Figure 2 | Accelerated slippage. A 2005 image of Kangerdlugssuaq, an outlet glacier of the Greenland ice sheet, from a Disaster Monitoring Constellation satellite. The glacier's calving speed doubled during 2004; the yellow line shows marginal position in 2000, about 4 km in front of imaged position.

together with unexpected and rapidly changing behaviour. Uncertainties remain, but the GRACE results provide one of the best estimates of overall mass balance of the ice sheet.

They do not, however, reveal the detailed pattern, at least not yet. It is vital that we use a variety of instruments and techniques to make continued observations of the ice sheet's response, and complement these with studies aimed at understanding the processes that are driving the observed changes. Such a programme will allow us to improve our predictive models of the Greenland ice sheet, and assess the timing and extent of its future contribution to sea-level rise. ∎

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0.7 mm yr^{-1} (ref. 2) — results from changes in the dynamics of outlet glaciers. Current model predictions from the Intergovernmental Panel on Climate Change suggest a sea-level rise of 0.5 ± 0.4 m during the 21st century. But these models contain only a small component of the dynamic response of glaciers[10], and the GRACE results indicate that more rapid changes are occurring than the models predict. The GRACE results can thus help us to re-evaluate the rates

of loss from the ice sheet that we should expect through climate warming.

It is clear that there is much we don't understand about the current response of the Greenland ice sheet. Records over short periods have to be treated with caution, and we cannot be certain that changes represent a profound alteration in the behaviour of the sheet. But several independent sources now confirm overall mass loss from the Greenland ice sheet,

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A precious little bundle

Bernard Wood

The three-million-year old skeleton of a three-year-old child provides an outstanding resource to understand the development of a human ancestor that seems to have both walked upright and climbed through trees.

The fragile bones of infants rarely survive long enough to make it into the hominin fossil record. But if they do, they provide precious evidence about the growth and development of the individual and its species. This helps researchers not only to understand how such processes have changed during hominin evolution, but also to interpret the function and the taxonomic significance of the better-sampled adult specimens. In this respect, the remarkably complete 3.3-million-year-old skeleton of a three-year-old *Australopithecus afarensis* female, found in Dikika, Ethiopia, is a veritable mine of information about a crucial stage in human evolutionary history. In this issue, the fossil is described by Alemseged *et al.* (page 296)[1], and its geological and palaeontological context is reported by Wynn *et al.* (page 332)[2].

Thanks to efforts in Ethiopia and elsewhere, we already know a good deal about *A. afarensis*. It has been called an 'archaic' hominin for

at least two reasons. First, it is old: its fossils date from between 4 million and 3 million years ago. Second, its morphology is archaic, in the sense that its brain case, jaws and limb bones are much more ape-like than those of later taxa that are rightly included in our own genus, *Homo*. When adjusted for its body size, the brain of *A. afarensis* is not much larger than that of a chimpanzee, and although it has lost the large canines that distinguish apes from hominins, other aspects of its dentition, such as its relatively large chewing teeth, are still primitive (Fig. 1).

There remains a great deal of controversy regarding the posture and locomotion of *A. afarensis*. Most researchers accept that it could stand upright and walk on two feet, but whether it could climb up and move through trees is still disputed. Some suggest that its adaptations to walking on two feet preclude any significant arboreal locomotion, and interpret any limb

features that support such locomotion as evolutionary baggage without any useful function[3]. Others suggest that a primitive limb morphology would not have persisted unless it served a purpose[4].

The Dikika infant is not the first early hominin infant to be found. That distinction belongs to the Taung child, whose discovery was reported just over 80 years ago[5]. What makes the Dikika infant remarkable is its unprecedented completeness for such a geologically ancient specimen. The infant was found in sediments that formed the bottom of a small channel close to where a river discharged into a lake[2]. This was not a turbulent stream or river. The flow was sluggish, typical of the type of braided streams that make up a river delta. The corpse of the infant was buried more or less intact, and the sediment in flood waters must have swiftly covered it.

Some parts of the specimen — the pelvis, the lowest part of the back and parts of the limbs — are still missing, but what is preserved is remarkably complete. The face, the brain case and the base of the cranium, the lower jaw, all but two of the teeth (including unerupted adult teeth still in the jaw), both collar bones, the vertebrae down to the lower back, many ribs, both knee caps and the delicate bone that holds open the throat, the hyoid, are all there. Even the medial epicondyle of the humerus has survived. This is the bony projection on
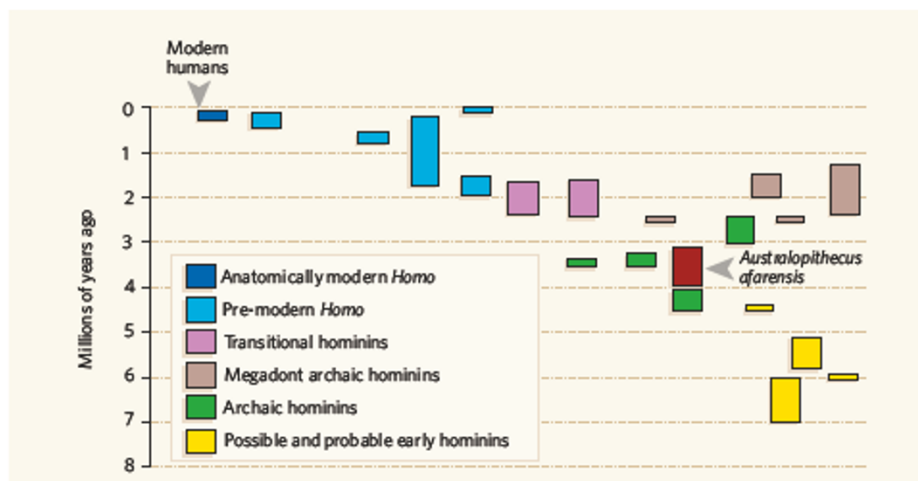
Figure 1 | A hominin taxonomy. Species are ordered according to the period of their fossil record and, left to right, according to their resemblance to modern humans: those with large brains, small chewing teeth and jaws similar to those of *Homo sapiens* are found to the left, those with large chewing teeth and jaws to the right. *Australopithecus afarensis*, an infant female specimen of which has been found in Dikika, Ethiopia[1,2], lived between 4 million and 3 million years ago. Its small brain is not much larger than that of a chimpanzee, but its dentition has features akin to those found in more modern hominins.

the inside of your elbow against which your left thumb rubs if you hold your right elbow with your left hand. In a three-year-old infant, this tiny piece of bone is still separate from the main shaft of the humerus. One must travel forward in time more than three million years, to a Neanderthal infant from Dederiyeh[6], Syria, to find a comparably complete hominin infant skeleton.

This anatomical cornucopia was not evident when the specimen was found in 2000: most of the Dikika infant was invisible, hidden within a slab of sandstone. Zeresenay Alemseged has devoted many thousands of hours over a five-year period to removing, painstakingly, the cement-like matrix that surrounds the delicate bones. The patience, time, skill and effort required to preserve and expose the morphology of this and other similar early hominin fossils[7] should not be underestimated.

But why are Alemseged *et al.*[1] so sure that the infant belongs to *A. afarensis*, and can we have confidence in its age — both the geological age of the fossil and the age of the child it represents? The geological age is secure. The Dikika sediments contain crucial evidence of the same layers of ash that have provided reliable argon–argon isotope ages at other East African fossil sites[2]. There are also subtle and not so subtle differences between the faces of *A. afarensis* and the other hominin taxa known from similarly aged rocks, and the Dikika infant already shows signs of the type of upper jaw and nasal morphology that is seen only in *A. afarensis*. These signs are a rounded area above the upper teeth; a separation between the bone covering the roots of the upper canine teeth and the edge of the opening for the nose; and hourglass-shaped nasal bones that fit into a recess in the frontal bone much like a tenon fits into a mortise.

The second of the two age estimates, the chronological age of the infant, is less secure.

All one can do is use the kind of computed-tomography imaging familiar from modern hospitals to compare the development of the yet-to-emerge permanent tooth germs of the Dikika infant with the teeth of modern human and chimpanzee infants of known ages[8]. The best match is with three-year-old chimpanzees. But it is highly unlikely that the pace of development of *A. afarensis* was exactly the same as that of modern chimpanzees. So, for now, the chronological age of the Dikika infant must remain an informed guess.

The discoverers of the Dikika fossil have only just begun the task of capturing all the data contained in the specimen, but already these preliminary data[1] are informing the controversy of how *A. afarensis* moved. If its mode of locomotion was exclusively on two legs, one would expect that the limb bones and the organs that help it to balance would be more similar to those of the only living bipedal higher primate (that is, us) than to those of chimpanzees and gorillas. These primates walk on two feet only rarely, if at all.

Alemseged *et al.*[1] pay careful attention to the shoulder, hand and the semicircular canals of the inner ear, the morphologies of which record the motion of the body. The shoulder-bone (scapula) of the fossil is more like that of a gorilla than a modern human, and the bones of the only complete finger are curved like those of a chimpanzee. Chimpanzee finger bones begin life only slightly curved, but become more curved when the hands are used to climb branches[9]; this is what seems to have happened in the case of the Dikika infant. Lastly, images of the inner ear of the specimen show it to have semicircular canals more like those of chimpanzees than of modern humans[10]. The fluid-filled semicircular canals are crucial in maintaining balance, and so all three lines of evidence suggest that the locomotion of *A. afarensis* was unlikely to

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have been restricted to walking on two feet.

I am especially intrigued by the detailed morphology of the hyoid bone in the throat of the fossil. Does the open space in the body of the hyoid mean that *A. afarensis* had air sacs in its neck? In the absence of large canines, these air sacs might have been a way in which males established a dominance hierarchy, and females judged the quality of a potential mate.

Whatever the answers to such questions, the Dikika infant has the potential to provide a wealth of information about the growth and development, function and taxonomy of *A. afarensis*. ■

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MATHEMATICAL PHYSICS

Search research

Michael F. Shlesinger

How does one best search for non-replenishable targets at unknown positions? An optimized search strategy could be applied to situations as diverse as animal foraging and time-sensitive rescue missions.

Operations research — the field that uses mathematical methods to optimize complex real-world structures and processes — grew out of the analysis of military problems during the Second World War. One such question was the optimization problem 'How to hunt a submarine'[1], the analysis of which had to take several factors into account. For instance, a figure-of-eight search pattern of an aircraft scouring littoral waters would be different from the pattern for a search of deep-ocean waters. The problem was also complicated by the fact that a negative search might mean only that a submarine was submerged, not that it was absent.

The aim of such searches is to remove the target, and, writing in *Physical Review E*, Bénichou and colleagues[2] bend their minds to minimizing the amount of time needed when searching for such 'non-revisitable' targets. Since the early days of aircraft hunting submarines, many types of search have been investigated in which the target may or may not be destroyed upon contact. One such study[3] interpreted data from transmitters attached to the legs of itinerant albatrosses. The radio signal was silenced when an albatross was in the water. What emerged was a fractal on–off signal pattern that was consistent with the bird flying a 'self-similar' pattern — one in which the whole has the same shape as smaller component parts — with the end of each segment punctuated by a water landing. Presumably, the flight pattern reflected a search for food, and perhaps also the lifetime of thermals on which the seabirds ride.

Whatever the exact reason, this research led to several papers demonstrating that fractal patterns of the albatross type, called Lévy flights, are an optimal search strategy. But under what conditions? The theoretical Lévy strategy has a wide distribution of flight segment lengths, and the mean of this distribution is infinite. But in the case of the albatross, the act of catching food cannot be accomplished during a flight (Fig. 1), so too much time is spent in the flight segments for a Lévy strategy to minimize search time.

At first glance, diffusion might seem to be a satisfactory strategy for minimizing search time. When a particle starting at an arbitrary origin moves randomly, its location is described by a gaussian probability distribution that spreads out with a variance that grows linearly with time. It might seem that any target will be found because its location will eventually fall under the spreading gaussian peak. But this is not so. Even in one dimension, some particle trajectories move to the right while a hidden, static target is on the left. Averaging over all possible trajectories presents the startling fact that the mean first-passage time to any particular target is infinite.

But what if there are many targets? Consider a random walker starting on a line of targets on a square lattice. Here, the walker gradually diffuses away from the line, so the targets are visited less and less over time. One can calculate that after a large number of jumps N, only $N^{1/2}/\ln N$ of the targets are visited. In three dimensions, the result is worse: even more targets go unfound, with only $\ln N$ sites discovered[4].

Despite this unpromising prognosis, Bénichou and colleagues[2] rely, in part, on diffusion in their two-dimensional search model for non-revisitable static targets. They propose a two-state search pattern. In the first, dynamic, case, the searching is diffusive, and the target is found immediately when it is within a certain distance, A. In a second, static, case, the seeker is stationary and 'reacts' with the target at a certain rate when the target comes within a certain range.

In both cases, the time spent on the search phase is a random variable. When the search phase ends, either successfully or unsuccessfully, the motion of the seeker changes to a relocating ballistic: it shoots off in a random direction for a random stretch of time during which, according to the model, discovery of a target is not possible. This phase is followed by a further search phase, and so the cycle continues.

The authors derive[2] an equation for the distribution of first-passage times required for the seeker to find the target, for a general model combining the static and dynamic cases and allowing for an arbitrary rate of diffusion, D, and rate of reaction, k. As an

Figure 1 | Gotcha! An albatross completes a search for an non-replenishable target. Bénichou and colleagues[2] consider optimal strategies for such searches.

D. HADDEN/ARDEA