extreme; humans are even slower. From this perspective, the question to ask is, what caused the extension of lifespan in human evolution?

The answer may lie in grandmothers' contribution to childcare. Unlike other primates, including chimpanzees[10], human children are unable to feed themselves when they reach weaning age. The foods we rely on are too difficult for young children to handle. This gives women whose fertility is ending (so they have no newborns of their own) an opportunity to influence the reproductive success of their daughters and survival of their grandchildren through assistance in food provisioning. In an ancestral population that was shifting from chimpanzee-like feeding to hard-to-handle foods[11], the more vigorous elder females could help more, thereby increasing the representation of their vigour in descendant generations, shifting rates of ageing[12], and lengthening average adult lifespans[13].

This 'grandmother hypothesis' accounts for various similarities and differences between the life histories of human females and those of our nearest living relatives. We live longer, mature later and space births more closely during the child-bearing years, whereas our fertility declines and we reach menopause at similar ages[14]. But does the hypothesis stand up to scrutiny?

A few studies have hinted at the relationship between postmenopausal longevity and the welfare of a woman's descendants, but most have been concerned about the timing of menopause. Lahdenperä and colleagues[1] focus squarely on the longevity question. They have analysed multi-generation records from two eighteenth- and nineteenth-century populations, Finnish (slow-growing) and Canadian (fast-growing). They show that in both of these populations the duration of a woman's postmenopausal survival affects both the reproductive success of her children and the survival of her grandchildren.

In neither the Finnish nor Canadian populations are these effects due to secular changes in both family size and longevity, or geographical differences that might give the same relationship independent of grandmother effects. Other studies have sometimes identified associations between postmenopausal longevity and numbers of children[15], and different grandmother effects through sons and daughters. Lahdenperä *et al.* find neither.

Finer-grained data for the Finnish population allow them to go further. Both sons and daughters who had a living mother past menopause had children sooner and at shorter intervals, and raised more of them to adulthood. These differences are independent of differences in wealth, and increased the longer the mothers lived. Fewer grandchildren were born if the grandmother was not living in the same village. Because postmenopausal mothers were at different ages when each of their children had children, Lahdenperä *et al.* could compare the success of children of the same mother depending on whether she was alive or dead, improving the likelihood that differences are due to her help. Grandmothers' effect on the survival of grandchildren did not begin until the children reached weaning age, another detail indicating that the investigators were directly measuring her help. By controlling so many of the likely confounding factors, Lahdenperä and colleagues show that the family assistance provided by grandmothers is a central determinant of our longevity.


POPPERFOTO.COM

Figure 2 **Helping hands for the young — Granny provides assistance.**

We age slowly. Physiological mechanisms must underlie that[16]. Accumulating evidence (referenced in ref. 13) shows that humans allocate more to cell and molecular maintenance and repair than do our nearest primate relatives. The grandmother hypothesis attributes our slow ageing to the help that older females can give their descendants[12]; females ageing more slowly in physiological systems other than their ovaries could help more. Questions about male life histories involve different trade-offs, but this hypothesis about shifting rates of ageing has implications for longevity in both sexes. Daughters and sons both inherit genes affecting levels of cellular maintenance and repair from their mothers. While others work to unravel these mechanisms, Lahdenperä and colleagues have found evidence that can help to explain why they are set differently in us than in our nearest nonhuman kin. ■

Kristen Hawkes is in the Department of Anthropology, University of Utah, 270 S. 1400 E. Stewart 102, Salt Lake City, Utah 84102, USA.
e-mail: hawkes@anthro.utah.edu

1. Lahdenperä, M., Lummaa, V., Helle, S., Tremblay, M. & Russell, A. F. *Nature* **428,** 178–181 (2004).
2. Oeppen, J. & Vaupel, J. W. *Science* **296,** 1029–1031 (2002).
3. Nishida, T. *et al. Am. J. Primatol.* **59,** 99–121 (2003).
4. Hill, K. *et al. J. Hum. Evol.* **39,** 1–14 (2001).
5. Kaplan, H. K. *Pop. Dev. Rev.* **20,** 753–791 (1994).
6. Harvey, P. H., Read, A. F. & Promislow, D. E. L. *Oxford Surv. Evol. Biol.* **6,** 13–31 (1989).
7. Ricklefs, R. E. *Am. Nat.* **152,** 24–44 (1998).
8. Charnov, E. L. *Life History Invariants: Some Explorations of Symmetry in Evolutionary Ecology* (Oxford Univ. Press, 1993).
9. Alvarez, H. P. *Am. J. Phys. Anthropol.* **133,** 435–450 (2000).
10. Goodall, J. *The Chimpanzees of Gombe* (Harvard Univ. Press, Cambridge, MA, 1986).
11. O'Connell, J. F., Hawkes, K. & Blurton Jones, N. G. *J. Hum. Evol.* **36,** 461–485 (1999).
12. Lee, R. D. *Proc. Natl Acad. Sci. USA* **100,** 9637–9642 (2003).
13. Hawkes, K. *Am. J. Hum. Biol.* **15,** 380–400 (2003).
14. Hawkes, K., O'Connell, J. F. & Blurton Jones, N. G. in *Primate Life Histories and Socioecology* (eds Kappeler, P. & Pereira, M.) 204–227 (Univ. Chicago Press, 2003).
15. Doblhammer, G. & Oeppen, J. *Proc. R. Soc. Lond. B* **270,** 1541–1547 (2003).
16. Ricklefs, R. E. & Wikelski, M. *Trends Ecol. Evol.* **17,** 462–468 (2002).
17. Coale, A. J. & Demeny, P. *Regional Model Life Tables and Stable Populations* 2nd edn (Princeton Univ. Press, 1983).

Quantum information

Flight of the qubit

Eugene Polzik

A trapped ion emits a photon. Ion and photon are entangled, so the photon carries away information on the state of the ion. Now realized, this system could become a communication link in a quantum network.

A quantum computer would be capable of performing certain operations, such as factoring large numbers, exponentially faster than its classical counterpart. It could also efficiently model processes that are excessively difficult to model using existing technology. Building such a computer is a formidable task, but spectacular progress has been made in the past few years. It is now widely acknowledged that one of the most promising systems for quantum computation is an array of ions, trapped and controlled inside an electric field. The initial proposal[1] by Ignacio Cirac and Peter Zoller in 1995 has since been followed up by a train of theoretical and experimental breakthroughs, which last year arrived at the demonstration of elementary quantum logic gates using trapped ions[2,3]. Now (page 153 of this issue), Blinov *et al.*[4] report the first observation of entanglement between a trapped ion and light — a significant step towards building a quantum network.

Entanglement is a quantum correlation between various parts of a system and is required for processing quantum information. The quantum logic gates[2,3] involving trapped ions were built with short-range entanglement, over only a few micrometres, created by electrical interaction between the ions. Such short-range interaction is not suitable for linking distant nodes of a quantum computer, let alone a large-scale network of such computers. Quantum networks should be linked with light, which is the best long-distance carrier of information, be it classical or quantum.

In a classical computer, bits of information are physically implemented as charges on tiny capacitors, and can take two distinct values, usually denoted 0 and 1. Quantum mechanics, however, allows for a superposition of states (written as $|0> + |1>$). This superposition, called a quantum bit or 'qubit', dramatically enhances computing and communication capabilities.

More specifically, in the work of Blinov *et al.*[4], a qubit formed by a trapped ion can exist in a superposition of two different orientations of its magnetic momentum, say 'up' and 'down', or +1 and −1. The superposition is then described as $\alpha|-1> + \beta|+1>$, where α and β are coefficients normalized so that the probability of the ion being somewhere is one: $|\alpha|^2 + |\beta|^2 = 1$. The trick by which Blinov *et al.* entangled an ion and a photon was to bring the ion into this superposition of states through the emission of the photon.

According to the conservation of angular momentum, if the ion is created in a spin-down state $|-1>$, the emitted photon is circularly polarized (a property of its electric-field vector) in the right-hand direction — let's call this state of photon polarization $|->$. Similarly, if the ion is created in a spin-up state $|+1>$, the emitted photon has left-hand circular polarization ($|+>$). Most importantly, if the ion ends up in an unknown superposition of spin-up and spin-down states, the emitted photon has a complementary superposition state. This is the essence of entanglement of two qubits, which can be written as a joint state for the ion–photon system, $\alpha|-1>|-> + \beta|+1>|+>$.

Such an entangled state has been generated before, most often between two photons, but also for two ions[2,3], two atoms[5] or an atom and a microwave photon in a cavity[5]. In fact, entanglement between atoms and light has been hinted at in a variety of experiments: for example, in the quantum correlations in light emitted by atomic ensembles[6,7]; in work on spin squeezing[8] and the entanglement of atomic ensembles[9]; and in early experiments on Bell inequalities, in which two photons were emitted by a single atom[10,11].

The real breakthrough achieved by Blinov *et al.*[4] is that, for the first time, entanglement has been observed between a stationary computational qubit (a trapped ion) and a 'flying' communication qubit (an optical photon). The emitted photon can carry a unique piece of information about the state of the ion over a long distance. Another advantage of the system is that trapped ions have exceptionally long lifetimes in entangled states. Although in this experiment the lifetime of demonstrated entanglement did not exceed a microsecond, it can potentially be increased by many orders of magnitude.

Note that the photon was emitted by the ion spontaneously. This means that the photon's state of polarization was random, as was the direction in which it was emitted. Blinov *et al.* excited the trapped ion in such a way that they could count the emitted photons one by one. They then chose to detect photons emitted only with a specific polarization and in only one direction. Although this selected only a small fraction of all photons emitted, when their detector registered a photon with a particular polarization Blinov *et al.* knew that the ion had been left in a well-defined superposition of states. (In principle, the choice of polarization at the photon detector could have been made after the photon was emitted, to demonstrate the nonlocality of the entangled photon–ion system via the violation of Bell inequalities.)

The fact that the generation of the entangled state was conditional on the detection of the photon to some extent limits the applications of this technique. However, that is not an obstacle to what seems to be the most promising application — the entanglement of two distant ions through the joint detection of two photons emitted by the two ions ('distant' in this context means tens of metres; the distance could be extended to many kilometres by using a different photon wavelength). Under present experimental conditions, the rate for this process would be small (proportional to the square of the already small rate of single-photon detection), but it could be increased by placing the ions in optical cavities. From there, the system could be scaled up by entangling each ion with its neighbour inside the trap, and a chain of such quantum circuits — a 'quantum repeater'[12] — could be constructed. Ultimately, a quantum link over a very long distance could be created. That's some way ahead, but Blinov *et al.*[4] have taken us a few more steps in this exciting direction. ■

Eugene Polzik is at the Niels Bohr Institute and at the Danish National Research Foundation Center for Quantum Optics (QUANTOP), Blegdamsvej 17, Copenhagen 2100, Denmark.
e-mail: polzik@nbi.dk

1. Cirac, J. I. & Zoller, P. *Phys. Rev. Lett.* **74,** 4091–4094 (1995).
2. Liebfried, D. *et al. Nature* **422,** 412–415 (2003).
3. Schmidt-Kaler, F. *et al. Nature* **422,** 408–411 (2003).
4. Blinov, B. B., Moehring, D. L., Duan, L.-M. & Monroe, C. *Nature* **428,** 153–157 (2004).
5. Rauschenbeutel, A. *et al. Science* **288,** 2024–2028 (2000).
6. Kuzmich, A. *et al. Nature* **423,** 731–734 (2003).
7. van der Wal, C. H. *et al. Science* **301,** 196–200 (2003).
8. Kuzmich, A., Mandel, L. & Bigelow, N. P. *Phys. Rev. Lett.* **85,** 1594–1597 (2000).
9. Julsgaard, B., Kozhekin, A. & Polzik, E. S. *Nature* **413,** 400–403 (2001).
10. Freedman, S. J. & Clauser, J. F. *Phys. Rev. Lett.* **28,** 938 (1972).
11. Aspect, A. *et al. Phys. Rev. Lett.* **47,** 460–463 (1981).
12. Briegel, H. J., Dur, W., Cirac, J. I. & Zoller, P. *Phys. Rev. Lett.* **81,** 5932–5935 (1998).

Global change

An Earth on fire

Helmut Weissert and Stefano M. Bernasconi

Fifty-five million years ago the Earth suddenly got much hotter. Events are recorded in a 'spike' in the carbon-isotope record, for which a provocative new explanation has been proposed.

In 1997–98, extreme El Niño climatic conditions in the tropical Pacific had severe consequences in Indonesia. A prolonged period of dry weather resulted in drought, and favoured the ensuing forest and peat fires (Fig. 1) that were among the largest of the past century. Massive amounts of carbon were released into the atmosphere, which led to the biggest annual increase in atmospheric CO_2 of the past 50 years[1]. Could natural wildfires, developing under more extreme climatic conditions, have had an even larger impact on the carbon cycle in the geological past? Writing in *Paleoceanography*, Kurtz and colleagues[2] propose that they did.

Kurtz *et al.* argue that 55 million years ago, during a time of dry climate, peat fires could have burned for thousands of years. They claim that these global wildfires released huge amounts of carbon into the atmosphere, which are recorded in a prominent negative 'spike' in the marine carbon-isotope record. This spike coincides with an episode known as the Palaeocene–Eocene thermal maximum, in which temperatures soared worldwide. This new model contrasts with the now widely accepted view that the negative carbon-isotope spike was produced by a huge burst of methane[3], triggered by climate-induced destabilization of methane-bearing gas hydrates beneath the sea floor.

The provocative argument developed by