GENOMICS

Vine work

The draft genome sequence of *Vitis vinifera*, the grapevine, described in this issue, provides plenty of scope for discussion over a glass of its fermented product. The sequence was published online on 26 August and now appears in print (The French–Italian Public Consortium for Grapevine Genome Characterization *Nature* **449,** 463–467; 2007).

The grape variety concerned is Pinot Noir, the classic red grape of Burgundy. But the vine sequenced does not produce exactly the same grape as that grown in the vineyards. The consortium chose to sequence a variety called PN40024, which has been bred by successive self-crossings to reduce the high degree of sequence variation that is characteristic of all grapevine varieties. The inbred strain allows efficient assembly of a high-quality sequence from whole-genome shotgun sequence data. In the shotgun technique the DNA is broken into many small fragments for sequencing and then reassembled from overlapping sequences.

The resulting genome sequence carries the imprint of millennia of selective breeding. For example, there are 116 genes and pseudogenes for terpene synthases, almost three times the number in the other three plant genomes so far sequenced. These enzymes synthesize the terpenoids that contribute to the aroma and flavour of wines, and pathways associated with tannins are similarly amplified.

Less obviously a target of selectivity are the genes that control the synthesis of resveratrol, the antioxidant credited with the health benefits claimed for moderate consumption of red wine. Yet there is a modest expansion, compared with the other sequenced plants, of the stilbene synthase genes associated with resveratrol synthesis.

So can we look forward to genetically engineered 'designer' wines? Probably not. There is a market for new grapes, as exemplified by Cabernet Sauvignon clone 337, which is gaining ground in California's Napa Valley. But the flavour and aroma of wine depend on many other factors, such as growth conditions and production methods. And when it comes to producing wines with greater health-giving properties, the prospect sounds too good to be true. So it probably is. However, grapevines are notoriously susceptible to pathogens and stresses, such as drought, that other *Vinus* species can resist. The availability of this genome sequence should speed up progress on introducing the appropriate resistance into economically important varieties of *V. vinifera*.

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With one grapevine genome sequenced, the way is clear for comparative oenogenomics. Yet when it comes to taste, perhaps the differences between a Pinot Noir with earthy and berry notes and a spicy or blowsy Gewürztraminer are best left to the realms of individual taste and a good thesaurus.

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efficiently decouple. This is where the new work comes in[1–3], as it demonstrates how an on-chip photon field can act as a 'bus', or conduit, for quantum information, thus allowing a pair of distant qubits to interact at will.

Sillanpää and colleagues' qubits[1] are carefully designed, micrometre-sized elements of a superconducting circuit. These elements are coupled to opposite ends of an on-chip electrical resonator, or 'cavity', in which a standing electromagnetic wave of several millimetres' wavelength is established. Using an external source of microwave light, the authors first prepared one of their qubits in a superposition of its ground and first excited energy states. They then transferred this state to the photon field in the adjacent cavity — the bus. Finally, at the other end of the bus, they mapped the state of the photon field to the state of another qubit initially in its ground state. A further universal entangling operation between qubits could be achieved with extra tricks involving 'visits' to either higher qubit energy levels or larger numbers of photons. Such tricks are often applied in similar experiments in systems that use trapped-ion vibrations, rather than photons, as the bus medium[4,5].

Majer and colleagues' work[2] is similar, but comes with an additional twist. They also can carry out quantum-state transfer over a large distance, but in their case they never actually excite the intermediate photon field. Instead, they use 'virtual' photons, which are very weak perturbations of their cavity's quantum light field. This sleight-of-hand allows the authors to carry out a universal entangling operation on a pair of distant qubits, without disturbing the bus itself.

Houck *et al.*[3] performed complementary work by demonstrating a 'single-photon gun' that generates forwards-flying photons, instead of photons confined in a cavity, that have a well-defined phase of oscillation. They did this by first preparing an arbitrary quantum state in a superconducting qubit tightly coupled to a cavity. They then allowed the qubit to decay spontaneously, so that it emitted a single photon into a transmission line for microwave light. Convincing data from quantum-state tomography of both the qubit and the photon show how the qubit's initial state is transferred to the photon.

A great advantage of recent circuit architectures that exploit such 'cavity quantum electrodynamic' (cavity QED) approaches[6–8] has been that the interaction between a superconducting qubit and a cavity can be much larger than the equivalent coupling between a real atom and a cavity. In addition, there is in principle room for hundreds of qubits on the same chip. Because any pair of qubits can be coupled, implementing algorithms and error-correction codes[9] in a quantum computer will be significantly easier. One can also speculate that flying qubits such as those demonstrated by Houck *et al.*[3] could be used to communicate between chips for a further scaling up.

But once qubits have been coupled using a photon field as a bus, how well can they be decoupled? One way to do this would be to ensure that the qubit excitation frequency is different from the resonance frequency of the cavity. This can help to suppress the coupling between the qubits and the cavity, but might not be enough for long timescales and for many qubits. A possible future direction would be to combine the best features of cavity-bus architectures and 'nonlinear parametric couplers'[10], which provide both tunable coupling and better isolation in their 'off' state.

A big remaining unknown is whether the lifetimes of complicated multi-qubit states can be made long enough for practical quantum computing. Nevertheless, the latest experiments[1–3] on cavity–qubit interactions add significantly to the already large body of evidence showing that even relatively macroscopic objects can behave purely according to the laws of quantum physics — with all the promise that that holds for large-scale applications. ■

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