to the system, which was then given a variable time for formation and crystallization of the vortices.

The vortex cores are far too small to be resolved by optical imaging. So Zwierlein and colleagues magnified the vortex cores and the whole vortex lattice by turning off the laser trap and releasing the system into free space, where it expanded. They also increased the size of the vortex cores, and thus their visibility, by changing the interaction strength during the expansion.

The authors first demonstrated the formation of vortex lattices in the lithium gas in the molecular BEC regime. Here the size of the fermion pairs is small compared with the typical interparticle distances, and a closely bound, bosonic molecule is formed (Fig. 1b). In the strongly interacting regime close to the Feshbach resonance on the BCS side, the pair size is comparable to typical interparticle distances. Here, the fermion pairs cannot bind together to form isolated molecules — yet similar vortex patterns were observed (Fig. 1c). The time required for the formation of the vortex lattice was about a hundred times longer than the expansion timescale — ruling out the possibility that vortices are formed during expansion.

The spectacular observation of vortices in a Fermi gas heralds the advent of a new era of research reaching far beyond Bose–Einstein condensation. As an immediate experimental step, interfering light fields can be used to simulate a crystal lattice[13], providing a unique tool for solving problems in condensed-matter physics[14]. And the amazing level of control demonstrated in the work of Zwierlein *et al.*[3] can be extended to more sophisticated systems — mixed Fermi systems could be used to simulate a nucleus of protons and neutrons, or exotic superconductors. This final proof of superfluidity in a Fermi system opens fantastic new prospects for many different fields of many-body quantum physics. ■

Rudolf Grimm is at the Institute of Experimental Physics, University of Innsbruck, and the Institute of Quantum Optics and Quantum Information, Austrian Academy of Sciences, 6020 Innsbruck, Austria.
e-mail: rudolf.grimm@ultracold.at

1. Cornell, E. & Wieman, C. *Rev. Mod. Phys.* **74,** 875–893 (2002).
2. Ketterle, W. *Rev. Mod. Phys.* **74,** 1131–1151 (2002).
3. Zwierlein, M. W., Abo-Shaeer, J. R., Schirotzek, A., Schunck, C. H. & Ketterle, W. *Nature* **435,** 1047–1051 (2005).
4. Tinkham, M. *Introduction to Superconductivity* 2nd edn (Dover, Mineola, NY, 2004).
5. Cho, A. *Science* **301,** 750–752 (2003).
6. Chevy, F. & Salomon, C. *Phys. World* **18** (3), 43–47 (2005).
7. Regal, C., Greiner, M. & Jin, D. S. *Phys. Rev. Lett.* **92,** 040403 (2004).
8. Zwierlein, M. W. *et al. Phys. Rev. Lett.* **92,** 120403 (2004).
9. Kinast, J., Hemmer, S. L., Gehm, M. E., Turlapov, A. & Thomas, J. E. *Phys. Rev. Lett.* **92,** 150402 (2004).
10. Bartenstein, M. *et al. Phys. Rev. Lett.* **92,** 203201 (2004).
11. Chin, C. *et al. Science* **305,** 1128–1130 (2004).
12. Kinast, J. *et al. Science* **307,** 1296–1299 (2005).
13. Köhl, M., Moritz, H., Stöferle, T., Günter, K. & Esslinger, T. *Phys. Rev. Lett.* **94,** 080403 (2005).
14. Jaksch, D. & Zoller, P. *Ann. Phys.* **315,** 52–79 (2005).

NEUROSCIENCE

Friends and grandmothers

Charles E. Connor

How do neurons in the brain represent movie stars, famous buildings and other familiar objects? Rare recordings from single neurons in the human brain provide a fresh perspective on the question.

'Grandmother cell' is a term coined by J. Y. Lettvin to parody the simplistic notion that the brain has a separate neuron to detect and represent every object (including one's grandmother)[1]. The phrase has become a shorthand for invoking all of the overwhelming practical arguments against a one-to-one object coding scheme[2]. No one wants to be accused of believing in grandmother cells. But on page 1102 of this issue, Quiroga *et al.*[3] describe a neuron in the human brain that looks for all the world like a 'Jennifer Aniston' cell. Ms Aniston could well become a grandmother herself someday. Are vision scientists now forced to drop their dismissive tone when discussing the neural representation of matriarchs?

A more technical term for the grandmother issue is 'sparseness' (Fig. 1). At earlier stages in the brain's object-representation pathway, the neural code for an object is a broad activity pattern distributed across a population of neurons, each responsive to some discrete visual feature[4]. At later processing stages, neurons become increasingly selective for combinations of features[5], and the code becomes increasingly sparse — that is, fewer neurons are activated by a given stimulus, although the code is still population-based[6]. Sparseness has its advantages, especially for memory, because compact coding maximizes total storage capacity, and some evidence suggests that 'sparsification' is a defining goal of visual infor-

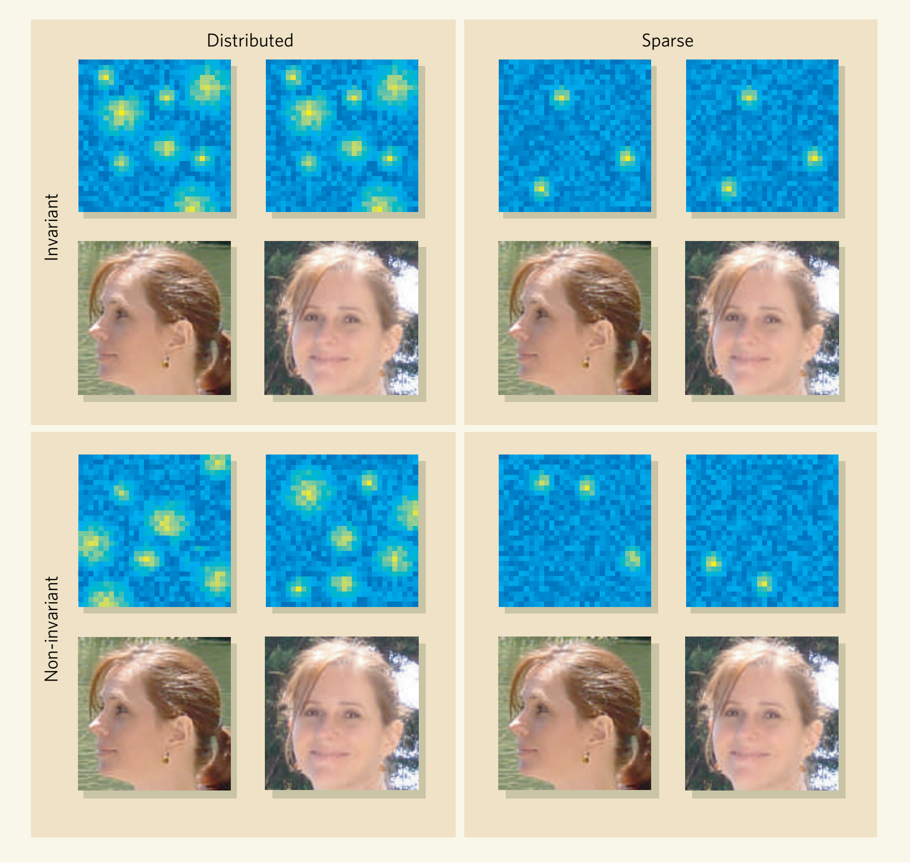

Figure 1 | Sparseness and invariance in neural coding of visual stimuli. The blue and yellow pixel plots represent a hypothetical neural population. Each pixel represents a neuron with low (blue) or high (yellow) activity. In distributed coding schemes (left column), many neurons are active in response to each stimulus. In sparse coding schemes (right column), few neurons are active. If the neural representation is invariant (top row), different views of the same person or object evoke identical activity patterns. If the neural representation is not invariant (bottom row), different views evoke different activity patterns. The implication of Quiroga and colleagues' results[3], at least as far as vision is concerned, is that neural representation is extremely sparse and invariant.

mation processing[7,8]. Grandmother cells are the theoretical limit of sparseness, where the representation of an object is reduced to a single neuron.

Quiroga and colleagues[3] report what seems to be the closest approach yet to that limit. They recorded neural activity from structures in the human medial temporal lobe that are associated with late-stage visual processing and long-term memory. The structures concerned were the entorhinal cortex, the parahippocampal gyrus, the amygdala and the hippocampus, and the recordings were made in the course of clinical procedures to treat epilepsy.

The first example cell responded significantly to seven different images of Jennifer Aniston but not to 80 other stimuli, including pictures of Julia Roberts and even pictures of Jennifer Aniston with Brad Pitt. The second example cell preferred Halle Berry in the same way. Altogether, 44 units (out of 137 with significant visual responses) were selective in this way for a single object out of those tested.

The striking aspect of these results is the consistency of responses across different images of the same person or object. This relates to another major issue in visual coding, 'invariance' (Fig. 1). One of the most difficult aspects of vision is that any given object must be recognizable from the front or side, in light or shadow, and so on. Somehow, given those very different retinal images, the brain consistently invokes the same set of memory associations that give the object meaning. According to 'view-invariant' theories, this is achieved in the visual cortex by some kind of neural calculation that transforms the visual structure in different images into a common format[9–11]. According to 'view-dependent' theories, it is achieved by learning temporal associations between different views and storing those associations in the memory[12–14].

Quiroga and colleagues' results[3] set a new benchmark for both sparseness and invariance, at least from a visual perspective. Most of the invariant structural characteristics in images of Jennifer Aniston (such as relative positions of eyes, nose and mouth) would be present in images of Julia Roberts as well. Thus, any distributed visual coding scheme would predict substantial overlap in the neural groups representing Aniston and Roberts; cells responding to one and not the other would be rare. The clean, visually invariant selectivity of the neurons described by Quiroga *et al.* implies a sparseness bordering on grandmotherliness.

However, as the authors discuss, these results may be best understood in a somewhat non-visual context. The brain structures that they studied stand at the far end of the object-representation pathway or beyond, and their responses may be more memory-related than strictly visual. In fact, several example cells responded not only to pictures but also to the printed name of a particular person or object. Clearly, this is a kind of invariance based on learned associations, not geometric transformation of visual structure, and these cells encode memory-based concepts rather than visual appearance.

How do you measure sparseness in conceptual space? It's a difficult proposition, requiring knowledge of how the subject associates different concepts in memory. The authors did their best (within the constraints of limited recording time) to test images that might be conceptually related. In one tantalizing example, a neuron responded to both Jennifer Aniston and Lisa Kudrow, her co-star on the television show *Friends*. What seems to be a sparse representation in visual space may be a distributed representation in sitcom space! In another example, a neuron responded to two unrelated stimuli commonly used by Quiroga *et al.* — pictures of Jennifer Aniston with Brad Pitt and pictures of the Sydney Opera House. This could reflect a new memory association produced by the close temporal proximity of these stimuli during the recording sessions, consistent with similar phenomena observed in monkey temporal cortex[15].

Thus, Quiroga and colleagues' findings may say less about visual representation as such than they do about memory representation and how it relates to visual inputs. Quiroga *et al.* have shown that, at or near the end of the transformation from visual information about object structure to memory-related conceptual information about object identity, the neural representation seems extremely sparse and invariant in the visual domain. As the authors note, these are predictable characteristics of an abstract, memory-based representation. But I doubt that anyone would have predicted such striking confirmation at the level of individual neurons. ■

Charles E. Connor is in the Department of Neuroscience and the Zanvyl Krieger Mind/Brain Institute, Johns Hopkins University, Baltimore, Maryland 21218, USA.
e-mail: connor@jhu.edu

1. Rose, D. *Perception* **25,** 881–886 (1996).
2. Barlow, H. B. *Perception* **1,** 371–394 (1972).
3. Quiroga, R. Q., Reddy, L., Kreiman, G., Koch, C. & Fried, I. *Nature* **435,** 1102–1107 (2005).
4. Pasupathy, A. & Connor, C. E. *Nature Neurosci.* **5,** 1332–1338 (2002).
5. Brincat, S. L. & Connor, C. E. *Nature Neurosci.* **7,** 880–886 (2004).
6. Young, M. P. & Yamane, S. *Science* **256,** 1327–1331 (1992).
7. Olshausen, B. A. & Field, D. J. *Nature* **381,** 607–609 (1996).
8. Vinje, W. E. & Gallant, J. L. *Science* **287,** 1273–1276 (2000).
9. Biederman, I. *Psychol. Rev.* **94,** 115–147 (1987).
10. Marr, D. & Nishihara, H. K. *Proc. R. Soc. Lond. B* **200,** 269–294 (1978).
11. Booth, M. C. & Rolls, E. T. *Cereb. Cortex* **8,** 510–523 (1998).
12. Bulthoff, H. H., Edelman, S. Y. & Tarr, M. J. *Cereb. Cortex* **5,** 247–260 (1995).
13. Vetter, T., Hurlbert, A. & Poggio, T. *Cereb. Cortex* **5,** 261–269 (1995).
14. Logothetis, N. K. & Pauls, J. *Cereb. Cortex* **5,** 270–288 (1995).
15. Sakai, K. & Miyashita, Y. *Nature* **354,** 152–155 (1991).

EARTH SCIENCE

New Madrid in motion

Martitia P. Tuttle

A new network of geodetic field stations has greatly improved monitoring of relative motion across a seismic zone in the central United States. It seems that rapid deformation is occurring across this fault system.

The New Madrid seismic zone lies 50–200 km from Memphis, Tennessee, and was the site of devastating earthquakes in 1811 and 1812. These earthquakes included three mainshocks and many aftershocks, with the largest earthquake having an estimated[1,2] magnitude of 7.4–8.1. Historically, New Madrid has been the most seismically active region in central and eastern North America — what hazard might it pose today?

This question has been the subject of vigorous debate in the Earth science and earthquake engineering communities[3,4]. The report by Smalley *et al.* (page 1088 of this issue)[5] will enlighten that debate. From high-precision Global Positioning System (GPS) measurements, made with a newly installed network of field stations, they conclude that the New Madrid seismic zone is rapidly deforming at rates of the same order of magnitude as those at the boundaries of tectonic plates. This result contradicts earlier estimates of low rates of deformation or strain accumulation[6], but is consistent with geological evidence for the occurrence of repeated 1811–1812-type (New Madrid) events in the past 2,000 years[7,8].

During the past 12 years, geologists found a record of New Madrid events in the form of earthquake-related features, known as sand blows (Fig. 1, overleaf). The sand blows formed as a result of liquefaction, a process by which water-saturated sandy sediment below the surface is liquefied and vented on the ground in response to strong earthquake shaking. Detailed study of hundreds of sand blows, some of which are associated with Native American archaeological sites, led to the interpretation that they formed during three, possibly four, New Madrid events of magnitude 7.6 or greater in the past 2,000 years[8].

In the 1990s, geophysicists undertook GPS measurements using a network of field