the magnetization switching, and reduced the electrical resistance of the channel, resulting in a considerable increase in the maximum current that could be applied before the device broke down. Indeed, Dainone *et al.* found that omitting this layer caused some damage to the ferromagnet–semiconductor interface, owing to the effect of the current pulse. The other layers have a property known as perpendicular magnetic anisotropy, which is essential for maintaining the up and down spin states of the electrons in the absence of an external magnetic field.

By placing the injector channel as close as possible to the quantum-dot layer, Dainone *et al.* ensured that the spin polarization of the electrons would be kept high as they moved through the semiconductor. This allowed the authors to achieve a high degree of circular polarization: switching the magnetization effected a change from 31% of photons being left-polarized to 31% of them being right-polarized. That the authors could accomplish this without needing to apply an external magnetic field makes the approach both practical and promising.

Dainone and colleagues found that they could generate light with intermediate polarization by using the current pulse to obtain intermediate magnetic states in the ferromagnet. Through precise control of the magnetization switching, they were able to establish multistate circular polarization. This is key to the applicability of the approach because it suggests that multilevel modulation will be possible for polarization-based optical communications, just as it is for intensity-based approaches.

The speed of polarization switching in the authors' device depended on the speed of magnetization, which, in turn, relied on the duration of the current pulse through the injector channel. The shorter the duration of the pulse, the larger the current required to switch the magnetization. Dainone *et al.* achieved a minimum pulse duration of 1 millisecond, but they predict that this could be shortened by changing the type of heavy metal in the spin injector.

Some other challenges remain. The authors used a single layer of quantum dots, but several layers would be better for maximizing the amplification of the light intensity. However, this would increase the distance between the injector channel and the extra light-emitting layers, and would thus reduce the spin polarization of the electrons injected into these layers. To incorporate quantum-dot multilayers, the authors therefore need to develop a spacer material that can suppress the electrons' tendency to become unpolarized as they move through the semiconductor.

The extent to which the light emitted is circularly polarized could also be increased by incorporating different materials into the injector channel. For example, the spin polarization of the electrons injected into the semiconductor would be enhanced by a material that has half-metallic properties (that is, a spin polarization of 100%) as well as perpendicular magnetic anisotropy. At room temperature, electron spin polarization decreases rapidly in gallium arsenide, the semiconductor material that the authors used. This problem might be solved by using dilute nitride gallium arsenide instead, because the defects introduced by nitrogen can have a 'spin-filtering' effect[7]. Even without these improvements, Dainone and colleagues' work presents an exciting glimpse of a way to achieve superior information technologies at little cost to the environment.

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In retrospect

50 years after a landmark paper on bird-flight origins

Kevin Padian

For a century, scientists pondered whether bird flight evolved by animals gliding down from trees or by creatures running and flapping from the ground up. A landmark 1974 paper reset the debate to focus on the evolution of the flight stroke instead.

One could speculate about how birds evolved flight without knowing what ancestors they evolved from, or with no information on the specifics of their body form, ecology or behaviour. And that had been exactly the state of the debate among palaeontologists and ornithologists since the issue was first broached in the 1870s, using imaginary ancestries, imaginary life histories and imaginary aerodynamics. In 1974, writing in the *Quarterly Review of Biology*, the palaeontologist John Ostrom[1] approached the conundrum using evidence from both the fossil record and the behaviour of living animals. And he effectively turned the debate on its head.

Why was the question of the origin of bird flight so difficult to solve? Consider the problem of evidence. Birds had to have come from forerunners, which had always been assumed to be reptiles rather than mammals. But the fossil record was incomplete between some major adaptive transitions (such as from ground- or tree-dwelling reptiles to flying birds), and potentially ancestral fossil reptile groups always seemed to have some but not all of the expected ancestral features, or to have them in the wrong combinations.

Between 1973 and 1976, Ostrom, working at Yale University in New Haven, Connecticut, published a series of papers[1–4] that proposed that birds evolved from small theropod (carnivorous) dinosaurs, and that bird flight evolved from the ground up, not from the trees down. He had assiduously studied *Archaeopteryx* – the earliest known bird and perhaps the world's most famous fossil species – of which 4 specimens were available at that time (there are now 12). His interest was piqued because, only a few years earlier, he had fully described the small theropod dinosaur *Deinonychus* (the model for raptors in the 1993 film *Jurassic Park*) from fossils found in Montana that dated to the early Cretaceous period (around 100 million to 110 million years ago)[5]. He was amazed by the extensive suite of similarities between theropod dinosaurs and *Archaeopteryx*[3,4].

For a century before Ostrom's work, palaeontologists had considered a variety of fossil reptile lineages, all at least as old as the late Triassic (roughly 225 million years ago), as possible bird ancestors. The default hypothesis was that birds evolved from a poorly defined group of creatures called thecodonts (a ragtag bunch related variably to crocodiles or dinosaurs), from a crocodile lineage or possibly from dinosaurs (ornithischians or saurischians)[3]. Responding to an argument raised by the British palaeontologist Alick Walker that birds evolved from a hypothetical type of tree-dwelling crocodile[6], Ostrom retorted with a list of features that *Deinonychus* and its relatives uniquely shared with birds[2], and followed his initial response with detailed analyses of the comparative anatomy[3,4]. In the latter papers, he established the hypothesis that birds evolved from theropod dinosaurs. Denialists continued to claim that bird origins had to be among earlier thecodonts, but they never produced credible evidence.

Here is the importance of Ostrom's seminal paper on the origin of bird flight from 1974. For a century, there had been two prevailing scenarios. The arboreal, or 'trees down', scenario proposed that birds evolved from a terrestrial quadrupedal reptile that (somehow) became bipedal, then (somehow) started climbing trees, then (somehow) began jumping between branches and eventually (somehow) gliding, and then (somehow) evolved powered flight. The contrasting 'ground up', or cursorial (meaning running), scenario posited that bird ancestors were terrestrial reptiles that (somehow) became bipedal, and that as good runners they were free to elaborate their forelimbs (somehow) into wings. There was no real empirical evidence for either scenario.

Although Ostrom's papers on *Archaeopteryx* and the origin of birds[3,4] appeared after his 1974 paper[1] entitled '*Archaeopteryx* and the origin of flight', the later papers were really preliminary to the first, because understanding that birds evolved from theropod dinosaurs effectively eliminated some models of the origins of bird flight. But in the 1974 paper, Ostrom wrote as if understanding the evolutionary (ancestral) origin of birds was not crucial to understanding the origin of flight. Interestingly, he did not argue that, because he had demonstrated that birds evolved from small theropod dinosaurs, all other ideas about flight origins that did not incorporate theropods must be wrong.

Ostrom began his 1974 paper by reviewing both the arboreal and cursorial hypotheses, and he stressed that the foot and hindlimb of *Archaeopteryx* had features that are characteristic (diagnostic) of theropod dinosaurs, which had never been interpreted as arboreal. Therefore, bipedality and cursoriality had to precede the origin of flight in birds. He was also able to dismiss the arboreal model, because the skeletal features it invoked had no real causal connection with flight, nor were they associated with true arboreality. All of the alleged arboreal features of *Archaeopteryx* are found in other theropods (some extremely large), which were universally accepted as non-arboreal runners. But he also rejected the conventional cursorial model, because it posited that the hypothetical small, proto-feathered wings of bird ancestors contributed to ground speed and hence take-off. He showed that in modern birds, which run and flap as they take off, and which have fully developed wings, the flapping is effective only once the bird is airborne.

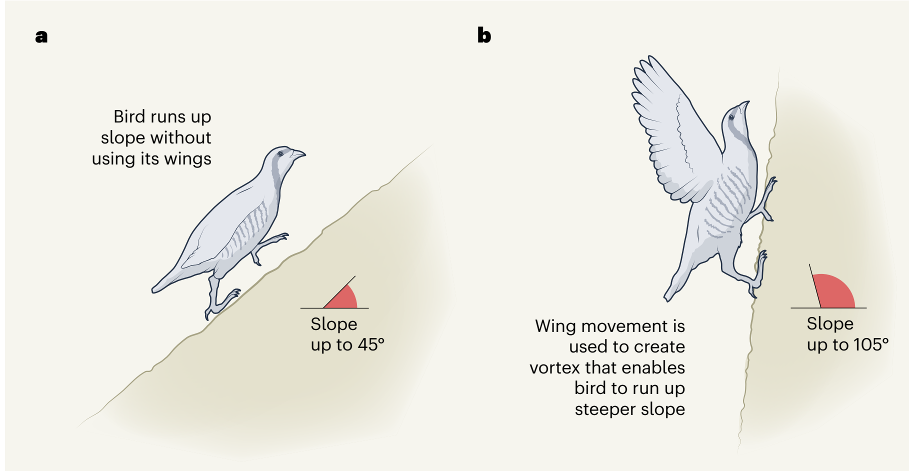

Figure 1 | The evolution of bird flight. Fifty years ago, a paper by Ostrom[1] reframed the debate about how bird flight evolved. Ostrom proposed that flight evolved in animals that lived on the ground rather than in those living in trees, and focused attention on explaining how flight evolved in terms of biomechanics. His ideas were later tested and supported by work, including a study[13] of chukar partridges (*Alectoris chukar*). **a**, These birds can move up slopes of up to 45° without using their wings. **b**, To move up steeper slopes, the birds flap their wings to create a vortex that provides an aerodynamic force that holds them on the slope. This capacity, which has been found in all groups of birds from flightless birds (ratites) to songbirds, might have been crucial for trying to escape predators. And with a slight adjustment of the wing angle, the vortex action changes from holding the bird to the surface to pushing the bird forwards in flight[13,14].

But Ostrom did not abandon the cursorial model — he reinvented it. Working from his knowledge of small, bipedal theropod dinosaurs, he showed that freeing a predator's hands from locomotory duties could enable the evolution of a variety of movements that enhanced predation. Enlarging the forelimbs and expanding the hand, especially with the elaboration of feathers, could have created a useful way to trap insects or other small prey that could move quickly and with erratic trajectories. He noted that even rudimentary feathers — for example, those of the flightless kiwi (*Apteryx* spp.) — provide insulation, which is probably their main function, although they could have been enlarged and elaborated for other functions[7,8].

Ostrom's 'insect net' hypothesis was not well received, partly because most researchers were biased towards the unsupported arboreal hypothesis, and partly because other work[9] showed that a leaping proto-bird that tried to trap insects with its proto-feathers would have incurred excess angular momentum, resulting in a loss of balance. Although leaping was not crucial to his idea, Ostrom conceded its defeat, noting that it had done its job: the terrestrial origin of birds and flight was now taken seriously.

However, neither Ostrom nor the arboreal and cursorial proponents actually tackled the central problem of how flight evolved in animals such as insects, pterosaurs, bats and birds. To answer this question, we must first ask what flight is (powered locomotion through a fluid medium), and then consider what is needed to fly. There must be an aerofoil (wing) that is rigid enough to direct air but flexible enough to be deformed usefully; a flight stroke that uses the wings to generate what is termed a vortex wake behind the animal that propels it forwards; metabolic capability to sustain flight; and neuromuscular coordination to permit 3D locomotion[7]. The centrality of the vortex wake was established independently in 1979 on experimental and theoretical grounds[10,11]. Yet few authors have engaged this centrality when speculating about flight origins[7,12].

Because Ostrom showed in 1974 that *Archaeopteryx* had no arboreal features, and that birds probably evolved from bipedal, terrestrial theropods[3,4], the arboreal theory was effectively dead, although it still has its proponents. A red herring in the arboreal model is the idea that gliding is somehow related to the evolution of powered flight. Gliding has evolved at least two dozen times in vertebrates, yet none of these groups is closely related to those with the ability to fly (birds, bats and pterosaurs). Gliding is a perfectly good adaptation, but no one has shown how the rudimentary aerial structures of gliders could lead in any way to active flight[7,12].

By contrast, there is now copious evidence that baby birds of most living groups can escape terrestrial predators by running vertically up tree trunks and other surfaces (Fig. 1), using their foot claws for grip and flapping their small proto-wings to create a vortex wake that holds them to the surface[13,14]. This unquestionably shows a crucial early adaptation of feathers, and rules out the idea that proto-birds must have climbed trees using their hand claws. But the problem has never really been ground up versus trees down: it has been about the evolution of the flight stroke, which can now be seen as having helped proto-birds to escape from terrestrial predators. Ostrom reset this debate in 1974, and its implications continue to resound[15].

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Ocean science

The surprising history of a Southern Ocean current

Natalie J. Burls

Reconstructions of the strength of a powerful current that circles the South Pole reveal that it has undergone no long-term change in the past five million years, even though Earth cooled substantially over that time. **See p.789**

South of human civilization lies the vast Southern Ocean, the waters of which get swept around the globe by the Antarctic circumpolar current (ACC). This formidable current transports more than 100 million cubic metres of water per second. Connecting the Pacific, Indian and Atlantic ocean basins, it has a central role in the global circulation of the world's oceans and in regulating climate[1]. Yet little is known about its history. On page 789, Lamy *et al.*[2] present impressive reconstructions of the strength of the ACC that reveal pronounced variability on the timescale of multiple millennia owing to changes in Earth's orbit (Fig. 1). Interestingly, the records also indicate that the current's strength has remained relatively stable over the past five million years, in spite of the long-term change in Earth's temperature[3–6]. This suggests that the impact of global cooling on the ACC has evolved over time — undergoing mechanistic changes that could reveal how future warming will affect this influential current.

For the past 2.7 million years, Earth's climate has been in a relatively cold state, with ice covering not only Antarctica, but also land in the Northern Hemisphere to varying extents. As Earth's orbit changes over time, so too does the amount of solar energy that the high latitudes receive, and this has led to Earth transitioning between 'glacial' and 'interglacial' states over tens of thousands of years. Glacial states are periods of expanded land and sea-ice extent, such as the Last Glacial Maximum, which occurred approximately 20,000 years ago, when the Laurentide Ice Sheet covered large parts of North America. By contrast, interglacial states are characterized by reduced ice coverage, such as the warm Holocene interglacial state that Earth has been in for approximately 11,000 years.

Scientists have previously[7–11] reconstructed the response of the ACC to fluctuations between glacial and interglacial conditions, using the size of silt particles[12] deposited on the ocean floor as a proxy for ACC strength. The degree and sign of the response has been found to vary depending on the location of the sediment record. But Lamy and colleagues' silt-derived records of ACC strength over several glacial–interglacial cycles show remarkable similarities across five distinct sites in the central South Pacific sector of the Southern Ocean. All of these records suggest that the ACC was weaker during glacial periods than during interglacials. Three of the five sites are from a north–south transect that spans a large latitudinal range of the ACC, and the other two sites straddle a key feature of underwater topography, known as the East Pacific Rise, that influences the ACC.

The overall strength of the ACC is determined by both the strength of westerly winds across the Southern Ocean and large-scale gradients in the density of its waters — northern waters are less dense than southern waters[1,13,14]. The weakening of the ACC during glacial periods was probably the result of changes in both of these factors. During glacial states, the westerly winds are thought to have shifted northwards in terms of where they peak, and to have potentially weakened[15]. Glacial conditions are also likely to have cooled waters in the northern parts of the Southern Ocean, making them denser, whereas the density of near-freezing southern waters would not have changed substantially[16]. Both mechanisms would have led to the ACC being weaker during glacial states than it was in interglacial states.

Given this mechanistic understanding of how the ACC has responded to changing temperatures over glacial–interglacial

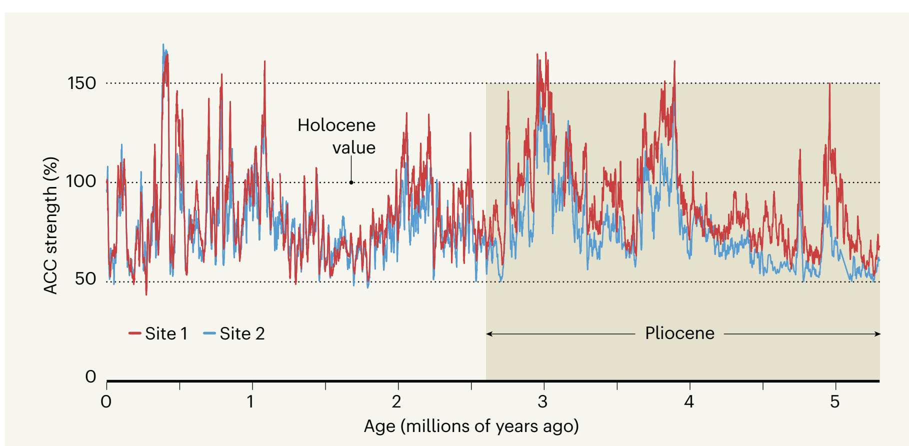

Figure 1 | Changes in the strength of the Antarctic circumpolar current. Lamy *et al.*[2] reconstructed a five-million-year history of the Antarctic circumpolar current (ACC) and found that its strength varied on timescales associated with changes in Earth's orbit, but remained relatively constant over the whole period. Data were similar across five distinct sites. ACC strengths for two sites are shown here relative to the average strength during the present Holocene epoch. A general increase in strength occurred between five million and three million years ago, when Earth was undergoing a period of cooling during the Pliocene epoch. This trend runs counter to the expectation that the ACC is weak during (cool) glacial states and strong during (warmer) interglacial states. (Adapted from Fig. 4d of ref. 2.)