories (which suggest that most of the information required for imitational behaviour matching originates from internal cognitive processes) with associative theories (which claim that this information is largely derived from external experience); and then goes on to propose a new associative sequence learning theory that suggests that imitation may actually be mediated by associative processes establishing correspondences in both horizontal and vertical dimensions. Vogt addresses the problem of how imitative action is dependent on perception – one of the most important issues in the cognitive psychology of imitation, while Bekkering and Prinz discuss the possible cognitive mechanisms that underlie imitative actions performed by human infants and children. They put forward the hypothesis that, during imitation, the action recognition process invariably interprets the observed motor patterns as goal-directed behaviours, and that the perception of these apparent goals activates a motor programme, which enables the corresponding actions in the imitator. In fact, the authors claim that several hitherto unexplained aspects of imitation by children can only be explained by the assumption that imitation relies heavily on observable goals and inferences about the actor's intentions during the performance of an act that will be imitated. In the concluding chapter, Goodenough addresses human imitation from the perspective of cultural transmission, arguing that such transmission occurs only through the actual imitation of actions and not ideas – each action must therefore be observed before it can be effectively replicated as a corresponding action, significantly slowing down the process of cultural transmission. This view could possibly be debated, especially in the light of current discussions on the remarkable fidelity of the memetic transmission of ideas. It does, however, drive home the point that imitation can only perhaps be successfully examined with reference to its social context, a view that is persistently echoed in many of the chapters of this comprehensive treatise.

In conclusion, it is not often that a collection of assorted papers on a particular multidisciplinary theme serves to necessarily bring together workers from different disciplines and encourage cross-talk between them. In my opinion, this book succeeds admirably and will continue to do so for some years to come.

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