NEWS & VIEWS

S. CHENN/CORBIS

HUMAN BEHAVIOUR

Brain trust

Antonio Damasio

As is the case with other social interactions, financial transactions depend on trust. That fact is behind ingenious experiments that explore the neurobiological underpinnings of human behaviour.

Michael Kosfeld and his colleagues got students in Zurich to play a serious game. The game involved real monetary exchanges between two people playing the anonymous roles of 'investor' and 'trustee'; beforehand, each subject had received either the neuropeptide oxytocin or an inert placebo, via nasal spray.

As a group, the investors who received oxytocin exhibited more trust in the anonymous trustee than did the investors who received the placebo. Because intranasally administered oxytocin crosses the blood–brain barrier into the central nervous system, Kosfeld *et al.* (page 673 of this issue)[1] conclude that the central action of oxytocin increases trusting behaviour; and because the oxytocin spray did not change the behaviour of the trustees, it seems that oxytocin only increases trust, not the reliability of the trustee. This is a remarkable finding, and to explain its significance we must first say a word about trust and about oxytocin itself.

Given the polarities of reward and punishment that pervade biology at various levels, trust is essential for the normal operation of human societies. Remove trust and you compromise love, friendship, trade and leadership. Little is known about the neurobiology of trust, although the phenomenon is beginning to attract attention[2].

As for oxytocin, it is a small peptide, consisting of nine amino acids, that is produced mostly in the hypothalamus, the brain's master controller of biological regulation, including emotion. Oxytocin acts both on certain targets of the body (it is best known for inducing labour and lactation) and on brain regions whose function is associated with emotional and social behaviours (the amygdala and nucleus accumbens, for example) — that is, it works both as a hormone and as a neuromodulator, a kind of neurotransmitter. In animals, oxytocin contributes to social attachments, including male and female bonding after mating, mother and infant bonding after childbirth, and assorted sexual behaviours[3,4]. Besides triggering complex and specific action-programmes, oxytocin may well work part of its charm by selectively lowering the natural resistance that animals have to the proximity of others, thus facilitating what is known as 'approach behaviour'.

Given this background, Kosfeld *et al.*[1] hypothesized, reasonably and perceptively, that oxytocin might be involved in trusting behaviour in humans. After all, trust and approach behaviour are indelibly linked. We commonly describe the child who approaches others with ease as 'trusting', and we use comparable descriptions for animals in similar situations. Kosfeld and colleagues' finding supports their hypothesis and opens the way to a richer understanding of perhaps the most complex tier of human social interactions. I once likened[5] oxytocin to a love potion, the magic elixir that makes Tristan fall for Isolde: add trust to the mix, for there is no love without trust.

Kosfeld *et al.* provide an engaging discussion of the possible mechanisms behind their finding. They reject the possibility that oxytocin has a nonspecific positive effect on social behaviour, because of its different influence on investors and trustees. Approach and trust possibly dominate the behaviour of investors, and that is where oxytocin works, whereas trustee behaviour is dominated by a principle of reciprocity, for which oxytocin seems irrelevant. Kosfeld *et al.* also reject the possibility that oxytocin merely reduces the sensitivity to risk, because in a control experiment in which the investors knew the trustee was a computer, they did not take any extra risks. The authors finally settle for an attractive pair of factors: that oxytocin overcomes the aversion to betrayal (which applies only to the investors), and that this is combined with the effects of reward that result from enhanced approach behaviour.

The significance of the study lies in what it can tell us about non-experimental circumstances, when the equivalent of an investor is not sniffing oxytocin. What might be happening then? First, perceiving certain social configurations probably leads to oxytocin release in selected brain regions — that is, the cognitive appraisal of a situation, based on an individual's genetic make-up and past experience, triggers a chain of neural events that includes (but is not limited to) the release of oxytocin. Second, oxytocin modulates the activity of cognitive neural networks, resulting in enhanced trusting behaviour. Whether this result is achieved via a mostly unconscious bias (by altering the competition among ensembles of neurons that represent varied choice options), or a conscious deliberative process, remains to be established — although the evidence seems to favour the former possibility in the current experiment. However, the input, along the cognitive chain, of neural events arising in brain areas associated with social and emotional responses is a requisite part of the explanation. The finding points to the crucial involvement of emotional phenomena in the processes leading from cognition to behaviour.

The authors' results open up possibilities for investigating conditions in which trust is either diminished, as in autism, or augmented. For example, patients with bilateral damage to the amygdala approach strangers with unusual ease, and fail to recognize untrustworthy individuals whom normal people would resolutely avoid[6]. In this case, damage to the amygdala may prevent the detection of the potential threat evoked by certain stimuli. And children with Williams syndrome, a rare genetic disorder, approach strangers fearlessly and indiscriminately[7]. Might their high level of trust be due to excessive oxytocin release?

Some may worry about the prospect that political operators will generously spray the crowd with oxytocin at rallies of their candidates. The scenario may be rather too close to reality for comfort, but those with such fears should note that current marketing techniques — for political and other products — may well exert their effects through the natural release of molecules such as oxytocin in response to well-crafted stimuli. Civic alarm at the prospect of such abuses should have started long before this study, and the authors cannot be blamed for raising it. Whatever the beneficial biomedical applications, or the abuses, may turn out to be, Kosfeld *et al.* have made a valuable contribution to our understanding of the role of neuromodulators in human behaviour that involves choice. ■

Antonio Damasio is in the Department of Neurology, University of Iowa College of Medicine, 200 Hawkins Drive, Iowa City, Iowa 52242, USA.
e-mail: antonio-damasio@uiowa.edu

1. Kosfeld, M., Heinrichs, M., Zak, P. J., Fischbacher, U. & Fehr, E. *Nature* **435,** 673–676 (2005).
2. King-Casas, B. *et al. Science* **308,** 78–83 (2005).
3. Carter, C. S. *Psychoneuroendocrinology* **23,** 779–818 (1998).
4. Insel, T. R. & Shapiro, L. E. *Proc. Natl Acad. Sci. USA* **89,** 5981–5985 (1992).
5. Damasio, A. R. *Descartes' Error: Emotion, Reason, and the Human Brain* (Penguin, New York, 1994).
6. Adolphs, R. & Damasio, A. R. *Nature* **393,** 470–474 (1998).
7. Doyle, T. F. *et al. Am. J. Med. Genet.* **124A,** 263–273 (2004).

COSMOLOGY

Digitizing the Universe

Nickolay Y. Gnedin

For years, cosmologists have been racing each other to develop ever more sophisticated and realistic models of the evolution of the Universe. The competition has just become considerably stiffer.

Since the first 'analogue' simulation by Erik Holmberg[1], who used the inverse-square law of light to mimic gravity, numerical cosmology has made remarkable progress: abstract particles and digital supercomputers have now replaced light bulbs and photometers as tools for measuring gravitational forces. But the ultimate dream of every cosmologist — to create a realistic model of the whole Universe inside a computer — remains elusive. The Universe is just too complicated and too large for even the fastest supercomputers.

So computational astrophysicists have to invent clever shortcuts. They hide physics that is too poorly known, or too complex to be modelled from first principles, in phenomenological (often called 'semi-analytical') models. On page 629 of this issue, Springel *et al.*[2] describe the best example of this approach to date, which they appropriately named the Millennium Run (if we forgive the overrun of a few years, it was indeed the largest and most realistic simulation of the last millennium).

Springel and colleagues[2] — an international collaboration of computational astrophysicists known as the Virgo Consortium — adopted arguably the best approach available to model the formation and evolution of galaxies and quasars in a representative volume of the Universe. They used an ultra-high-resolution simulation to follow in unprecedented detail the evolution of dark matter — invisible material that is the dominant source of gravity in the Universe. Ironically, although the nature of dark matter remains unknown, its clustering properties (the ways it clumps together into 'haloes') are rather well understood, thanks to a substantial amount of observational data gathered in the past decade, and to ever more accurate numerical simulations. At present, cosmologists can simulate dark matter, which we can't see, better than galaxies and gas, which we can.

The Virgo Consortium therefore combined the best dark-matter simulation to date with a semi-analytical, but physically motivated, model of the formation of stars and supermassive black holes. These latter, despite being dubbed 'black', are actually the brightest objects in the Universe — 'quasars'. Sitting at the centres of galaxies, quasars accrete large quantities of very hot gas, which emits enormous amounts of radiation just before being swallowed for ever by a black hole. The consortium's end-product — the Millennium Run — gives us the most detailed and accurate

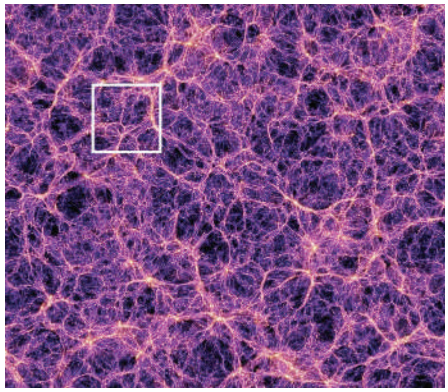

Figure 1 | Simulated cosmos. The density distribution of matter in a slice of the computational volume of the Millennium Run model, showing large clusters with densities 1,000 times the mean density of the Universe (yellow); a 'cosmic web' of filamentary structures 10 to 100 times denser than the mean (purple); and the mostly empty regions (black), often called voids, which contain less than 10% of the mean density of the Universe. The white square shows the size of the computational volume for a full hydrodynamic simulation that would use up the same computational resources as the Millennium Run. (Figure courtesy of Volker Springel.)

theoretical prediction so far of the properties of galaxies and quasars, from the dawn of cosmic time to the present.

An alternative approach (of which I am a devout adherent) to this kind of semi-analytical modelling is to use a hydrodynamic simulation code, which follows the complex swirl of cosmic gas from the largest scales down to the tiny and ultra-dense molecular clouds where stars are born. Unfortunately, however, the vastly greater numerical complexity of such calculations means that the direct hydrodynamic approach cannot, at present, be used to model a representative piece of the Universe for the whole duration of cosmic evolution. The extent to which hydrodynamic simulations lag behind the Millennium Run in this respect is illustrated in Figure 1.

What could the Millennium Run be used for? Springel *et al.*[2] have only scratched the surface, but the agreement between the simulation and observational results is already stunning. To take just one example, the Sloan Digital Sky Survey[3] (SDSS), a project that aims to map in detail a quarter of the sky, continues to discover ever more distant quasars[4]. The current record holder is a truly remarkable object. Taking account of the time its light has