resent chemical kinetics. But models that systematically integrate several scales are also important. For example, stochastic chemical kinetics (D. Bray, Univ. Cambridge) can be used to model individual molecular interactions at various levels of detail. Such models capture fluctuations that tend to clump together in models based simply on differential equations. Also, the chemical dynamics of cells must be integrated with mechanical aspects (D. Ingber, Harvard Med. School), which — just as in complex engineering systems — become increasingly important at the network level. In another parallel to engineering principles, a model that integrates hypersensitivity and positive feedback in a signalling pathway known as the MAP kinase cascade predicts the occurrence of switch-like behaviour, where some internal chemical state of the pathway switches, as in a digital system (J. Ferrell, Stanford Univ.). Such behaviour is uncovered experimentally only when single cells are analysed (which is not common).

Widespread interest in sophisticated software is new. But the general approach of integrated modelling has a long and successful history. Computer modelling of individual ion channels and transporters in cardiac cells, at the level of differential equations, goes back 40 years. Since then, models of heart function have incorporated further details, such as pacemaker activity, the genetic defects underlying arrhythmic heart beats, mechanical–electrical feedback, and regional patterns of expression of ion transporters, to the point where high-fidelity simulations of the whole heart are possible (D. Noble, Oxford Univ.). Iterative interactions between experiment and simulation, and between molecular mechanisms and the physiology of the whole organ, were essential to this success.

Speaking from the experimentalist's point of view, T. Pollard (Salk Inst., San Diego) described how computation fits into a broad agenda for analysing cell-biological data. He detailed a model for cell motility, which involves actin filaments — a type of cytoskeletal structure. The model was constructed from a huge amount of experimental knowledge, including quantitative data on the identities, affinity constants and reaction rates of the interacting molecules. Such data are collected only rarely, but will become increasingly important.

Several other areas of biology have benefited from the interaction of experiment and modelling. For example, reaction–diffusion models (standard models of spatially dependent chemical kinetics) formed the basis for the first detailed picture of the transport of molecules into and out of the nucleus (A. Smith and I. Macara, Univ. Virginia). Likewise, the transport and sorting of proteins between the endoplasmic reticulum and the Golgi complex have been analysed by combining modelling with studies involving fluorescent markers (J. Lippincott-Schwartz, NIH, Bethesda). The transport of fluorescently labelled RNA granules to cellular sites of protein synthesis can be broken down into three characteristic patterns — vibrations, oscillations and movement. A stochastic model, integrating the rates at which motor proteins bind to these granules and are activated, can account for all of these behaviours (J. Carson, Univ. Connecticut Health Center).

Finally, the availability of electrophysiological and fluorescence methods to obtain quantitative data has made the dynamics of calcium ions one of the most popular subjects for modelling. A new model of calcium 'sparks' — the release of calcium ions from an organelle known as the sarcoplasmic reticulum — can account for the previously mysterious 'termination' phase of a spark (J. Lederer, Univ. Maryland). This model involves interactions within a cluster of calcium channels, and regulation of the channels by calcium within the sarcoplasmic reticulum. Sparks in skeletal muscle can be studied in preparations from frog muscle, and have been further analysed with a model that incorporates the characteristics of the microscope used to gather the data (D. Uttenweiler, Univ. Heidelberg). An image-based model of calcium waves in a neuron (L. Loew, Univ. Connecticut Health Center) emphasized the role of cell geometry, which can control the spatial and temporal patterns of calcium ions.

A prominent theme was that biology needs more theory, in addition to modelling and computation, to make sense of complex networks. Without underlying theories, software would be of limited use in engineering systems. Theory has a rather bad reputation among biologists, in part because the ideas so popular in physics — such as pattern formation, critical phase transitions and chaos — have proved largely irrelevant to molecular biology. So far, engineering theories of communication, control and computing have had little contact with biology, but perhaps that should change. If biologists are much like physicists in stretching the limits of experimental reductionism, they are also like engineers in revelling in the enormity, variety and sheer complexity of the systems they study. No interest in spherical cows here. ■

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Daedalus

The art of spinning

The gecko, that engaging lizard that climbs walls and runs across ceilings, is alleged to do so by means of the 'setae' on its feet — tiny hairs which stick to its anchorage by van der Waals forces. Daedalus does not believe it. A crumbly wall or powdery ceiling would easily defeat such forces, which occur only between surfaces in very intimate contact.

Similarly, engineering slip gauges, which are ground to better than 0.01 millimetre, cling together when 'wrung' into a pile for measurement. Again, Daedalus absolves van der Waals forces, and atmospheric pressure, from this feat. He reckons that the thin film of oil on the gauges is responsible, hauling them together by capillary forces. If the gauges were carefully dried by means of dichloromethane, for example, and then heated to about 35 °C (the boiling point of that solvent), they should fall apart.

In fact, Daedalus reckons that the only application of van der Waals forces in ordinary life is the ancient art of spinning. The business of taking short fibres, and twisting them together into a long, strong thread, is most remarkable. The fat on wool, and the oil on cotton, must play an initial role, tying the strands together. Yet after a while van der Waals forces must play their part, for the fabric does not fall apart again on washing.

So Daedalus proposes a new spinning technology. An initial thread, maybe a wire or carbon fibre, or even a traditional yarn, will be raised to a high voltage while other porous materials are released around it. Expanded polystyrene, paper pieces, cotton, wool and so on will be released nearby and will stick firmly by coulombic forces, which must also bring the surfaces into intimate contact. The resulting 'open fibre' should be as strong as anything van der Waals forces could bring about. Daedalus wonders whether oil will be needed to reinforce the initial bond before the fibre is converted to a fabric and washed.

All sorts of materials can be floated onto open fibre: fumed silica, fine metal wires, even expanded vermiculite. Daedalus has set his sights on a fibre as strong as conventional ones, but with far more 'bulk' and thermal resistance. It will knit or loom-weave into an amazingly warm cloth. DREADCO engineers have free rein to add any bulky insulator to the fibre, in the hope of improving these properties. Daedalus himself hopes to gain a bit of insight into how ordinary spinning actually works. David Jones