thaceae, Annonaceae, Araceae, Arecaceae, Magnoliaceae and Nymphaeaceae) being visited by more than 220 species of *Cyclocephala* alone[13]. Heat reward may have been even more important during the early evolution of the flowering plants.

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Psychophysics

How fielders arrive in time to catch the ball

Tracking an object moving in three dimensions, whether as an insect pursuing a mate on the wing[1] or as a batsman aiming to hit an approaching ball[2], provides the spatial and temporal information needed to intercept it. Here we show how fielders use such tracking signals to arrive at the right place in time to catch a ball — they run so that their angle of gaze elevation to the ball increases at a decreasing rate while their horizontal gaze angle to the ball increases at a constant rate (unless the distance to be run is small). Allowing the horizontal angle to increase minimizes the acceleration that the fielder must achieve to reach the interception point at the same time as the ball[3].

Figure 1a shows two sources of information that the fielder receives from tracking the ball: the angle of elevation of gaze (α) and the horizontal angle through which the gaze system has rotated relative to the initial direction from fielder to ball (δ). Fielders run so that α increases at a decreasing rate[4] — in principle, this guarantees interception. The locus of points from which α has increased by the appropriate amount in the ensuing time interval lie on a circle centred on the vertical projection of the ball to the ground. As the ball falls, the circles decrease in diameter and the fielder, moving through successive circles, homes in on the interception point (Fig. 1b).

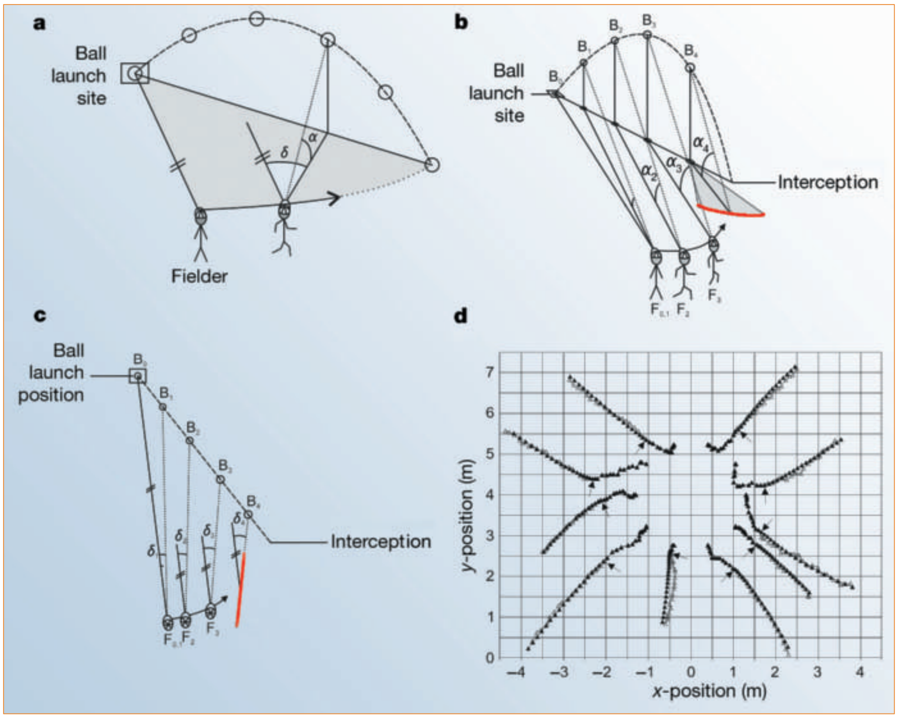

Figure 1 Keeping an eye on the ball. **a,** Angles of gaze from fielder to ball: α is the angle of gaze elevation; δ is the angle of horizontal gaze rotation relative to starting direction. **b,** Movement of a fielder to adjust α. As indicated by the arrow, a fielder at position F_3 must move to a position on the red arc bounding the shaded region in the ensuing time interval to ensure that $d\alpha/dt$ decreases at a particular rate. **c,** Aerial view of ball and fielder; the red line shows the locus of points to which the fielder at position F_3 must move in the ensuing time interval to ensure that $d\delta/dt$ remains constant. **d,** Paths of real (light triangles) and simulated (dark triangles) fielders for ten catches. Initially, the simulated fielder was moved to the same positions as the real fielder; after the point marked by the arrow, it moved under the constraints for α and δ described in the text.

However, running so that α increases at a decreasing rate would not in itself be an effective strategy. Early in the ball's flight, there is little constraint on the direction in which the fielder must run, as the circle of points that satisfies the α constraint is large. If the fielder does not initially move towards the interception point, he may not be able to run fast enough to implement the strategy as the flight nears its end. Efficient interception requires the fielder to select a point in the circle that is towards the interception point[5].

We have found that fielders usually run so that δ increases at a constant rate[3]. This requires them to move at successive time intervals to a point from which δ would have an appropriate value, given the position of the ball at the end of the time interval. These points lie on a straight line (Fig. 1c). To satisfy both constraints, the fielder must move to the point at which the line and circle intersect, thereby ensuring that the fielder is moving towards the interception point throughout the ball's flight.

We simulated a fielder moving under these constraints to catch balls on the same trajectories as those caught by real fielders. The simulated fielder was moved to the same positions as the real fielder for the first 600 ms to give the same initial visual experience as the fielder, and then moved so that α increased at the average declining rate and δ increased at the average rate experienced by the real fielder up to that point. The similarity between the real and simulated fielders' running paths can be seen in Fig. 1d.

According to our theory, fielders do not explicitly select their direction or speed when running. They move in way that satisfies the constraints for the changes in α and δ. This view of the fielder's strategy as based on repeated local constraint satisfaction, rather than on a calculation of where the ball will ultimately fall, is consistent with the subjective sensation of running to catch a ball. You do not know exactly where the ball will land, but you do know whether or not you will be able to intercept it. This presumably reflects the knowledge that you have been able to satisfy the constraints (or not).

The origin of the strategy may be that a child watching objects that hit him or her will experience α increasing at a decreasing rate, whereas watching balls that pass by will produce a declining α and an accelerating δ (ref. 3). When the child tries to catch the ball, he or she will run in a way that reproduces previous experiences with objects that hit and avoids those from objects that missed.

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Flightless birds

When did the dodo become extinct?

The extinction of the dodo (*Raphus cucullatus* L.; Fig. 1) is commonly dated to the last confirmed sighting in 1662, reported by Volkert Evertsz on an islet off Mauritius[1,2]. By this time, the dodo had become extremely rare — the previous sighting having been 24 years earlier — but the species probably persisted unseen beyond this date. Here we use a statistical method to establish the actual extinction time of the dodo as 1690, almost 30 years after its most recent sighting.

In most cases, the extinction of a species must be inferred from the record of sightings or from collections of individual organisms. But when a species becomes increasingly rare before its final extinction, it may continue to exist unseen for many years — so the time of its last sighting may be a poor estimate of the time of extinction.

We applied an optimal linear estimation method based on the sighting record of the dodo to determine when the bird finally became extinct. Let $T_1 > T_2 > ... > T_k$ be the k most recent sighting times of a species, ordered from most recent to least recent. Interest centres on using this record to estimate the extinction time, θ. In this context, optimal linear estimation is based on the remarkable result that the joint distribution of the k most recent sighting times has (at least roughly) the same 'Weibull form', regardless of the parent distribution of the complete sighting record[3].

Briefly, the optimal linear estimator of θ has the form of a weighted sum of the sighting times, calculated as

$$\hat{\theta} = \sum_{i=1}^{k} a_i T_i$$

The vector of weights is given by

$$a = (e^t \Lambda^{-1} e)^{-1} \Lambda^{-1} e$$

where e is a vector of k 1's and Λ is the symmetric $k \times k$ matrix with typical element $\lambda_{ij} = (\Gamma(2\hat{\nu}+i)\Gamma(\hat{\nu}+j))/(\Gamma(\hat{\nu}+i)\Gamma(j))$, $j \leq i$, and where Γ is the standard gamma function. Also,

$$\hat{\nu} = \frac{1}{k-1} \sum_{i=1}^{k-2} \log \frac{T_1 - T_k}{T_1 - T_{i+1}}$$

is an estimate of the shape parameter of the joint Weibull distribution of the k most recent sighting times. An approximate $1-\alpha$ confidence interval for θ is given by

$$\left(T_1 + \frac{T_1 - T_k}{S_L - 1}, T_1 + \frac{T_1 - T_k}{S_U - 1}\right)$$

where $S_L = (-\log(1-\alpha/2)/k)^{-\hat{\nu}}$ and $S_U = (-\log(\alpha/2)/k)^{-\hat{\nu}}$.

The $k = 10$ most recent confirmed sighting times of the dodo are 1662, 1638, 1631, 1628, 1628, 1611, 1607, 1602, 1601 and 1598.

An escaped slave named Simon claimed to have seen a dodo as recently as 1674. However, the reliability of this and other later claims are open to question. For this record, the estimated shape parameter is $\hat{\nu} = 0.39$ and the estimated extinction time is $\hat{\theta} = 1690$. The approximate 0.95 confidence interval for θ is (1669, 1797). The width of this interval is a result of the low sighting rate of the dodo at the end of its sighting record. Because this rate was so low, it is impossible to rule out an extinction date as late as 1797. This implies that the purported sighting in 1674 cannot be ruled out on the basis of extinction time alone. If a sighting in 1674 is included in the record, the estimated extinction time is extended only modestly to 1700 and actually narrows the confidence interval to (1679, 1790).

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Figure 1 Dead as a dodo: the flightless bird from Mauritius and the adjacent islands weighed in at about 23 kg and was hunted to extinction. Its last confirmed sighting was in 1662, although an escaped slave claimed to have seen the bird as recently as 1674. In fact, it is estimated by using a Weibull distribution method that the dodo may have persisted until 1690, almost 30 years after its presumed extinction date. Although gone forever, the dodo's lumbering appearance in Lewis Carroll's *Alice's Adventures in Wonderland* has ensured that it will not be forgotten.

COMMUNICATIONS ARISING

Astronomy

Black holes, fleas and microlithography

Fresnel lenses allow almost perfect imaging in widely different circumstances, but their focus is perfect only for a single wavelength. Wang *et al.*[1] have shown how the effective bandpass may be widened for X-ray microscopy by using a compound diffractive/refractive lens near to an absorption edge. A compound lens has also been proposed for high-energy astronomy, working well above all absorption edges[2,3]. Although the scale is very different, we point out here that the principle is the same. Ever since Galileo constructed an astronomical telescope that he was able to reconfigure to study fleas and gnats, astronomy and microscopy have relied on optics that are closely related, but different in detail.

In principle, the highest resolution in each case is obtained with the shortest wavelengths — X-rays or γ-rays. In microscopy and microlithography, the spatial resolution of the optical system dictates the level of detail in images and the fineness of structures in integrated circuits. Resolution better than 30 nm has been reported[4]