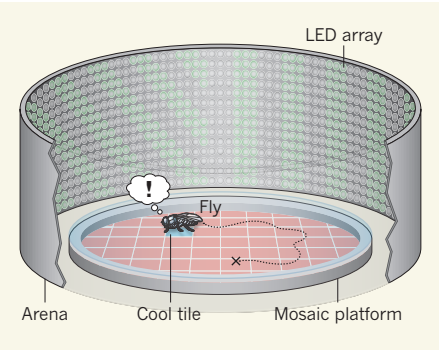

Figure 1 | Model for studying visually guided spatial memory[3]. Individual flies are free to roam on a platform made of heated tiles. Visual patterns on the surrounding walls — generated by arrays of light-emitting diodes (LEDs) — provide orientation cues to guide navigation to a single cool tile. Flies remember the position of this safe tile after the visual patterns have been rotated by 90° and the platform is uniformly heated.

left or right)[9]. In Ofstad and colleagues' test, the insects can move in any direction on the disk to reach the cool tile.

Ofstad *et al.*[3] also investigated what parts of the fly brain are required for spatial memories. Much effort has focused on the role of the mushroom bodies in memory formation; these are a pair of structures in the insect brain that are involved in some forms of learning and memory. For example, olfactory memories — which depend on the association of one of two odorants with appetitive or aversive cues and which are analysed by an orientation test between the two odorants — are formed in the mushroom bodies[10]. In cockroaches, cutting the mushroom bodies with foil blades hinders the formation of a spatial memory that also uses visual landmarks[6]. However, studies in *Drosophila* have shown[9] that the simple spatial memory tested using the heat-box paradigm does not require these structures.

Using several techniques, Ofstad and co-workers[3] show that the mushroom bodies are not required for visually guided spatial memory either. Instead, they find that altering the ellipsoid body — part of the four-component central complex that has been associated with premotor functions (involving voluntary movement) and some other types of memories — strongly reduced the flies' ability to form spatial memories. These results are consistent with the idea that there is no single centre in the fly brain for memory formation, and that specialized neural systems are crucial for different forms of memory.

In addition to the identification of parts of the nervous system that are essential for spatial memory, the authors' design of a rapid, visually guided spatial memory test in *Drosophila* raises the exciting prospect of genetic analyses of this form of memory. If results from previous comparative genetic studies[9] are anything to go by, one should expect that only some genes will have common roles in memory formation across tasks, with others having functions of greater specificity. Identification of the genes and neural circuits that are crucial for visually guided spatial memory is an exciting prospect indeed. ■

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QUANTUM PHYSICS

How to catch a wave

The wavefunction is a central mathematical entity in quantum physics. It is used to completely describe the state of a system. A means of probing it directly is now on hand. SEE LETTER P.188

ONUR HOSTEN

Quantum mechanics is the framework for describing the physics of the microscopic world. Central to this description is the wavefunction, which contains all the information about the relevant physical system. To date, experimental determination of wavefunctions has been accomplished only through inferences based on indirect measurements. But that has now changed. On page 188 of this issue, Lundeen *et al.*[1] present a method to measure the wavefunction directly.

The complex-valued wavefunction associated with a quantum system is not itself considered to be a physical element of quantum theory. Nevertheless, its absolute square, for instance, represents a probability distribution associated with particular outcomes of an experiment; for example, the outcome of finding a particle at a certain location. In this context, a question naturally arises: despite its abstract existence, can an unknown wavefunction of a system be determined experimentally? With just a single copy of the system in hand, this turns out to be impossible — even in principle — owing to the random disturbance that the measurement process imposes on the system[2]. However, with an ensemble of identically prepared systems, it is possible to determine the wavefunction.

By making a set of measurements of each of several different physical properties on the ensemble of identically prepared systems, and using the obtained probability distributions associated with these properties, the sought-after wavefunction can be constructed algorithmically. This indirect way of characterizing the wavefunction is known as quantum-state tomography[3,4], and it has been a quintessential tool in the field of quantum-information science. By contrast, Lundeen and colleagues' method[1] directly probes the real and imaginary parts of the wavefunction of the ensemble, as they demonstrate with measurements carried out on the transverse spatial wavefunction of single photons.

The key to their technique is the concept of weak quantum measurements. In a generic quantum measurement, the system to be measured is first coupled to another system, the meter, and information about a property of the system, the observable, is acquired from the meter. The system–meter coupling moves the pointer of the meter by different amounts for different states of the observable, and the initial location of the pointer contains some quantum uncertainty. The measurement is said to be a strong one, after the system–meter interaction is over, if the pointer states corresponding to different states of the observable move away from one another by more than the initial uncertainty on the pointer. A weak measurement is simply the case in which the relevant pointer states still overlap to a large extent, yielding little information about the system and disturbing it insignificantly in a single measurement.

Weak measurements take on a new life when combined with post-selection — that is, when they are conditioned on the outcome of a following strong measurement. Prior to post-selection, the centre of the pointer shows the average value of the measured observable. Following post-selection, owing to an interference effect, the pointer shifts to a new value called the weak value of the observable[5]. Note that ascertaining a weak value requires many repetitions of the same measurement on identically prepared systems, so that the pointer's centre can be identified. In the past two decades, weak values have been used extensively to analyse certain quantum paradoxes, for example Hardy's paradox[6], and most recently

they have led to quite useful techniques for measuring small signals[7,8].

At the heart of Lundeen and colleagues' method[1] lies the observation that a weak measurement of a particle's position followed by a strong measurement of its momentum should yield the particle's spatial wavefunction as the weak value, provided that the measured momentum is zero. A photon's position along an axis (x-axis) transverse to a chosen central propagation axis (z-axis) is no exception to this argument. In their experiment, Lundeen *et al.* obtain single photons by means of a process known as spontaneous parametric down-conversion, and, with various optical elements, shape the to-be-determined transverse spatial wavefunction ($\Psi(x)$, where x is the spatial position) of the photons. The meter they use for the weak measurements is the polarization of the very same photons, which serves as a qubit (two-level) meter[9]. A narrow piece cut from an optical element called a waveplate placed at position $x = x_0$ (say at $z = 0$) implements the weak-measurement coupling, rotating very slightly the polarization of the photons if they propagate through this location.

Post-selection of photons with zero momentum is accomplished by first sending the photons through a lens, and then, at the focal plane, blocking all the photons but the ones at position $x = 0$ with a narrow slit. After this stage, an analysis of the polarization of the remaining photons yields $\Psi(x_0)$. In particular, by convention, the average rotation of the polarization is proportional to the real part of $\Psi(x_0)$, and the average change in the ellipticity of the polarization is proportional to the imaginary part of $\Psi(x_0)$. This procedure is repeated for different positions x of the waveplate to map out the complete wavefunction $\Psi(x)$ at $z = 0$. Lundeen and colleagues show that the described procedure works reliably.

The authors' finding — as I phrase it colloquially, that a wavefunction meter can be built to probe wavefunctions, almost like a voltmeter (or oscilloscope) is used to measure voltages — is conceptually rather surprising. Beyond philosophical issues, the results represent a practical finding: their method can be used as a tool in a wide range of fields, from optical to atomic to solid-state physics, all of which are touched on by quantum-information science. But whether the current method can be a viable alternative to quantum-state tomography is yet to be explored. This will require testing if the system–meter coupling can be practically realized in various physical systems and circumstances. It would be interesting to see this work extended to wavefunctions of multi-particle entangled quantum states. ■

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DNA REPAIR

Cyclin D1 multitasks

Cyclin D1 is one of the drivers of the cell cycle, and its deregulation may promote the development of tumours. Surprisingly, this protein also mediates the repair of damaged DNA, a mechanism that commonly prevents cancer. SEE LETTER P.230

JIRI BARTEK & JIRI LUKAS

The maintenance of genome integrity is a fundamental biological process. A complex network of proteins detects damaged DNA, signals this detection and repairs the damage, to prevent life-threatening diseases such as cancer[1]. This machinery is particularly crucial in cells going through the cell-division cycle, a proliferative process that can go awry in various cancers[1,2]. But the orchestration of the DNA-damage response and the cell cycle is far from understood, despite the key roles of the two processes in cell physiology and pathology. An exciting report by Jirawatnotai and colleagues in this issue[3] (page 230) sheds new light on the matter, identifying an unexpected function for the cell-cycle protein cyclin D1 in DNA repair.

Cyclin proteins drive the cell cycle in partnership with a family of catalytic proteins called cyclin-dependent kinases (CDKs). Various cyclin–CDK complexes fuel the highly regulated progression through the G1, S, G2 and M phases of the cycle by phosphorylating — thereby activating or inactivating — a