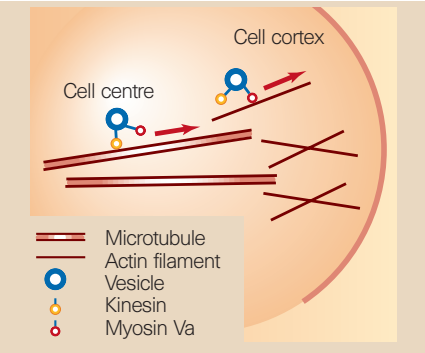

Figure 1 **Vesicle transport in the cell by a bifunctional vehicle. Huang *et al.*[1] show that the molecular motors kinesin and myosin, which run on microtubules and actin filaments respectively, interact on the vesicle membrane.**

transport is thought[4] to be mediated by myosin Va.

Huang *et al.*[1] now show that a region in the myosin Va tail, termed the AF-6/cno homology domain, specifically interacts with a roughly 100-amino-acid segment of the conventional kinesin tail. They identified these interacting subdomains using a yeast two-hybrid screen. The interaction is highly specific, and is restricted to the ubiquitous isoform of conventional kinesin — not even the closely related neuronal kinesin interacts. The authors also found that the two motors bind to one another *in vitro* and that they co-immunoprecipitate from mouse brain extracts, making a strong case for a specific interaction *in vitro*. But the evidence to show an association *in vivo* is less revealing, largely because both motors are distributed in a punctate and dispersed fashion in the cell line used, as seen by immunofluorescence microscopy.

The cooperation and interdependence of actin- and microtubule-based cytoskeletal systems has long been known[5]. But the discovery that the motors associated with these two cytoskeletal fibre systems are also coordinated in membrane traffic is more recent. For example, coordination of kinesin's activity with that of the microtubule motor dynein has been shown in a reconstituted *in vitro* system for the bidirectional movement of melanophore pigment granules[6] and phagosomes[7]. Other studies point to a close interrelationship between actin and microtubule motors in membrane transport. Kuznetsov *et al.*[8] were the first to suggest that the same vesicle can move on both microtubules and actin filaments. Mitochondria of cultured axons[9] and pigment granules of melanophores[10] also use both of these tracks. Moreover, in sea urchin eggs, exocytic vesicles required to close wounds in the plasma membrane are recruited by a two-step transport process that involves first a microtubule motor (kinesin) and then a myosin[11]. So, evidence for cooperation of microtubule- and actin-dependent motors is mounting, although we don't yet know how the activities of the two motors are coordinated.

The new twist offered by Huang *et al.*[1] is that the motors may interact directly, a possibility not previously considered. Their findings open an exciting direction for future research, and may eventually lead to an explanation for some puzzling observations such as the localization of myosin Va in spindles[12] and centrosomes[13]. However, it remains to be seen whether the principle is a general one. The kinesin involved in amphibian melanosome movements is probably kinesin II, not conventional kinesin. Moreover, the yeast Smy1 (a kinesin-related protein) and Myo2 (a class V myosin[14]), which clearly interact genetically, lack the conserved interacting domains identified by Huang and colleagues.

As always, big research challenges lie ahead. How is the kinesin/myosin motor 'bouquet' attached to membranes? Is this a long-term attachment, or are complexes recruited from the cytoplasm when needed? Once attached, how is activity of the motors regulated? Possibly, as in many other cellular processes[15], the answer will be a large protein assembly that coordinates and regulates these activities. The direct interaction of molecular motors may just be our first glimpse at such a motor-protein machine. If confirmed, the transport of cellular goods — just as the distribution of apples — may be in the hands of closely interacting (molecular) partners. □

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Reproductive biology

Deep-sea clams feel the heat

Cindy Lee Van Dover

Reproductive behaviours — the elaborate nesting rites of birds, cannibalistic courtships of praying mantis, lumbering love of elephants — are the centrepiece of television nature shows. The more remote the location, the more secretive the behaviour, the greater the hushed awe in the narrator's voice. By these measures, then, a narrator would be moved to virtual silence by video images of giant white clams spawning in the wild, more than 1,100 m below the surface of the sea. Such images have been documented by Fujiwara *et al.*[1,2], as they describe in *Deep-Sea Research*; even more remarkably, part of the project involved experiments at these depths.

The giant white clams, *Calyptogena soyoae*, of Sagami Bay, Japan (Fig. 1, overleaf), belong to the same genus as clams living in cracks between lobes of basalt lava at hydrothermal vents in the eastern Pacific. Like the vent clams, *C. soyoae* are host to endosymbiotic, chemoautotrophic, sulphide-oxidizing microorganisms, from which they derive their nutrition[3]. In Sagami Bay, the clams thrive in dense populations of hundreds to thousands in soft sediments where cold porewaters ('cold seeps'), rich in sulphide, migrate to the surface. The Sagami clams were the subject of a video and sensor observatory that gathered images and environmental data over an 18-month period. During this time, spawning clams of both sexes were recorded 11 times, invariably associated with brief (less than two-hour) and hydrographically unexplained rises in temperature of about 0.1–0.2 °C in the overlying seawater, but uncorrelated with lunar or seasonal cycles.

What makes the new observations[1,2] especially compelling is the experimental test of the hypothesis that the clams respond reproductively to slight increases in water temperature. Using the submersible *Shinkai 2000*, Fujiwara *et al.* placed a plastic dome equipped with a light bulb over an aggregation of clams and induced spawning within five minutes of turning on the light (which increased the temperature to 2.2 °C). At least five of the ten or so clams beneath the dome took part in this reproductive activity during more than one hour of observation. As is often the case in shallow-water bivalves, male clams spawned first. The neutrally buoyant gametes formed small clouds that drifted downstream, possibly stimulating females to spawn. No clams spawned in the control treatment.

It was not so long ago that the deep sea was viewed as the most unchanging environment on our planet, with a constant temperature and lack of food. With no external cues,

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Figure 1 **The giant white clams of Sagami Bay, which live and reproduce at depths of over 1,100 m.**

deep-sea organisms were thought to have no periodicity in reproductive activity. In the past decade, however, through studies of seasonal pulses of photosynthetically derived detritus to the seabed and lagged but correlated periodicities in the reproductive condition of bottom-dwelling echinoderms[4], the idea of the deep sea as a homogeneous environment has been abandoned. Even in this modern context, the work of Fujiwara and colleagues stands out as, to my knowledge, the first experimental demonstration of a direct link between a putative external cue and reproductive response in the deep sea.

The advantage of cued reproductive behaviour in species with broadcast spawning is patent: fertilization rates are increased where spawning is synchronized, and mixed pools of gametes and then larvae generated by mass spawning may find statistical refuge from predation and loss from the system by virtue of their larger numbers. The sensitivity of the Sagami clams to minute temperature changes may be an elegant reflection of the capacity for fine-tuning of animal to environment, and of the selective advantage of reproductive synchrony in this species.

Based on histological studies, such synchrony has been inferred for several organisms inhabiting deep-sea hydrothermal vents as well[5], begging the question of what the cues are in these ecosystems. Temperature might seem an unlikely possibility, given the already thermal nature of the system, but in fact predictable tidal signals are readily detected in time-series measurements at hydrothermal vents, with waxings and wanings of flow and thermal anomalies on diurnal and other lunar cycles[6]. Elaborations on the spawning experiments of Fujiwara *et al.* may allow resolution of some of the unanswered questions about reproductive behaviour and larval development in vent organisms. □

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Quantum control

Sculpting a wavepacket

Wolfgang P. Schleich

Thirty years ago, in a seminal article on the operational approach towards quantum mechanics, Willis E. Lamb[1] described the situation in quantum theory and measurement[2] by quoting Mark Twain: "Everybody talks about the weather but nobody does anything about it". In the past few years, this situation has changed drastically — we now have precise instructions for two of the main stages of the measurement process in quantum mechanics, preparation and measurement of the quantum state (for an overview, see ref. 3). Another breakthrough is reported on page 233 of this issue by Weinacht *et al.*[4], who describe an experiment in which they shape an atomic electron's wavefunction and drive it into a chosen state using tailored laser pulses (Fig. 1, overleaf). This work opens a new avenue in the field of coherent control and will have important applications in quantum computing and bond-selective chemistry.

Classical mechanics governs the motion of macroscopic objects; for example, the state and future motion of a tennis ball is completely determined by its position and momentum at a given time. In contrast, quantum mechanics is needed to describe the motion of microscopic objects, such as an electron in an atom. Heisenberg's uncertainty principle forbids assigning both a well-defined position and momentum to the electron. So, to determine completely the state of this quantum mechanical system, we need a whole distribution of position *and* momentum values for the electron (that is, the Wigner function).

Another way of expressing the state of a quantum mechanical system is the wavefunction, introduced in 1926 by Erwin Schrödinger. This quantity is a function of either position *or* momentum, and can take on complex values, having both real and imaginary parts. In the early days of quantum mechanics the physical interpretation of the wavefunction was subject to heated debate, and Schrödinger originally argued that only the real part of this quantity had physical significance. However, Max Born pointed out that only the absolute value squared of the wavefunction is directly experimentally accessible and corresponds to the probability of finding the position or momentum of a particle. (These historical discussions are summarized in ref. 2.) Since we can always represent a complex number by its amplitude and phase, this implies that only the amplitude can be measured directly. The phase is also needed to uniquely describe the quantum state, but how does one find this phase experimentally?

The question of 'phase retrieval' has a long experimental and theoretical history in classical optics, and in the field of quantum theory Wolfgang Pauli addressed it for the first time in 1933. Only recently, however, have techniques[3] to reconstruct the complete wavefunction of a quantum mechanical system been implemented experimentally — in systems such as an ion, a diatomic molecule, an atomic beam or an electromagnetic field.

In a paper published last year, Weinacht *et al.*[5], reconstructed the quantum state of a bound electron in a caesium atom. They used a variant of quantum state holography[6,7] to measure the quantum state of the electron. Like classical holography, this technique relies on the interference between an object and a reference wave. In the case of a highly excited atom (a Rydberg atom), the object wave is the quantum state of the electron and the reference wave is a known state. In this experiment, which was a forerunner to the latest work, they illuminated the atom with two laser pulses derived from a common source (see lower section of Fig. 1). One pulse passed through a pulse shaper (box with dials), which allowed them to manipulate the amplitude, form and frequency of this pulse. Due to the different path lengths, there was a variable time delay between the two pulses. The first pulse (yellow) created an object wavefunction and the second one (red) served as a reference. Weinacht *et al.*[5] measured the population of the individual energy eigenstates by applying a varying electric field across the condenser plates (shown in brown in Fig. 1). References 6 and 7 provide algorithms, which allow the reconstruc-