whole and by consciously applying rules they had been taught in language therapy[11]. These and other strategies allow them to converse competently, although this has made life difficult for psycholinguists trying to work out the underlying disorder from the behaviour of affected adults.

If *FOXP2* really does prove necessary for the development of the human faculty of language and speech, one can imagine unprecedented lines of future research. Comparisons of the gene in humans to those in chimpanzees and other primates, and analyses of the types and patterns of sequence variation within the region of *FOXP2*, could add to our understanding of how human language evolved[12,13]. An examination of the functions and expression patterns of the gene (and of other genes it might set off) in fetal and adult brain tissue could shed light on how parts of the human brain are prepared for their role in cognitive information processing.

The discovery of a gene implicated in speech and language is among the first fruits of the Human Genome Project for the cognitive sciences. Just as the 1990s are remembered as the decade of the brain and the dawn of cognitive neuroscience, the first decade of the twenty-first century may well be thought of as the decade of the gene and the dawn of cognitive genetics. ■

Steven Pinker is in the Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA.
e-mail: steve@psyche.mit.edu

1. Darwin, C. *Descent of Man* (John Murray, London, 1871).
2. Lai, C. S. L., Fisher, S. E., Hurst, J. A., Vargha-Khadem, F. & Monaco, A. P. *Nature* **413,** 519–523 (2001).
3. Chomsky, N. *Language* **35,** 26–58 (1959).
4. Lenneberg, E. in *The Structure of Language: Readings in the Philosophy of Language* (eds Fodor, J. A. & Katz, J. J.) 579–603 (Prentice-Hall, Englewood Cliffs, NJ, 1964).
5. Stromswold, K. *Language* (in the press).
6. Hurst, J. A., Baraitser, M., Auger, E., Graham, F. & Norrell, S. *Dev. Med. Child Neurol.* **32,** 347–355 (1990).
7. Gopnik, M. & Crago, M. *Cognition* **39,** 1–50 (1991).
8. Vargha-Khadem, F. *et al. Proc. Natl Acad. Sci. USA* **92,** 930–933 (1995).
9. Pinker, S. *Words and Rules: The Ingredients of Language* (Basic Books, New York, 1999).
10. Fisher, S. E., Vargha-Khadem, F., Watkins, K. E., Monaco, A. P. & Pembrey, M. E. *Nature Genet.* **18,** 168–170 (1998).
11. Ullman, M. T. & Gopnik, M. *Appl. Psycholing.* **20,** 51–117 (1999).
12. Kreitman, M. *Annu. Rev. Genom. Hum. Genet.* **1,** 539–559 (2000).
13. Aquadro, C. in *Limits to Knowledge in Evolutionary Biology* (eds Clegg, M. T., Hecht, M. K. & MacIntyre, J.) 135–149 (Plenum, New York, 1999).

Bose–Einstein condensates

Mastering the language of atoms

Ron Folman and Jörg Schmiedmayer

Physicists can already make ultracold atoms perform quantum tricks in sophisticated magnetic and optical traps. But a fast route to trapping atoms on a microchip opens up new possibilities.

Atoms are the building blocks of all matter. They have a positively charged nucleus and their outer boundaries are defined by electron clouds. They remain electrically neutral, but the number of electrons governs their chemical properties. Atoms have long been studied and exploited by mankind. Yet we are just now learning a whole new way of communicating with them. On page 498 of this issue, Reichel and colleagues[1] describe another step on this journey. Their achievement may result in new insights into the foundations of quantum theory, and lead to applications on the verge of science fiction such as the quantum computer.

Six years ago a new state of matter[2–7] — the Bose–Einstein condensate (BEC), named after those who predicted its existence — was first created in a dilute gas of atoms. In a BEC, the usual energy distribution for an ensemble of particles no longer exists; all particles are forced to acquire the same energy. Furthermore, this energy is always the lowest allowed by quantum theory; it can be close but not equal to zero. A BEC contains up to ten million atoms, all at a temperature just above absolute zero (a few nanokelvin). In such a state, the macroscopic cloud of atoms has quantum features, which are distinctly different from those of the classical world we observe around us.

Until now, such clouds of ultracold atoms have only been handled from a distance. This is mainly because a BEC is so delicate that any contact with other atoms will destroy it. For this reason, BEC experiments are performed inside ultrahigh-vacuum chambers, providing an environment similar to that found in space. The clouds are trapped, manipulated and observed in magnetic, electric or light fields, which usually originate from sources outside the chamber, such as lasers or magnetic coils. The geometry of traps produced by these sources is therefore limited. A source close to the BEC could provide much tighter and more complex traps, but there were fears that the ultralow-temperature cloud would not survive in the presence of higher-temperature objects.

The achievement of Reichel and colleagues[1] in Munich — and the parallel work by C. Zimmermann's group in Tübingen[8] — is to put the source of the trapping fields inside the ultrahigh-vacuum chamber, a few tens of micrometres away from the atom cloud. The experiments solve both of the

Box 1 The atom-chip toolbox

Many of today's electronic devices are unthinkable without miniaturization. By similarly shrinking elements used in atom optics, such as atom traps, guides, mirrors, beam-splitters and interferometers, and by fabricating them using modern solid-state techniques (lithography) stemming from electronics and optics, physicists hope to achieve a similar level of control over atoms as they have over electrons and photons. The preparation, manipulation and measurement sensitivity must reach a level at which quantum effects are dominant.

Why use atom chips? First, studying quantum behaviour requires the observed system to be isolated from its environment because any interaction would quickly destroy the delicate quantum effects. The neutral atom is an excellent choice in this matter — because it has no charge, it interacts with its environment in a relatively weak way.

Second, chips offer a platform that is robust, scaleable (it allows for arrays of traps, for example) and accurate. Together, atoms and chips make a powerful combination. Lithographic techniques can now create structures with length scales below 100 nm, which is smaller than the quantum-mechanical (de Broglie) wavelength of the cooled atoms, ensuring control at the quantum level. The small size of the traps allows atoms to be positioned in individual sites separated by small distances, enabling them to interact in a controlled way. Because the atoms themselves are well localized (within 10 nm) they can be manipulated and detected by miniaturized light elements, such as micro-cavities and solid-state wave guides, which today can be fabricated on the same chip.

A long-term goal is to fabricate everything on the same chip — from the light sources (micro-lasers) to the readout electronics — producing a truly integrated self-sufficient device. The hope is that such devices will do for quantum atom optics what integrated circuits did for electronics. Atom chips are already an outstanding research tool. Perhaps the day is not far off when they will also be household items, in clocks, communications and even computing. **R. F. & J. S.**

above problems: the proximity of the source enables more complex, tight and accurate manipulation of the BEC, and the BEC survives being close to the much warmer object. Moreover, the Munich researchers have taken it one step further by creating an atom 'conveyer belt' to move the BEC cloud around at will.

What's more, the Munich group showed that the initial formation of the BEC is also much simpler than in previous experiments, as less stringent ultrahigh-vacuum requirements are needed. This is because the tight traps they have created reduce the cooling time of the atoms by more than a factor of ten — a BEC can now be formed in less than a second. These short cooling times mean that any unwelcome atoms in the chamber have much less time to destroy the cloud.

How did they do it? Both experiments use a device called an 'atom chip'[9–11], in analogy to a computer chip (Box 1). In a conventional microchip, electrons move inside miniature 'traps' formed by the wires embedded in a solid-state object[12]. In the atom chip, currents and charges also flow within wires patterned on the surface of a robust solid-state device. But unlike trapped electrons in a regular chip, here atoms hover a few micrometres above the surface of the chip — inside the invisible walls created by field potentials generated by the charges and currents inside the chip. Such surface traps help the atoms maintain their ultrahigh-vacuum environment. Researchers have already used atom chips to manipulate thermal atoms, but until now no one was sure it could be done with a BEC.

Now that we are able to trap and cool the atoms, we can control their position and velocity. We also know how to control their internal properties, such as the state of the electron clouds in the atom, known as hyperfine states. So all the relevant parameters can now be controlled and measured. This should encourage new experiments in atom manipulation (matter–wave quantum optics[13]), including chaos (using complex field potentials), nonlinearity (due to atom–atom interactions), entanglement (atom–atom correlations), atom–light interactions, low-dimensional physics and more.

Another issue in need of more insight is quantum decoherence. This is the process responsible for the classical features of our everyday world, despite its underlying quantum nature — it is what happens when a quantum state is destroyed. This elusive border between classical and quantum states has been a source of debate and confusion since the early days of quantum theory[14]. In atom-chip experiments, decoherence can be examined in complicated potentials and with carefully tailored environments. Furthermore, the question of surface-induced decoherence can be addressed in detail; this is important because such decoherence may undermine the whole concept of the atom chip[15].

What next? The atom chip might lead to miniaturized versions of highly accurate atomic clocks and acceleration sensors[16], which are already used for precision measurements. Such tiny systems could be useful in navigation systems. The atom chip could also be integrated into quantum communication and encryption systems, which ensure information security. In quantum information, a 'qubit' is the quantum equivalent of a classical 'bit' of information. So, for example, the atom chip may enable the conversion of 'flying qubits' (photons that can travel along optical fibres) into 'storage qubits' — atoms that can be kept in a single location for a long time without changing their quantum state. A final example, and the most far-reaching, is the quantum computer, for which quantum theory predicts a new type of computing logic, able in some cases to outrun the present classical computers by many orders of magnitude in processing time[17,18]. Once further advances are made on issues such as single-atom trapping and controlled entanglement, which are needed to do computations[19], the atom chip could turn out to be the obvious choice for building a quantum computer. ■

Ron Folman and Jörg Schmiedmayer are at the Physikalisches Institute, University of Heidelberg, Philosophen weg 12, Heidelberg 69120, Germany.
e-mails: folman@physi.uni-heidelberg.de
schmiedmayer@physi.uni-heidelberg.de

---

1. Hänsel, W., Hommelhoff, P., Hänsch, T. W. & Reichel, J. *Nature* **413,** 498–501 (2001).
2. Anderson, M. H. *et al. Science* **269,** 198–201 (1995).
3. Metcalf, H. & van der Straten, P. *Phys. Rep.* **244,** 203–285 (1994).
4. Ketterle, W. & van Druten, N. J. *Adv. Atom. Mol. Opt. Phys.* **37,** 181–236 (1996).
5. Chu, S. *Rev. Mod. Phys.* **70,** 685–706 (1998).
6. Cohen-Tannoudji, C. *Rev. Mod. Phys.* **70,** 707–719 (1998).
7. Phillips, W. D. *Rev. Mod. Phys.* **70,** 721–741 (1998).
8. Ott, H. *et al.* http://arXiv.org/abs/cond-mat/0109322
9. Folman, R. *et al. Phys. Rev. Lett.* **84,** 4749–4752 (2000).
10. Folman, R. *et al. Adv. Atom. Mol. Opt. Phys.* (in the press).
11. European ACQUIRE collaboration: http://www.physi.uni-heidelberg.de/groups/acquire/esummary.htm
12. Buks, E. *et al. Nature* **391,** 871–874 (1998).
13. Berman, P. R. (ed.) *Atom Interferometry* (Academic, San Diego, 1997).
14. Giulini, D. *et al. Decoherence and the Appearance of a Classical World in Quantum Theory* (Springer, Berlin, 1996).
15. Henkel, C. & Wilkens, M. *Europhys. Lett.* **47,** 414–420 (1999).
16. Peters, A., Chung, K. Y. & Chu, S. *Nature* **400,** 849–852 (1999).
17. Bouwmeester, D., Ekert, A. & Zeilinger, A. (eds) *The Physics of Quantum Information* (Springer, Berlin, 2000).
18. Bennett, C. H. & DiVincenzo, D. P. *Nature* **404,** 247–255 (2000).
19. Zoller, P. http://th-physik.uibk.ac.at/qo/zoller/PZListOf Publications.html

---

Bacterial genomics

A plague o' both your hosts

Stewart T. Cole and Carmen Buchrieser

The genome of the bacterium that causes plague is highly dynamic, and scarred by genes acquired from other organisms. Does this explain its ability to kill both mammals and insects?

The course of human evolution has been shaped by three major factors: natural disasters, wars and infectious diseases such as tuberculosis, syphilis, typhus and cholera. In the past few years the darkest secrets of the bacteria responsible for each of these diseases have been unveiled by genomics, and on page 523 of this issue[1] Parkhill and colleagues describe the latest subject of this approach — *Yersinia pestis*, the bacterium that causes plague. Ten years ago, at the height of Operation Desert Storm, the threat of biological weapons was ever present (and today that threat has reared its head again, in the form of bioterrorism). Foremost among these weapons was *Y. pestis*, a formidable airborne adversary that rapidly kills humans if left to its own devices.

There have been three plague pandemics, which were collectively responsible for the loss of 200 million lives. The second of these left an indelible mark on world history: over one-third of the population of Europe succumbed to the disease between 1347 and 1350. There was, however, some hidden benefit for the survivors and their descendants, as the pandemic contributed to the elimination of leprosy from the continent by removing the reservoir of the causative organism, *Mycobacterium leprae*[2]. At the time, leprosy patients were sequestered in leprosaria run by various religious orders, and neither the carers nor the cared-for were spared by the Black Death. Intriguingly, as we will see below, there are many parallels between the genomes of the plague and leprosy bacteria. During the third pandemic, which spread from south China in 1894, Alexandre Yersin isolated the bacterium that now bears his name, and a little later Paul-Louis Simond showed that fleas are involved in transmitting plague.

Yersinia pestis has an interesting yet complex natural history involving a mammalian reservoir and an insect vector (Fig. 1, overleaf). It is primarily a rodent pathogen, with a predilection for rats, and is usually transmitted to humans by fleas following the death of the rodent. The bacterium then spreads from the initial site of infection, the flea-bite, to the lymph nodes, where local replication causes a swelling, or bubo, lead-