Individually, detailed control of the whole lattice is possible (I. Bloch, MPI für Quantenoptik, Garching), allowing complex entangled states of many atoms to be created.

Entanglement, in which the properties of different atoms are inextricably intertwined, is a key quantum phenomenon that underlies quantum information processing. Entangled atoms could be used to implement certain quantum algorithms (I. Cirac, MPI für Quantenoptik, Garching). In particular, it should be possible to use this system to simulate the properties of other, less well-controlled, quantum systems.

Trapped atoms and ions can be studied today, but many researchers believe that the future of QIP lies with solid-state devices (A. Briggs, Univ. Oxford). One early proposal that generated a great deal of excitement uses the spin of phosphorus nuclei implanted in a silicon matrix to store the quantum information. The nuclei are controlled and observed through the behaviour of their surrounding electrons.

Building such a device would be extremely difficult, involving placing individual atoms at precisely known locations inside a silicon chip and then building tiny electrodes and transistors around them. These ideas have been demonstrated (R. Clark, Univ. New South Wales) and a device with two phosphorus atoms has been constructed. Early results suggest that these two atoms can be controlled and observed. Another proposal based on superconducting quantum interference devices (SQUIDs) has also made substantial progress (G. Wendin, Chalmers Univ., Göteborg). Several working single-atom SQUID devices have been constructed, and attempts to couple two SQUIDs are underway.

In addition to the new results announced at the meeting, several themes for future work emerged. Although many simple demonstrations of QIP have been achieved, only one of these, quantum cryptography (J. Rarity, QinetiQ), could really be described as practical. But before we can make existing toy systems do something useful, we will have to greatly improve the precision of quantum logic gates (J. Jones, Univ. Oxford) and of sources and detectors (I. Walmsley, Univ. Oxford).

It has long been noted that there seems to be a close connection between the controllable interactions needed to implement quantum logic, and the uncontrollable interactions that cause decoherence. Is this simply an artefact of the systems studied so far, or does it reflect some underlying principle? In fact, whenever two quantum objects interact with one another they must also interact with their environment (A. Fisher, Univ. College London). The strengths of these desirable and undesirable interactions are inevitably related, and real quantum computers will need this ratio to be as large as possible. To achieve this will require an extremely careful choice of environment.

Will these ideas lead to a practical quantum computer? The progress so far is remarkable, but the difficulties can hardly be overstated. Whether or not we eventually get there, we will certainly see some interesting scenery on the way.

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Neurobiology

The importance of depression

Charles F. Stevens

We, and other animals, can generally pinpoint the source of a sound in space regardless of how loud it is. A study involving experimentation and computer modelling reveals how our brains perform this clever task.

Information flows from one nerve cell to the next at highly specialized points of contact called synapses. All synapses exhibit depression — a decrease in the strength of the connection that occurs after rapid and repeated use — and this might seem like a bad idea, a design fault that prevents synapses from keeping up with the demands placed on them. But on page 66 of this issue, Cook and colleagues show that depression is a feature, not a bug, in auditory synaptic transmission. In fact, synaptic depression is used to compute sound levels and to correct neuronal signals, so that the brain’s representation of the source of a sound in space is not confounded by the intensity of the sound.

Comprehending the contribution made by Cook et al. depends on understanding one of the main ways in which we determine the spatial source of sounds. You may have noticed that when you hear a series of noises whose source you cannot locate — a bird chirping, for example — you automatically turn your head as you listen. This is because you determine the location of the sound by using the tiny differences in the time it takes for the sounds to reach your two ears. And you turn your head to maximize this difference. If you are facing the source of a sound, the signal arrives simultaneously at both ears, but if the sound originates from, say, your left side, the signal is not generated on each cycle of the sound wave. If this time-locking did not occur, you would not work, because the brain needs precise information about the relative arrival times of sounds at the two ears. A nerve impulse is not generated on each cycle of the sound pressure wave; rather, many cycles are skipped in any particular nerve fibre, so that only by looking across a population of inputs can the brain know when each wave arrived. As sound intensity increases, however, nerves fire on more and more of the cycles. So, the average number of nerve impulses per second depends on sound intensity, whereas the timing of each impulse, relative to the phase of the sound wave, is independent of intensity.

The fact that higher-intensity sounds

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produce more nerve impulses causes a potentially serious problem for the neuronal mechanisms used to locate the source of the sound. Each olivary neuron doing the coincidence detection receives inputs from many neurons stimulated by each ear, so that the system still works even when any particular axon fails to produce a nerve impulse on a specific cycle of the sound wave. But if too many axons from one ear produce impulses on a particular cycle—something that could happen with loud sounds—then the coincidence of the many inputs from just that ear would be capable of producing an output in the medial olivary nucleus (or the nucleus laminaris), and the localization mechanism would break down. Behaviourally, though, we and other animals can pinpoint a sound's spatial source pretty accurately irrespective of its intensity. How do the coincidence detectors keep from being overwhelmed by loud sounds? This is the question that Cook et al. asked.

Because the problem with loud sounds is that they cause nerve impulses to be produced on too many cycles of the sound pressure wave, Cook et al. reasoned that an easy way for the brain to compensate for this would be to decrease the amount of neurotransmitter released in response to each impulse. Neurotransmitters are the chemicals that pass signals at synapses from one neuron (here, an ear-stimulated neuron) to the next (an olivary neuron). In other words, if the synapses were correctly depressed with use, this could compensate for the greater number of impulses.

To test this idea, Cook et al. characterized the properties of depression at the input synapses of the nucleus laminaris in chicks, and found that these synapses do indeed decrease in strength with use. But can this depression actually compensate for the too-large inputs that result from loud sounds? To find out, the authors constructed a biophysically realistic computer model of neurons from the nucleus laminaris, and incorporated the synaptic depression as found in their experiments. They could then examine the effect of synaptic depression on coincidence detection by simply turning depression on or off in the model. Indeed, Cook et al. found that coincidence detection in their model works well, irrespective of sound loudness, when synaptic depression is present, but not when it is absent. Synaptic depression is a feature of neural computation, not a bug.

Short-term synaptic plasticity—the increase and decrease of synaptic strength that depends on the history of synaptic use—is a prominent feature of all synapses, and can easily cause several-fold changes in synaptic strength. Although various authors have speculated that short-term plasticity provides a functionally important dynamic filter for arriving nerve impulses (see the first four citations in ref. 2), testing this notion is difficult and the earlier work was mainly speculative. Cook et al. have provided the first documented use for such plasticity.

Now we need to understand the mechanisms through which the correct properties of synaptic plasticity are set up in development and then adjusted throughout life. Charles F. Stevens is at the Molecular Neurobiology Laboratory at the Salk Institute, and the Howard Hughes Medical Institute, 10010 North Torrey Pines Road, La Jolla, California 92037, USA. e-mail: stevens@salk.edu


**Sodium at Io**

**Donald M. Hunten**

It has been known for some years that Jupiter's satellite Io has sodium as a component of its atmosphere. The source, it now seems, is sodium chloride emitted by volcanoes on Io's surface.

Io, the innermost of Jupiter's four Galilean satellites, is anomalous in various respects. One curiosity is its atmosphere, and the 'plasma torus' of ionized matter through which the planet orbits. On page 45 of this issue, Lellouch et al. describe observations that will help settle thinking about a puzzling constituent of the atmosphere and torus, and its origins.

The true dimension of Io's strangeness first became apparent only in 1974, when R. A. Brown identified the intense emission of yellow 'sodium D lines' in spectroscopic studies of Io. It was soon established that these emissions come from an extended region—the 'neutral torus'—that is much larger than the visual disk of Io and which shares its orbit around Jupiter. Two years later came the discovery that this region is also occupied by Io's plasma torus, which consists of ionized material that has been created by the impact of electrons on neutral molecules and atoms. The satellite's orbit is embedded in the torus, which has turned...