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The Building of Biological Organization

Born 1952 in Pennsylvania. Studied Chemistry and Mathematics at Dartmouth College. Ph.D. in Biology, Harvard University, 1978. Junior Fellow in the Harvard Society of Fellows (1978/80), Assistant and Associate Professor at Yale University (1980/86). Since 1986, Professor of Biology, Cornell University. Major areas of scientific interest: the evolution and organization of insect societies, animal communication, and operations research. Books: *Honeybee Ecology: A Study of Adaptation in Social Life* (1985, Princeton University Press), and *The Wisdom of the Hive* (1995, Harvard University Press). — Address: Section of Neurobiology and Behavior, Mudd Hall, Cornell University, Ithaca, NY 14853, USA.

I came to the Wissenschaftskolleg with the hope of achieving two goals: to finish writing one book on the organization of honey bee colonies, and to begin writing a second book (with three other fellows — Scott Camazine, Jean Louis Deneubourg, and Nigel Franks) on the phenomenon of self-organization in animal groups. Despite being in Berlin only four months, complete success was achieved in the first project, and good progress was made in the second endeavour.

The book on the bees, titled *The Wisdom of the Hive*, summarizes what is known about how the thousands of individuals within a honey bee colony work together as a harmonious whole in gathering their food. This book, however, is not just about honey bees. Bees are simply aesthetically pleasing and easily studied animals whose sophisticated colonies vividly express an important puzzle in biology: What are the devices of social coordination, built by natural selection, that have enabled certain species to make the transition from independent organism to integrated society? The study of the honey bee colony, especially its food collection, has yielded what is probably the best understood example of cooperative group functioning outside the realm of human society. This example deepens our understanding of the mechanisms of cooperation in one species in particular and, by providing a solid baseline for comparative studies, helps us

understand the means of cooperation within animal societies in general. I feel the book will serve its purpose if readers can gain from it a sense of how a honey bee colony functions as a unit of biological organization.

I feel most grateful to the Wissenschaftskolleg for providing a haven for undisturbed concentration and long periods of searching thought, without which I could not have written the final, synthetic chapter of this book. In it I identify the main features of honey bee colony organization and place them in a larger context, by drawing comparisons between the inner workings of a bee colony and those of other kinds of functionally organized groups. These include multicellular organisms (groups of cells), colonies of marine invertebrates (groups of zooids), certain human organizations (groups of people), and multiprocessor computers (groups of electronic processors). All such highly cooperative groups share the basic problem of rationally allocating their members among various activities so that the more urgent needs of the ensemble are satisfied before the less urgent ones. They also share the problem of coordinating the actions of their members to achieve coherent patterns of activity. The solutions to these problems, however, vary greatly among the different kinds of integrated group. By comparing these solutions and reflecting on the functional significance of their similarities and differences, we deepen our understanding of the mechanisms that make close cooperation a reality.

With respect to the second project, the joint writing of a book on self-organization in animal groups, I enjoyed an incredibly fruitful exchange of ideas with my colleagues on the "collective intelligence team" as we strove to identify the fundamental concepts of self-organization as they apply to biological (living), as opposed to physical (non-living), systems. In both types of systems, one finds that groups of interacting subunits can build patterns (definite arrangements of the subunits in time or space) without any intervening external influence, such as a pre-existing pattern in the environment or a plan imposed by a leader. The puzzle is how patterns nevertheless arise. This mystery is especially strong in the case of certain insect societies, consisting of many thousands of individuals, which build extremely sophisticated nests and other structures in homogeneous environments and without anyone possessing synoptic knowledge of the building process. Somehow each individual contributes in the proper way to the collective enterprise despite the absence of supervision. Our book, titled *Building Biological Superstructures: Models of Self-Organization*, will provide the first coherent statement of the puzzle and will review what is currently known about its answer. These are issues that have never been clearly discussed in the biological literature, hence our group was faced with the challenge of delineating an essentially new avenue of scientific investigation. Without the cross-fertilization that is possible at the Wis-

senschaftskolleg, where one may engage in numerous, long, and hard discussions, our research group never would have achieved the progress that it did. With the basic conceptual framework assembled, our group is well on the way to completing its project.

As a final point, I wish to thank all those who made the stay so enjoyable for me and my family We deeply appreciate the cheerful and efficient assistance of the entire staff at the Wissenschaftskolleg. I feel especially grateful to Dr. Hans-Georg Lindenberg for his assistance with computers, Frau von Klitzing for her help in arranging schooling for one of my daughters, Frau Sanders for help in purchasing theatre tickets and many other kindnesses, and Frau Hund for her enthusiastic language classes. My family and I look back most fondly on our four months in Berlin. To all, we give thanks.