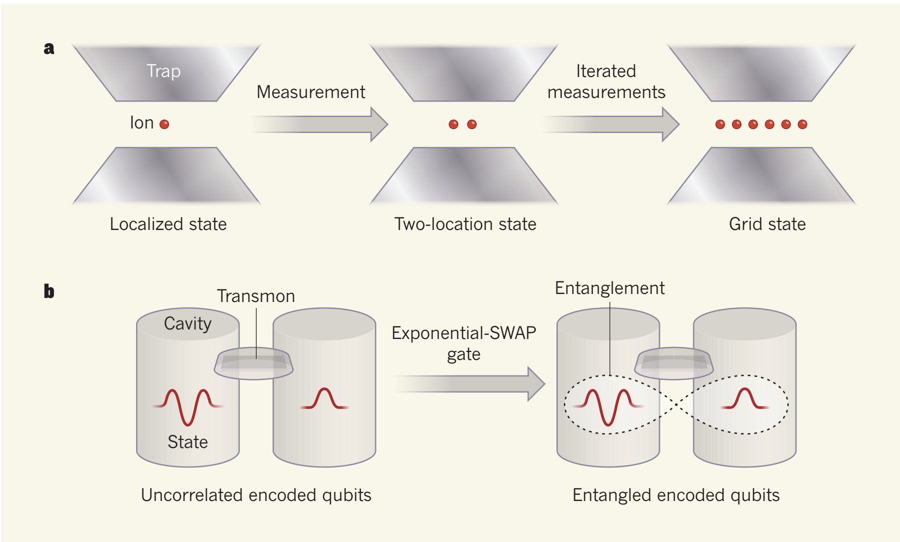

Figure 1 | Encoding and manipulating quantum bits (qubits). **a**, Flühmann *et al.*[1] report an experiment in which a single ion is prepared in a localized quantum state in an electromagnetic trap. A measurement of the system causes the ion to become delocalized in two distinct locations. Iterating these measurements leads to the ion being delocalized in a grid. The authors show that these grid states are a good approximation of a long-sought type of encoded qubit called a GKP-encoded qubit[5]. **b**, Gao *et al.*[2] present an experiment in which two superconducting cavities are coupled by a superconducting electrical component known as a transmon. A qubit is encoded in the state of the microwave field contained in each of the cavities. The authors demonstrate an operation called an exponential-SWAP gate[8] that causes these two states to become entangled (correlated in a non-classical way). Crucially, this operation works regardless of the way in which the qubits are encoded.

are called discrete variables, and they are intrinsically digital[3]. On the other hand, there are quantum features that have infinitely many distinguishable states, such as the position of a quantum harmonic oscillator — the quantum-mechanical version of a mass suspended on a spring. These features are known as continuous variables and are intrinsically analog[4].

From the transmission of data over the Internet to data analysis, classical information is typically encoded in digital form because of the existence of robust digital error-correction schemes. Therefore, when it comes to quantum information, it is natural to consider discrete-variable systems, such as two-state systems called quantum bits (qubits). This approach has been well explored in the past few decades. However, error correction remains challenging, and it ultimately requires a single logical qubit (a qubit that can be used for programming) to be suitably encoded into many physical qubits (actual implementations of qubits). In other words, it is necessary to enlarge the dimension of the space, and the choice of discrete-variable systems then turns out to be not so obvious.

Consequently, various methods have been proposed for encoding a logical qubit into the infinite-dimensional space offered by a single continuous-variable system, rather than by many discrete-variable ones. A celebrated continuous-variable encoding is the Gottesman–Kitaev–Preskill (GKP) scheme[5], which was proposed in 2001. A crucial feature of this scheme is that most encoded operations (manipulations of logical qubits) belong to a set of operations that, in general, can be easily implemented[6]. However, a method for generating GKP-encoded qubits has been elusive. Flühmann and colleagues have succeeded in this endeavour by preparing a quantum harmonic oscillator in a state that resembles a GKP-encoded qubit. They used an architecture consisting of an oscillator in the form of an atomic ion that is free to oscillate along one axis of an electromagnetic trap.

The authors' technique involves two steps (Fig. 1a). First, the ion is confined in a state of motion that has a well-defined position in the trap, using a technique that exploits energy loss to reduce the uncertainty in the ion's motion[7]. Second, a sequence of measurements is taken using laser pulses, after which the ion is delocalized in specific regions of the trap, akin to a grid. Flühmann *et al.* managed to prove that these grid states are a good approximation of a GKP-encoded qubit. Importantly, they found that such encoded states could be manipulated at will, achieving fidelities (a measure of the similarity of quantum states) of 87–97%.

As mentioned, GKP encoding is not the only option, and other schemes exist that can be more convenient, depending on the system at hand. It is therefore desirable to be able to manipulate logical qubits using operations that are independent of the encoding. An example of such an operation is the exponential-SWAP gate[8] (the exponential function of the operation that swaps two logical qubits), which was proposed in 2016. A crucial feature of the exponential-SWAP gate is that any algorithm can be run

NATURE

50 Years Ago

Apollo 9, which was launched on February 28, will go through the motions of a landing on the Moon but in the comparative safety of an Earth orbit. The enterprise involves the first testing in space of the lunar module which is to ferry men from the command module to the lunar surface and back again. The trials include a manned flight of the lunar module on a trajectory of the kind planned for the Moon landing. The pilot of the lunar module will go outside for two hours, and during their 150 orbits of the Earth the three-man crew will have ample practice at shuttling between the two spacecraft. Most of the activity which makes Apollo 9 NASA's busiest manned mission yet is crammed in the first five days of the ten-day flight. This is to ensure that as many as possible of the more important tests are carried out if the flight has to be cut short. The remainder of the mission is as much as anything an endurance test to verify that the spacecraft systems — and the men within them — can last the duration of a trip to the Moon and back.
From *Nature* 1 March 1969

100 Years Ago

Mr. T. A. Joyce describes in the January issue of *Man* a remarkable wooden stool recently acquired by the British Museum from the island of Eleuthera, Bahamas. Objects of wood from the West Indies are by no means common, and specimens from the Bahamas are exceedingly rare. From one of the shorter sides of the seat of this chair projects a knob, which has been carved to represent a grotesque human head, of which the eyes and mouth have evidently at some time been emphasised by inlay, probably of shell. These State chairs were used for a honorific purpose, for chiefs and other distinguished persons.
From *Nature* 27 February 1919