irradiated to generate defects throughout the sample[2].

abundance of NV–NV pairs is correspondingly low, and instead an NV–N pair was studied.

The NV spin was coherently excited and its evolution observed as a function of time. Coupling between the NV and N spins produces a modulation of the observed signal, whose depth yields a measure of the entanglement, whereas the frequency indicates the coupling strength, in the present case 13 MHz. This may be contrasted with the state-of-the-art demonstration of coherent coupling between spins in semiconductor quantum dots[5] at temperatures of 100 mK, where a tunable exchange coupling with frequency of ~60 MHz was measured between spins with an observed T_2 of ~1 µs. The optically active NV spin does not require such extreme temperatures, and instead can be cooled through optical pumping (while the crystal remains at room temperature). By tuning the magnetic field such that both the N and NV spins are in resonance, the cooling of the NV centre can be efficiently transferred to the N spin.

These experiments show that coupling to light is a powerful tool for initialization and readout at the end of a computation. However, recent ideas have highlighted the enormous power of making measurements on qubits as a way to drive a computation forward[6]. Instead of trying to switch interactions on and off between neighbouring entities in the traditional fashion, measurements on spins are made. Crucially, the system is not measured completely, but rather in such a way as to deliberately not learn about the system fully. Nature itself does not 'know' which of the possible states created the observed outcome. The result is a superposition of the states that could have yielded that measurement. Thus (assuming their coherence lifetimes are long enough), arrays of isolated solid-state qubits can be placed into a highly entangled state (called a graph state) and a computation is then performed by systematically measuring each qubit (see Fig. 1b).

The optical properties and long coherence times of NV spins lend themselves to this kind of graph-state architecture. The observation of spin-pair coupling is also significant, as the presence of more than one qubit at each node can make the construction of the graph more efficient[7]. The dark N spin has even better relaxation properties than the measurable NV centre[8], so together the pair make a good match.

There are several challenges facing the scaling of the powerful properties of NV centres into a full quantum computer. In view of creating an array of spins within a crystal, the N_2 implantation technique will only scale up in a limited way (for example, using N_3^+ or N_5^+ ions). Such defect clusters will be disordered, though this randomness could be exploited as a means to identify each one spectrally[9]. To generate a large and ordered array would require considerable development of ion-beam focusing to obtain exquisite positional control, and the inability to control the conversion of dark N defects into NV centres will also frustrate larger assemblies of coupled spins. However, for graph-state quantum computing with nitrogen defects in diamond using schemes such as those in ref. 6, the challenge will be to develop efficient and coherent techniques for optical readout that do not dephase the spin state, for example, using optical cavities that are fabricated within a single crystal[10].

If, and when, a scalable controlled entanglement is demonstrated, this NV approach will really have won its spurs, and other qubit candidates currently dominating the field may suddenly find themselves outclassed.

REFERENCES

1. Gaebel, T. **2,** 408–413 (2006).
2. Epstein, R. J., Mendoza, F. M., Kato, Y. K. & Awschalom, D. D. **1,** 94–98 (2005).
3. Meijer, J. **87,** 261909 (2005).
4. Rabeau, J. R. **88**, 023113 (2006).
5. Petta, J. R. **309,** 2180–2184 (2005).
6. Lim, Y. L., Barrett, S. D., Beige, A., Kok, P. & Kwek, L. C. **73,** 012304 (2006).
7. Benjamin, S.C., Browne, D. E., Fitzsimons, J. & Morton, J. J. L. Preprint at <http://arxiv.org/abs/quant-ph/0509209> (2005).