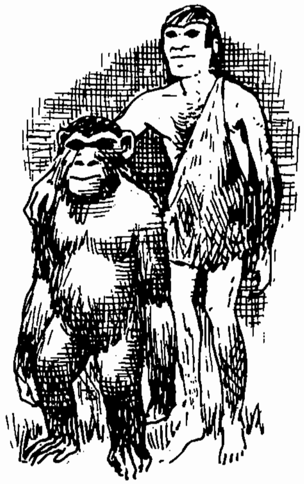

The Importance of Being Human

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In the summer of 1965, my paleontological colleague, Bryan Patterson, was in charge of a Harvard expedition working near the shore of Lake Turkana in northern Kenya. At a locality called Kanapoi, while he was searching in deposits believed to be of the early Pleistocene (the last geological epoch before the present), he picked up an important fossil. The broken lower end of a left humerus (the upper arm), it was easily recognized as *hominoid*; that is, it came from a creature of the group that includes humans and their closest living relatives, the apes, but not from a monkey.

What was the special importance of the fossil? From shape and size it could be seen at once not to belong to a gorilla, an orangutan, or a gibbon (and the last two have never been present in Africa anyhow). It was extraordinarily similar to the same piece in modern humans; in fact, it was indistinguishable. But the date of the deposit was certainly before the existence of anything like modern humans, and after the field season was over, volcanic basalt from a bed lying

above the deposit gave an age estimate, by radioisotope dating, of about 2½ million years. The oldest human stage that had been established so far was that of the erect-walking but small-brained and large-jawed australopithecines found by Louis Leakey at Olduvai Gorge, which had been dated at about 1¾ million years. If this small piece of arm bone were "human," or *hominid*, in the sense of belonging to such a creature, it would extend the continuous record of human evolution backward three-quarters of a million years at a single bound.

But there was one problem. This piece of elbow joint in humans can easily be told from that in orangs, gorillas, and gibbons, but not from that in chimpanzees. Although the rest of a chimpanzee's bone is shorter and stouter, this region is so similar in the two species that many, if not most, specimens defy classification as one or the other on examination. In spite of different uses of the arm, this particular part shows such slight, subtle, and inconstant distinctions in size and shape as to baffle ordinary methods of study even by experts. The problem, therefore, was this: either the bone was that of the earliest australopithecine yet found in our direct ancestral history or it was simply that of an ancestral chimpanzee, in which case we could breathe normally. What about testing something old with something new? Could an electronic computer tell us anything useful?

A computer, of course, does not really "tell" anything. It merely makes possible answers to mathematical questions that we would not live long enough to answer if we tried to work them out with simple calculating machines. With its enormous capacities and speed, a computer transfers the effort from getting the right answer to getting the right question. Biological material—bones or skulls are good examples—lends itself to particular kinds of questions. Because the genes they inherit are capable of a virtually infinite number of different combinations, no two individuals of a population or species are exactly alike (with the spectacular exception of identical twins). So, quite apart from different habits of use, diet, or other accidents of growth, human elbow joints vary normally in size and details of shape, though they vary within a limit of form that is basic to the actions of human elbow joints.

Quite different species of animals, of course, have quite different forms in various body parts. Any beginner can distinguish between a cheek tooth of a mammalian carnivore, with its narrow, knifelike shearing crown, and that of a herbivore, which has a broad surface for grinding vegetable matter. These are marked evolutionary divergences. Within herbivores the differences are smaller, and within groups of herbivores such as pigs (for example, domestic pigs, wild boars, warthogs, etc.) or elephants, species distinctions are matters for experts, who can obtain a wealth of information from fossils about the history of pigs and elephants or about the exact species of animals present at a given time in the past at a fossil locality such as Kanapoi. Finally, for particular parts, such as the elbow joint in chimpanzees and humans, the species distinctions may be so slight as to be eclipsed by the variation *within* each species, already described. That is the situation we are faced with here.

This is not just a matter of impression: it may be viewed quantitatively. Some time ago, Professor William L. Straus of Johns Hopkins University, a man with much experience in such studies, tried to deal with the same problem when the same piece of the humerus of a species of australopithecine was found at the site of Kromdraai, near Pretoria, South Africa. In this case, it was plain that the bone belonged to *Paranthropus,* the species in question, because other skeletal and cranial parts of the same species had been found at the site, and the bone could hardly be assigned to anything else. Here the problem was whether the bone was more humanlike or more apelike, since the hominid ("human") position of the australopithecines at that time was less clear. Professor Straus made a number of typical measurements of human and chimpanzee bones in an attempt to find differences between them. He found statistically significant differences[1] in the averages of certain of the measurements, but the absolute differences were slight, and the overlap in each measurement between human and chimp was so great that the *Paranthropus* fragment could not be allocated to either. In no case did its measurements lie outside the range of either human or chimpanzee, though the figures were more often closer to the mean, or average, figures for the latter.

This was no solution and led to no decision as to the relationships of *Paranthropus,* insofar as the arm could shed light on them. In such a case, we need a method that is not limited to comparisons of single measurements, that somehow takes account of the whole shape of the bone, or part, as the eye tries to do, and that also has some way of emphasizing the really telling differences in shape between two species, if they exist. Now here is an important point: in the end, any such problem comes down to a mathematical question because the eye itself (though very seldom consciously) attempts to assess the *average* differences in proportions and complex aspects of shape, to rate the varying importance of these, and, finally, to judge the probability that a given total shape, in a single case, falls nearer to the essential basic form within the variation of one population than to that of another. These are questions of quantity and probability, whether measured or not, and are thus statistical in nature. After all, educated opinion is always the weighing of probabilities. And here is another important point: biologists and anthropologists—and members of many other sciences—are not often strong in mathematics of a higher order, though they may see only too acutely the limits of their own ways of solving problems. At the same time, mathematicians, although they have hearts of gold, are not usually sufficiently conversant with the niceties of biological problems to understand just what the biologist is trying to gain by using a mathematical analysis. When the two really get together, however, the rewards in the way of new solutions may be great. And I must say that mathematical training among biologists who see better what such training can offer has increased notably in recent years.

Fortunately, the particular problem of the Kanapoi fossil is not exceedingly complex, and the solution was provided some years ago by the great English

[1]The reader may recall that, when statisticians can detect a difference likely to be a real effect and not one stemming from chance variation, they call it "statistically significant." By saying "statistically" they warn us that the absolute size of the difference may be small and seemingly unimportant because it depends on the objects being studied.

statistician and geneticist R. A. Fisher in the form of the ***discriminant function.*** The discriminant function eliminates the futile business of looking at measurements one at a time, of finding that the overlap prevents discrimination of two sets of specimens, such as human and chimp elbow joints, even though they are known to be from quite different animals, and of being unable to place something such as the *Paranthropus* specimen logically nearer one group than the other. It has a set of weights with which to multiply a number of different measurements of a specimen, the sum of the products being a single *discriminant score* that makes the best attainable use of all the information in the several measurements. Given two groups, such as humans and chimpanzees, the computation develops the optimum set of weights possible from the measurements used: the effect is to sift out important differences—often quite invisible to the eye or in average figures—so as to emphasize precisely the aspects of shape and size that will best discriminate between the two groups. That is, compared to just that variation *within* a set of human elbow joints, or chimpanzee elbow joints, the distinctions *between* the sets are searched out mathematically so that the discriminant scores of the two groups are segregated one from the other to the maximum degree possible, limited only by the information contained in the measurements. Thus the overlap, acting as a mask to hide any real group differences, is reduced or removed.

The basic idea of the discriminant function may be appreciated graphically in the case of *two* measurements, represented by the two axes of Figure 1. (The measurements might be heights and girths of two different groups of men.) The oval areas correspond to groups of individuals from two populations A and B. If we look just at measurement 1 by dropping projections on the horizontal axis, we find considerable overlap between the two populations. The same holds for measurement 2. On the other hand, the slanted line perfectly separates the two populations. This is not the place for mathematical detail, but to write the previous sentence is to say that looking at something like

$$(\text{Measurement } 1) + 2 \times (\text{Measurement } 2)$$

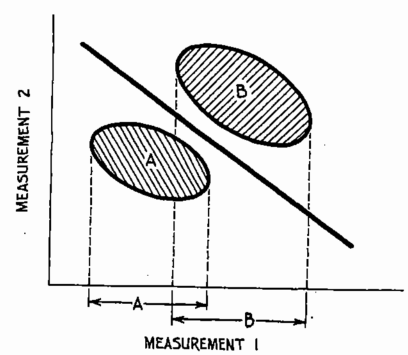

Figure 1 *Two measurements together separate groups better than either separately.*

gives us a new score, the discriminant score, which permits much better separation of the populations than either of measurements 1 or 2 alone. If there are more than two measurements, as in the present case, then there are great potential gains in combining measurements.

Professor Patterson and I felt fairly strongly that the Kanapoi fragment was hominid—on the human, not the ape, side of the hominoid group as a whole. But we wanted to demonstrate this statistically, not merely to voice an opinion to which opposing opinions could be raised by others. As a strategy, we examined human and chimpanzee humeri to see what measurements would most likely reflect such differences as we thought appeared, whether frequently or not. Figure 2 shows the fragment itself and some of the measurements. To begin with, we took the total breadth across the whole lower end, as a matter of general size (measurement 1). Second, the more projecting inner, or medial, epicondyle (at the left in the figure) has a snub-nosed, or slightly turned-up, aspect in some chimpanzees, and we hoped to register this effect by measuring from the lowest point on the trochlear ridge both to the "beak" of the epicondyle and to the nearest point on the shoulder just above it (measurements 2 and 3). The idea was that a slightly greater difference between these two would reflect a deeper curve and more upturned epicondyle. We also measured the backward protrusion of the central, or trochlear, ridge of the joint, the length and breadth of the oval inner face of the medial epicondyle (none of these is shown in Figure 2), and an oblique height of the opposite, or lateral, epicondyle. We thought these measurements showed some tendency to vary one way in humans, the other in chimpanzees, though not being the rule in either (if there *were* regular distinctions, obviously the problem of discrimination would be much less). We were not certain of the functional meaning of the possible differences, but they logically could be related mostly to muscle attachments connected with simpler and more powerful use of the flexor and extensor muscles of the hand in the chimp, in hanging by the arms or supporting the body in ground-walking by the characteristic resting on the middle knuckles, all as contrasted with the more general, but more complex and varied, use of the hands in humans.

Now this is just where the cooperation comes in. It is the paleontologist's or anthropologist's business, from his or her background knowledge, to find

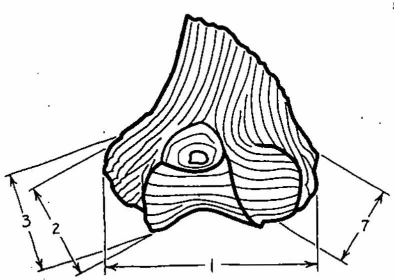

Figure 2 *Kanapoi humeral fragment and measurements taken.*

measurements that will carry important and real information as to differences. It is the statistician's business to say how the measurements can be put together to bring out the differences for evaluation. Here, cooperation had already gone so far in recent years that the biologists knew in advance what statisticians could offer them and we planned our work accordingly.

We measured 40 human bones in the Peabody Museum at Harvard and 40 chimpanzee bones in the Harvard Museum of Comparative Zoology and the American Museum of Natural History in New York. As in Straus's measurements, the overlap of human and chimp was great, but the mean differences, resulting from the special selection of measurements, were in most cases better defined. The means for the two groups and the figures for both the Kanapoi and Kromdraai fragments (the latter taken on two casts) are given in millimeters in Table 1.

The chimpanzee specimens, as a sample, may be accidentally a little large on the average. The *Paranthropus* fragment is obviously small in all dimensions and so appears "human" when we glance at this list; however, this does not necessarily mean that the shape relations conform to those of humans. The correspondences of the Kanapoi measurements to the human means (of this particular sample) are very close throughout—closer than we might expect any random human bone to be in all its measurements.

To assure ourselves of this apparent closeness, we computed a discriminant function from the human and chimp figures. For only seven measurements and such small samples, the calculations could be done by hand, though at the cost of no little labor. In technical language, matrices have to be formed of the sums of all the cross multiplications of all the measurements of all the individuals both within each group and of the total lot; other steps require the inversion of one matrix and the determination of the latent roots of another. Inversion by hand of a matrix of even the modest size of 7 × 7 is a tedious business and one open to error. This all leads to finding the discriminant function, which takes the seven measurements from a specimen, multiplies each measurement by a weight specific to that measurement, and then adds these products to give the discriminant score. This is a great deal of arithmetic, and we can only say that to have a computer handle such a job in a matter of minutes is very welcome. Waiting for paint to dry or for a film to be developed now seems long and drawn out by comparison, and such easy computation has obviously greatly encouraged undertakings such as the one described here.

Table 1 Measurements

Measurement	*Chimp Mean*	*Human Mean*	*Kanapoi*	*Paranthropus*	*Scaled Vector*
1. Bi-epicondylar width	64.1	58.0	60.2	53.6	− .09
2. Trochlea-medial epi. distance	44.8	40.7	41.7	33.6	+ .40
3. Trochlea-supracondyl dist.	41.3	38.8	39.4	32.1	− .62
4. Posterior trochlear edge	26.4	22.1	22.2	19.9	+ .11
5. Medial epi. length	24.7	20.3	20.8	15.5	+ .19
6. Medial epi. breadth	12.8	12.6	13.9	10.4	− .32
7. Lateral epi. height	31.5	26.7	27.6	24.9	+ .56

The last column in Table 1 gives not the actual weights in the discriminant function as used, but rather a rescaled form of the weights with their relative importance in proper perspective (because, for example, a small measurement, such as thumb length, might require a much larger weight in the function than a large measure, such as stature, to make it effective). These figures show how a number of measurements combine to form a single pattern of greatest difference between the two groups. As might have been expected, the two measurements to register the snub-nosed effect of the medial epicondyle, or its opposite, are useful, as shown by the large size of the scaled vector values. The plus value of measurement 2 and the minus value of measurement 3 combine to make the total discriminant score higher when the epicondyle is most turned up; that is, when measurement 2 is high relative to measurement 3 (see Figure 1), the function creates a greater positive value to add and a smaller minus value to subtract in the total score, and when the opposite is true, with the shoulder of the condyle more sloping, there is on balance a greater minus value in the total score. The lateral epicondyle (measurement 7) also adds a greater plus value when it is high, while the breadth of the medial epicondyle (measurement 6) adds to a plus value (or rather subtracts *least* from a total value) when it is relatively narrow.

Table 1 shows that the above are indeed characteristic human-chimp differences in the averages (though small ones), all of which tend to produce higher score values for the chimpanzee. We note that there is almost no *absolute* difference in measurement 6, the breadth of the medial epicondyle, certainly not a significant one, and yet this measurement is important in discrimination because it is *relatively* narrow in chimpanzees, whose other measurements (in these samples) are larger, on the average, than the human measurements.

We notice also that because the discriminant score is affected by all measurements, it takes account of variation in form toward or away from a basic pattern: if a chimpanzee bone lacks any snubbing of the medial epicondyle, it may exhibit another combination of narrow epicondylar face or high lateral epicondyle, and so it may score in a chimpanzee direction anyhow.

When the discriminant scores were calculated, they produced a far greater separation of human and chimpanzee bones than did any of the measurements singly. Here are the mean score values, and the limits of the individuals in each group:

	Mean	*Range*
Chimpanzee	99.77	67–130
Human	61.42	40–84

All but two of the chimpanzee values fall between 80 and 120, and all but one of the human values fall between 50 and 75, which are nonoverlapping intervals. So the separation was very good: of 80 specimens, only 3 overlapped, falling closer to the wrong mean figure than to their own. Unquestionably, this is a successful procedure to distinguish human and chimpanzee humeri by measurement, with a much greater probability of correct assignment than is possible by eye.

Now for the scores of the Kanapoi and *Paranthropus* fragments. These were 59.4 and 63.9, respectively, very close to the human average (almost too good to be true, being closer than most of the known human individuals) and, of course, outside the range of the 40 chimpanzee values entirely. Using statistical theory we compute that, had either bone actually belonged to a chimpanzee, it would have a discriminant score as small as those above (or smaller) with a probability of only about 1 in 500. With so small a probability, we conclude that the two bones did not come from chimpanzees, but from hominids, and that is the answer to the question we framed.

Of course, we must be careful. The real question (because of the material we used) was this: how do the fragments classify themselves when they are asked to choose between *modern* human and *modern* chimpanzee arm bones? These were the only alternatives which we offered to fossil creatures which existed when there were no modern humans, and when ancestral chimpanzees might also have differed significantly from those of today. Nevertheless, we have good grounds for inferring from their shape that the arm bones were used, on the whole, like those of humans and, at least, not like those of the African apes, terrestrial though they are to a great extent. This takes care of the Kanapoi individual and, as a bonus, says the same thing for the hitherto baffling fragment from Kromdraai.

To review: unable to establish from visual inspection that the Kanapoi fossil did not belong to an animal like a chimpanzee, we turned to measurement and a statistical procedure that could be applied with the help of a computer. (As biologists, we knew from experience how to state the problem and extract a great deal of information, but how to order, analyze, and judge the information we learned from statisticians.) Though moderately complex, the discriminant function is well suited to the biological realities of individual variation and group differences in shape and gives an answer that states a numerical probability from the known evidence. So, by the middle of 1966, Professor Patterson and I had concluded that we could rule out the possibility that he had found the bone of an ape and that from what we know about East Africa, the only other possible possessor of the fossil was an early hominid, that is, an australopithecine.

Much more is now known in 1988 about australopithecines and about East African paleontology. The Kanapoi formation is dated at more than 4 million years ago, not 2½ million. On a later expedition, Professor Patterson found a piece of a lower jaw, at Lothagam Hill west of Lake Turkana, dated at about 5 million years ago. This has been diagnosed as very probably hominid, as have a couple of other minor fragments found elsewhere in the same region. There is now a general consensus that hominid origins lie between 5 and perhaps 8 million years in the past.

Also, a considerable amount of skeletal material has been recovered elsewhere in East Africa that is more than 3 million years old, especially in the Ethiopian sample made famous by "Lucy." But the Kanapoi fossil is still the earliest such limb fragment, and it is still decidedly modern in form—as confirmed by later and more complex analyses—compared to Lucy and her companions. In any case our original conclusion, that it represents an australopithecine, is sustained and now appears much less surprising. And we may take note that our 1967 statistical analysis was decidely helpful in affirming the importance of the Kanapoi fossil, before the later material was in hand.

PROBLEMS

1. In the hypothetical example of Figure 1, project the values of measurement 2 for groups A and B onto the vertical axis and indicate the interval where the two populations overlap on measurement 2. Use Figure 1 to explain why we need to look at both measurements (or a function of these measurements) to be able to classify an individual as being in A or B.
2. Suppose instead of the two populations in Figure 1 we have the populations in Figure 3 below. It is then very easy to discriminate between the two populations. How would you do it?

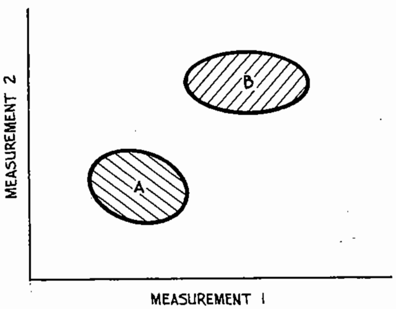

Figure 3

Use this example and the one in Figure 1 to explain when discriminant functions are needed.

3. In Table 1 note that there is almost no difference in measurement 6 for humans and chimpanzees, yet it was one of the measurements that helped to discriminate between the two populations. Explain how measurement 6 might help in disciminating between the two populations.
4. Give a detailed example of your own in which a discriminant function analysis might be appropriate.