THE ANALOGUE VIDEO RESHAPER—A NEW TOOL FOR PALAEONTOLOGISTS

by R. M. APPLEBY *and* G. L. JONES

ABSTRACT. A television-based system has been devised to overcome two classes of problem, crushing and distortion, and subjectivity in choice of features to be compared. The system is an automation of D'Arcy Thompson's method of transformation. Removal of the effects of shear is demonstrated from *Angelina*. Other illustrations comprise intraspecific variation in *Chlamys varia* (Linnaeus) and *Goniorhynchia boueti* (Davidson), variation in *Micraster*, ontogenetic variation in the reptile *Stenopterygius quadricissus* (E. Fraas), and phylogenetic variation in a group of closely related hominids. The system has proved more sensitive and quicker than existing practices and although no attempt is made to solve any specific problem, suggestions for discussion are raised.

THE palaeontologist often faces two problems, first, having to work with crushed and deformed material and, secondly, subjectivity in his choice of parameters to be described, measured, and weighted. Both may lead to unconscious bias and error in resulting comparisons. Until recently no method of making rapid accurate restorations of deformed or crushed fossils was known, but various methods of comparing organisms have been devised and used over the years. By far the most ingenious and productive of these is the graphical method of Thompson (1917) known as the method of transformations. This method is a modification of the way an artist enlarges a drawing. The artist places a rectilinear grid over the subject to be enlarged. He then draws a grid of the requisite size and redraws the subject so that it occupies the same relative position on the enlarged grid. D'Arcy Thompson placed the grid on the first form and then redrew the grid over the form with which it was to be compared, so that the grid was modified to pass over similar or homologous points on the second form. Although the two subjects were often complex, the resulting modified grid was relatively more simple and also capable of more complete mathematical analysis.

Thompson's method was the first to encompass the comparison of all the features and measurable quantities in a two-dimensional view in one operation, but other kinds of methods have been devised to increase the scope of comparisons. Olson and Miller (1958) found that the closer the correlations between sets of measures (ρ-groups), the more recognizable the functional sets (F-groups) among the parts measured. The results are expressed as correlation diagrams between the measures, but these unfortunately remove the pictorial appreciation of the dispositions of the functional groups in the organisms. The method also tends to reduce the recognition of the possible evolutionary value of loosely correlated but consistently present sets of measures. Although the assembling of data by this method is laborious it is susceptible to digital treatment. Other palaeontologists believe that equations may be written for the totality of shape information representing the organism. Using such equations, digital comparisons with other organisms should then be possible but this is a very difficult procedure, requiring expensive hardware and much time. Results have yet to be published.

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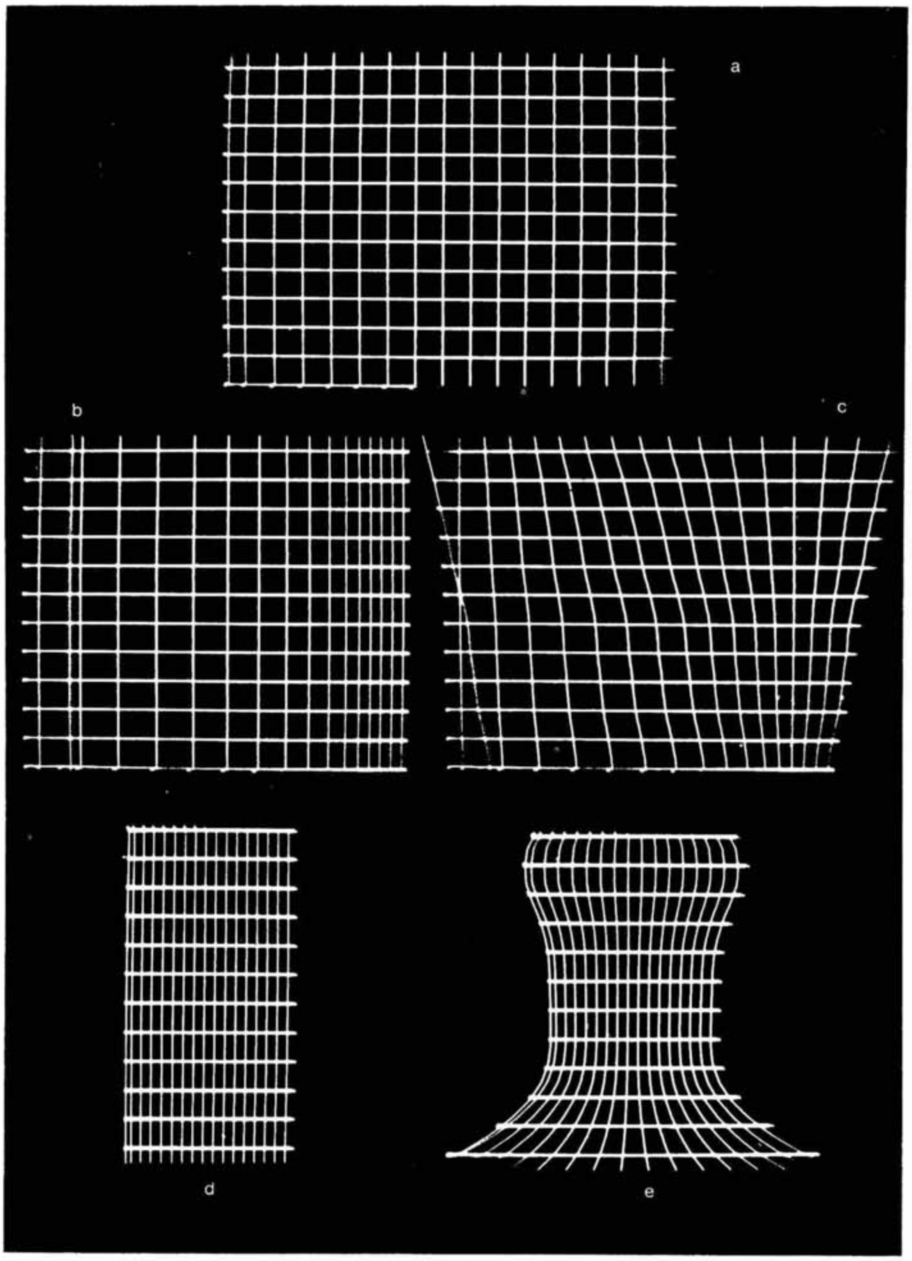
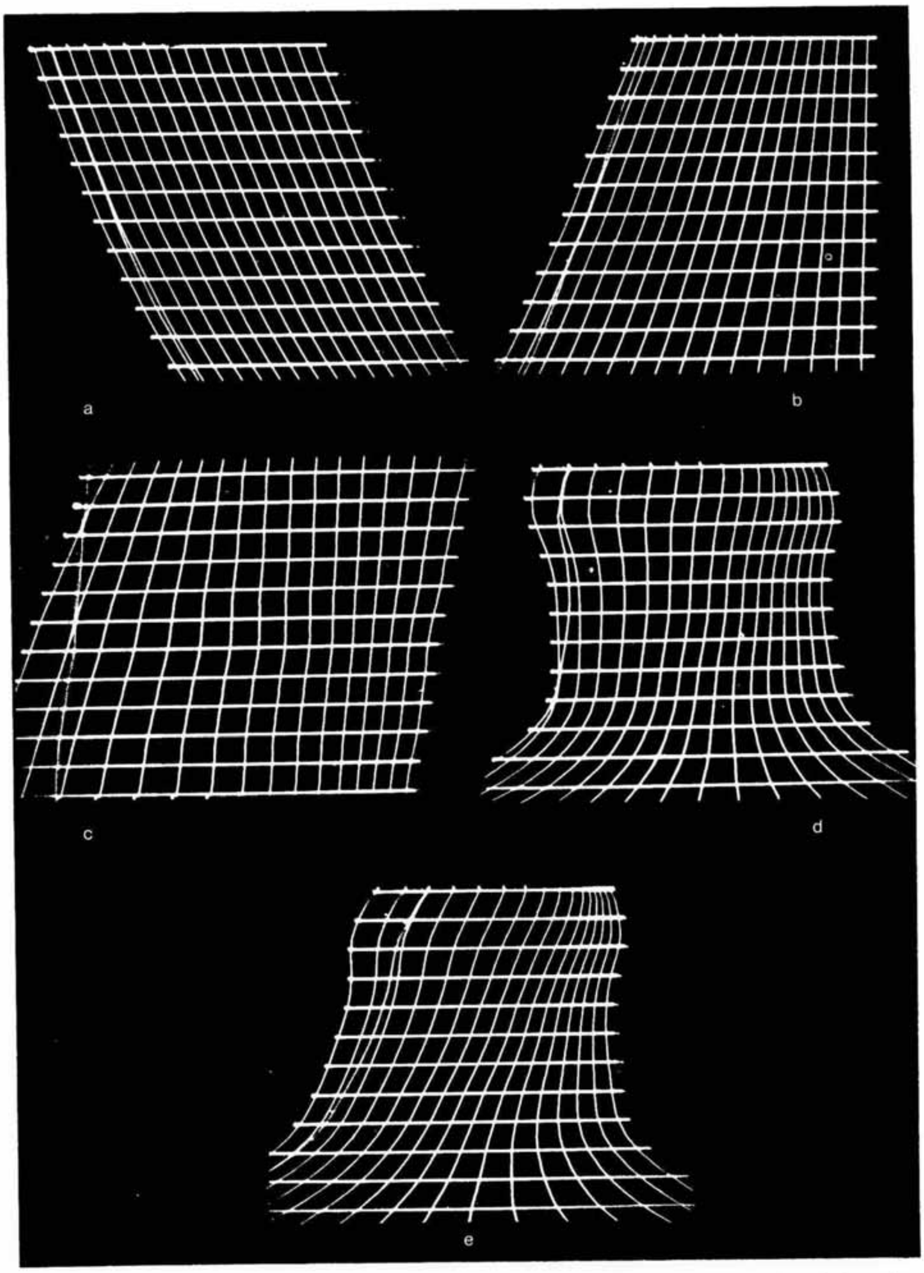
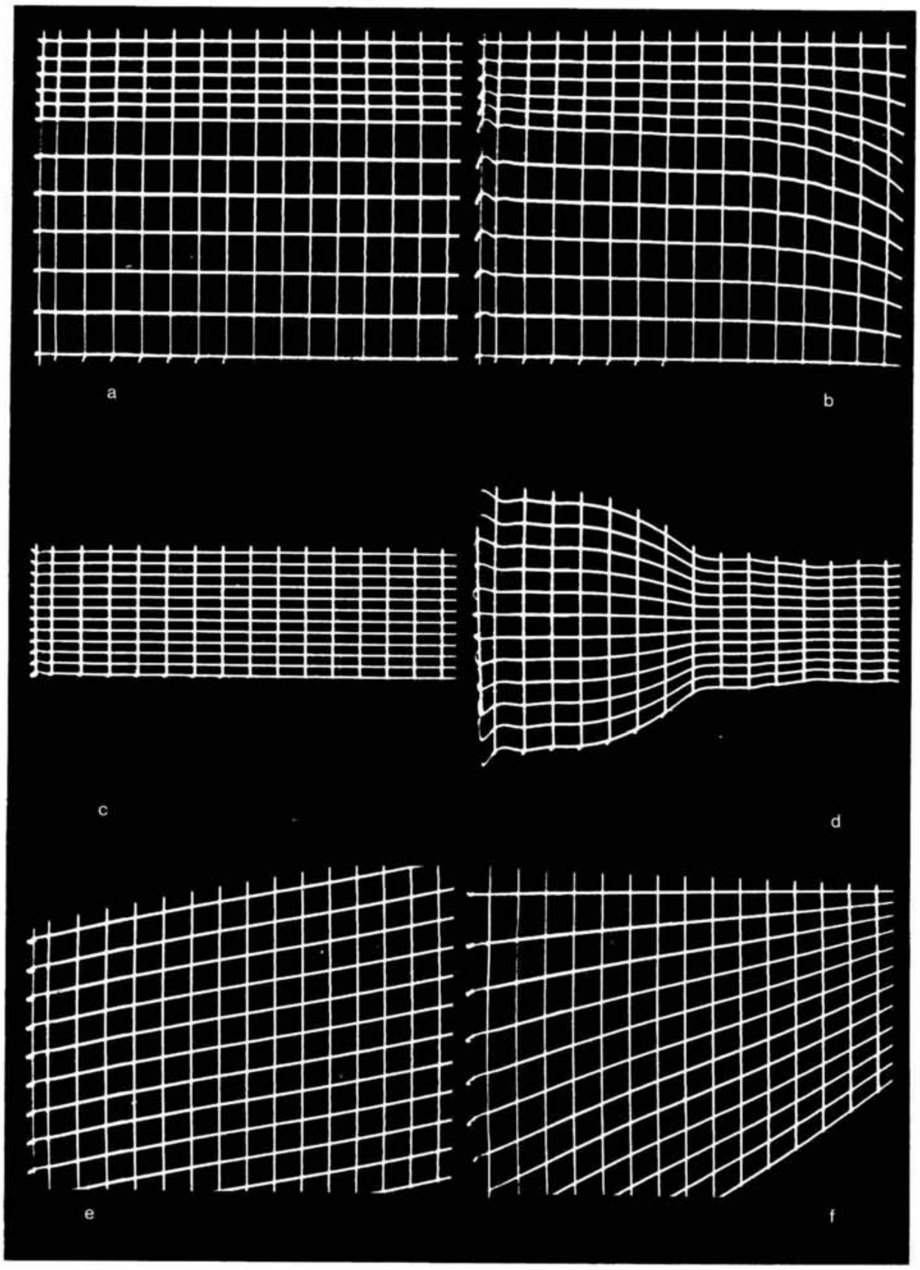


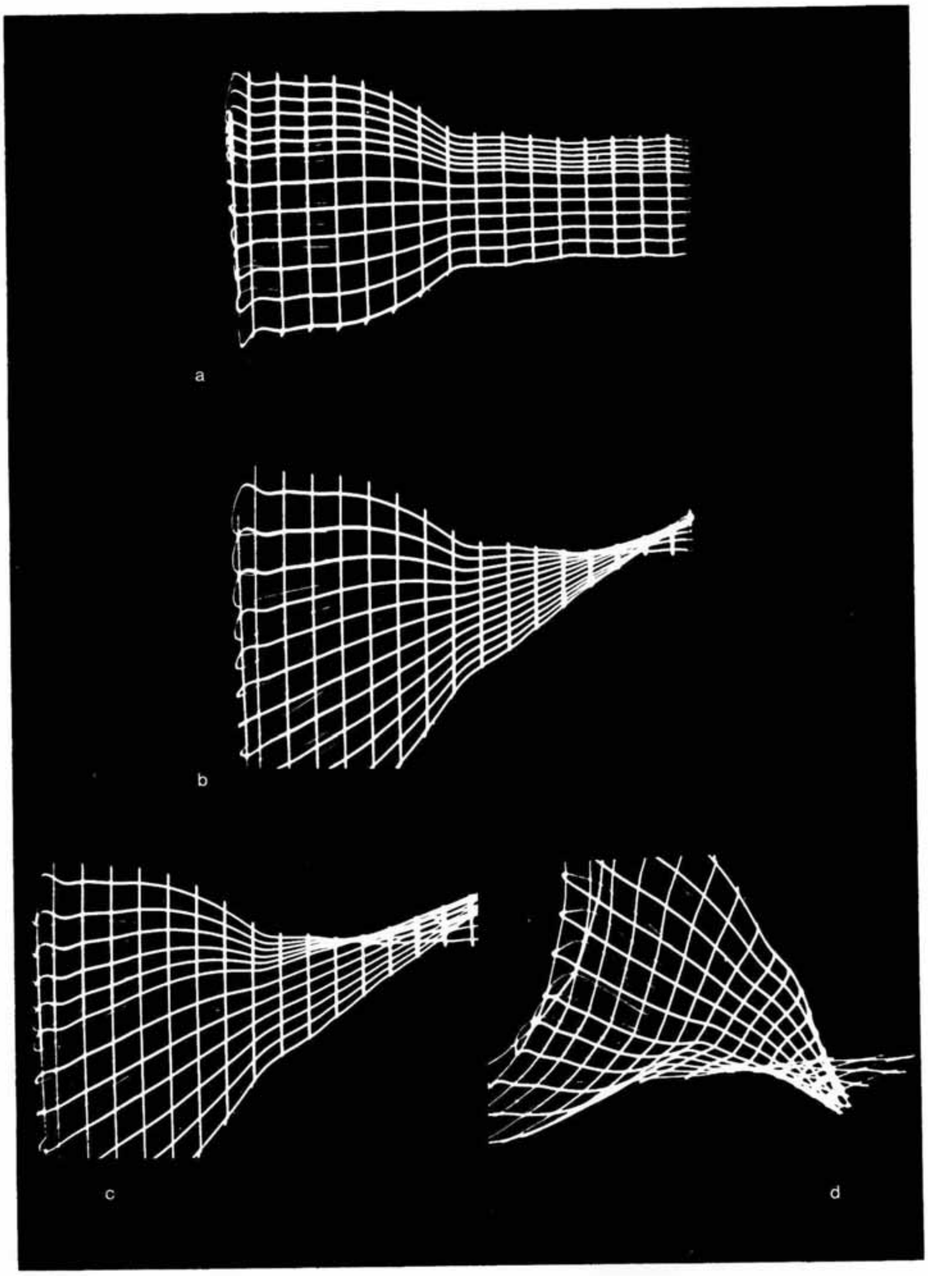
TEXT-FIG. 1. Figs. *a–e*. Illustrations of electronically generated grids. *a*, unmodified rectilinear grid. *b*, grid showing horizontal non-linearity. *c*, as for fig. *b* but with down-screen modification of the horizontal non-linearity. *d*, grid showing reduction of amplitude horizontally. *e*, as for fig. *d* but with down-screen modification of the horizontal amplitude.



TEXT-FIG. 2. Figs. *a–e*. Further illustrations of electronically generated grids. *a*, grid showing horizontal tilt with some curvature introduced. *b*, as for fig. *a* but with down-screen modification of degree of horizontal tilt. *c*, combination of text-fig. 1, fig. *c* and text-fig. 2, fig. *b*. *d*, combination of text-fig. 1, fig. *c* and text-fig. 1, fig. *d*. *e*, combination of text-fig. 1, fig. *c*, text-fig. 1, fig. *e*, and text-fig. 2, fig. *b*. All horizontal variations with their down-screen modifications are illustrated in this figure.



TEXT-FIG. 3. Figs. *a–f*. Further illustrations of electronically generated grids. *a*, grid showing vertical non-linearity. *b*, as for fig. *a* but with across-screen modification of vertical non-linearity. *c*, grid showing reduction of amplitude vertically. *d*, as for fig. *c* but with across-screen modification of vertical amplitude. *e*, grid showing vertical tilt of original rectilinear grid. *f*, as for fig. *e* but with across-screen modification of the degree of tilt.



TEXT-FIG. 4. Figs. *a–d*. Further illustrations of electronically generated grids. *a*, combination of text-fig. 3, fig. *b* and text-fig. 3, fig. *d*. *b*, combination of text-fig. 3, fig. *d* and text-fig. 3, fig. *f*. *c*, combination of text-fig. 3, fig. *b*, text-fig. 3, fig. *d*, and text-fig. 3, fig. *f*. *d*, combination of text-fig. 2, fig. *e* and text-fig. 4, fig. *c*. This is an example of the combination of all horizontal manipulations with their down-screen modifications together with all vertical manipulations with their across-screen modifications.

But alongside these new approaches, the original Thompson method has continued to interest palaeontologists and other scientists. It served as a starting-point for Huxley's (1932) work on allometry, while Harris (1947) suggested that the method might be used to investigate problems in genetics. Other users include Lull and Gray (1949) on growth in ceratopsians, Langston (1953) on Permian amphibians, and Chatterjee (1974) on rhynchosaurs. Simpson *et al.* (1960) regarded it as a 'very interesting way of making similar comparisons in greater detail and taking into account areas and angles or directions as well as linear dimensions', and Sokal and Sneath (1963), recognizing both its value and its time consuming nature, called for automation of the method of transformations. Blackith *et al.* (1963) discussed the use of transformation grids in the study of growth and form, while Bliss (1958) and Lu (1965) applied Fourier analyses to the grids. Sneath (1967), using third-order curves, and Cooper (1965), using quadratic discriminant functions, have both examined pattern recognition with respect to deformed grids.

However, it is not the purpose of this paper to discuss the mathematical treatment of grids or the directions of development of numerical methods which are described in detail in many papers and books such as Clark and Medawar (1945); Simpson *et al.* (1960); Sokal and Sneath (1963); Sneath (1967); Smirnoff (1963, 1968, 1969); and Blackith and Reyment (1971). The object of this paper is to describe, with examples, a rapid and accurate way of performing Thompson's transformations, using a new television method. It is more accurate than the work of the artist, it is relatively cheap, and it enables libraries of grids to be produced quickly.

DESCRIPTION OF THE ANALOGUE VIDEO RESHAPER (AVR)

The fundamental principle of the system is controlled distortion of the basic rectangle of the television picture. Non-linearity (of any chosen type) may be introduced, both vertically and horizontally, the size of the picture may be contracted or expanded horizontally or vertically, and the picture may be tilted into parallelograms, trapezia, or other shapes, some curved, in both horizontal and vertical directions. Controls are also built in so that the modifications may be altered at will in separate parts of the picture.

Using these facilities, a still television picture of an animal viewed by television camera A, may be modified until it fits a static picture of another animal, viewed by television camera B, which remains on the screen while the match is being made. An electronically generated rectilinear grid may be superimposed on the picture being fitted which is automatically modified at the same time. The resultant picture on the screen is of two animals matched together, with a modified grid superimposed, the whole of which is similar to Thompson's transformations. Switching may be used to give any combination of either picture and either grid. Both the picture and the rectilinear grid may be switched out so that the modified grid alone remains.

EXPLANATION OF PLATE 85

Figs. 1–4. Removal of shear from *Angelina* (× 1⅓). 1, *Angelina* as collected (National Museum of Wales No. 27-110-G836). 2, the same with the electronic rectilinear grid superimposed. 3, the specimen restored to bilateral symmetry. 4, the restored specimen with the deformed electronic grid superimposed enabling the shear angle to be measured.

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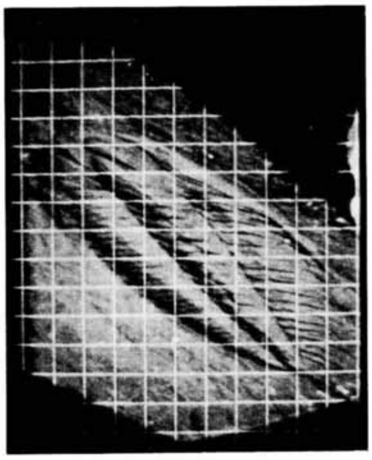

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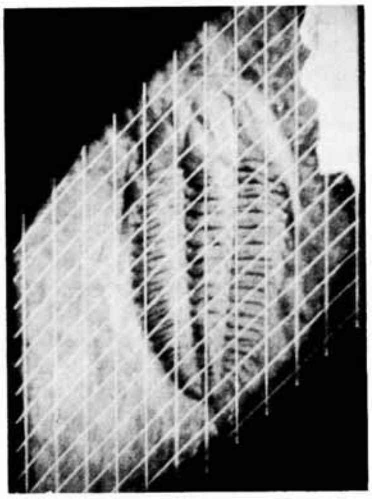

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APPLEBY and JONES, *Angelina*

Text-figs. 1–4 show a sample of each kind of grid. It is often desirable to standardize one principal dimension common to both subjects so that, when they are displayed on the cathode ray tube prior to comparison, they are covered by identical grids. This ensures that the length of each square in the grid is the unit of measurement for both pictures. If during a match a square is distorted, it is easy, using calipers, to determine its relationship to the size of the original square.

The apparatus, excluding the television cameras and associated lighting, is of desk-top size, and for those who are interested in the detailed electronic engineering a technical account is given in Appleby and Jones (1972). No programming or knowledge of electronics is required to operate the AVR. The principles of operation may be demonstrated in a few minutes and after a short learning period for each different research project, the operator can exploit the full capacity of the system.

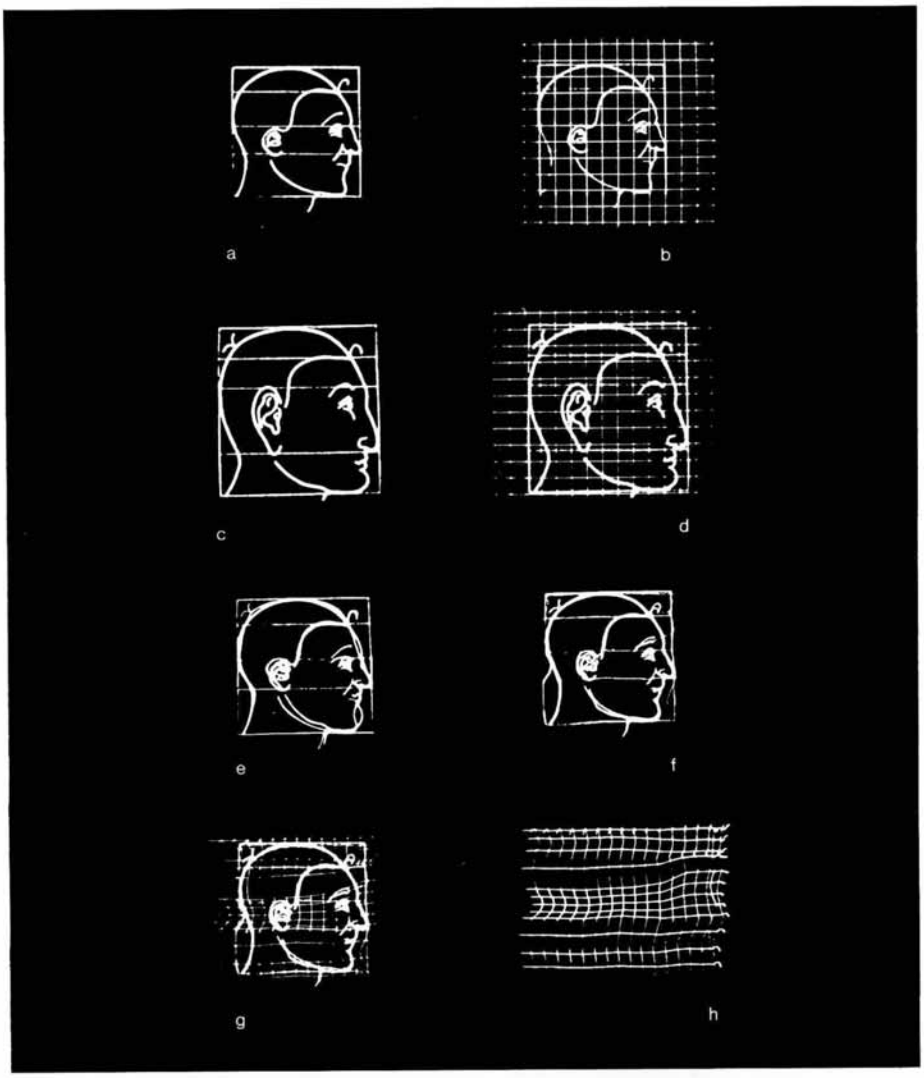
EXAMPLES

None of the following examples is intended to be a study of a particular problem in any depth but is intended to show the scope of the system. Advantages of the system are many: it handles specimens, half-tone photographs, and line-drawings equally well; crushing may be removed quickly in many cases; operation is rapid. The system will probably lead to a feasible new approach to statistical treatment of complex objects (e.g. Sneath 1967), and will make easier studies of morphology, growth, and evolution. Only those forms which possess a predominantly radial symmetry present difficulties, although these are not insuperable using the present system. A projected polar version will enable these to be processed with greater ease.

The examples given below illustrate part of the range of groups and taxonomic ranks already processed by the system.

Comparisons with material used by Thompson

A test was carried out on one of Thompson's (1917) illustrations, a set of line-drawings after Dürer, of human heads seen from the right. Thompson used them to illustrate the effect of applying a vertical non-linearity to the human head and to compare the results with an apparently 'average' head. For the average head (text-fig. 5, figs. *a*, *b*) the guide lines given were three lines drawn horizontally from front to back of the head at approximately equal intervals down the drawing. Text-fig. 5, fig. *b* shows this with a square grid superimposed. For the second drawing (text-fig. 5, figs. *c*, *d*), these lines were spaced unequally and the face redrawn. It looks quite different. In order to check the accuracy of the second drawing with the AVR, the new face, drawn over the non-linearly spaced lines, was placed before a television camera and the lines were returned and matched to their original and more regularly spaced positions (text-fig. 5, fig. *e*). Interestingly, the original face was not very accurately re-created due to artist's error, but using the AVR the 'new' face was accurately superimposed over the 'average' one. The results may be seen in text-fig. 5. The superimposed electronic grid (text-fig. 5, fig. *g*) and the grid alone (text-fig. 5, fig. *h*) show that the artist was largely right in his use of non-linearity down the face, but that he had failed to apply less modification to the region of the eye and nose than to the rest of the head.



TEXT-FIG. 5. Figs. *a–h*. Comparisons of heads by Dürer which were used by D'Arcy Thompson to illustrate the method of transformations. *a*, an 'average' head, from D'Arcy Thompson after Dürer. *b*, the same with a rectilinear grid superimposed. *c*, second head from D'Arcy Thompson after Dürer with the middle part of the head expanded. *d*, the head as in fig. *c* but with a rectilinear grid superimposed. *e*, the second head matched to the 'average' one using D'Arcy Thompson's criteria. *f*, the second head superimposed on the 'average' one using only the contours of the heads. *g*, as for fig. *f* but with the electronic grid superimposed to indicate the modifications used to make the match using this method. *h*, the modified grid alone.

Removal of the effects of shear

A simple example of the use of the system for uncrushing fossils is the removal of shear from the trilobite *Angelina* (Pl. 85, figs. 1–4). The specimen was mounted before the television camera and photographed (Pl. 85, fig. 1). A rectilinear grid was then switched in and a photograph taken (Pl. 85, fig. 2). The grid was then switched out, the trilobite returned to bilateral symmetry, and the grid switched in again. Photographs were taken at each stage (Pl. 85, figs. 4, 5). The removal of the distortion took approximately five seconds. A further advantage of the system shown by this example is its relationship to shearing in the rock. The fossil is in a matrix in which lineations which are related to shear directions are present. These disappear from the screen when the shear is removed from the fossil. The lineation angle may be measured accurately from the photograph of the modified grid. There is probably a future for the use of the system using lineations only, when fossils are absent.

Infraspecific variation

(*a*) Two specimens of *Chlamys varia* (Linnaeus) valves were collected from the beach at Aberavon, South Wales, and brought to the same dorsoventral length before the television cameras and subjected to the AVR matching process. In Plate 86, figs. 1, 2 the smaller of the two valves is shown with and without the square grid. In Plate 86, figs. 3, 4 the larger of the two valves is similarly illustrated. The difference of size between the two shells is 0·7 cm, measured at their maximum dorsoventral heights. The shells are slightly worn because they were separated valves collected after a limited period of reworking on the beach. In spite of the small size difference between them, other differences could be seen when the smaller and presumably younger shell was matched to the larger shell (Pl. 86, fig. 5), especially when the modified grid was switched in (Pl. 86, fig. 6). The greatest difference is on the posterior side, but in the hinge and ear region the smaller specimen has been contracted relatively to fit the larger. Measurement with calipers shows that there is no relative elongation of the ears at the hinge. The calipers also show that although the anterior side is also expanded dorsoventrally, it is also expanded anteroposteriorly, giving the grid a more rectilinear appearance. The differences between these two variants of the one species *C. varia* bring out the need to compare not only large numbers from a fossil assemblage but also the need, where the structure of the shell permits, for comparison of growth series to be made using deformed grids in order to compare growth patterns statistically. Digital read-out followed by a version of the trend-surface analysis described by Sneath (1967) would together increase the accuracy and speed of this process.

(*b*) Two specimens of *Goniorhynchia boueti* (Davidson) from the Great Oolite Clays (Jurassic) at Langton Herring, Dorset, were examined using the apparatus.

EXPLANATION OF PLATE 86

Figs. 1–6. Comparison of two specimens of *Chlamys varia* (Linnaeus). 1, the smaller specimen unmodified (×0·95). 2, the same with the rectilinear grid superimposed. 3, the larger specimen unmodified (×1·1). 4, the larger specimen with the rectilinear grid superimposed. 5, the smaller specimen matched to the larger one. 6, the matched specimens with the modified grid of the smaller specimen superimposed.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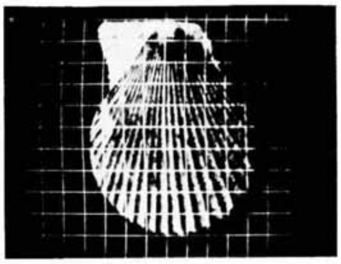
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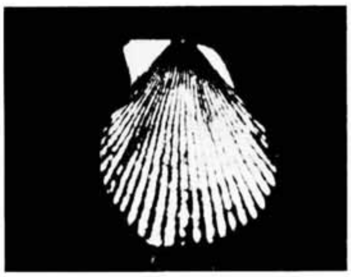
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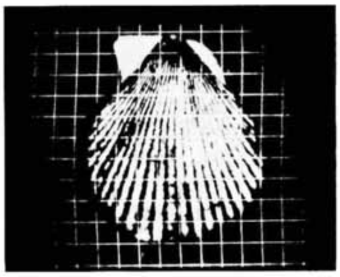
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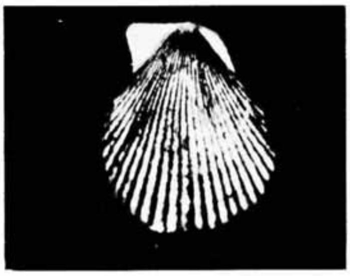
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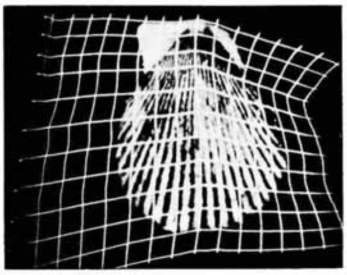
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APPLEBY and JONES, *Chlamys*

The locality is the same as Aitken and McKerrow's (1948). Both belong to Series 2 of Aitken and McKerrow and closely resemble the individual 'G' in plate 2 of their paper. The two individuals were selected for comparison because of their uncrushed appearance and because they had slightly different shapes and sizes. The smaller of the two has a small piece of matrix attached to one end of the commissure. Both were brought to uniform width before the television cameras, the piece of matrix giving rise to a possible error estimated at no more than 3%. As may be expected when a more inflated specimen is fitted to a less inflated one brought to the same breadth, the modified grid shows contractions in various areas but it is interesting to note the nature of the modifications as a whole. There are three categories: areas of contraction, absence of contraction, and expansion areas which show that the specimen being modified is relatively smaller in these areas or directions. The unaffected part of the grid shows that the sulcus area remains almost constant in spite of the size differences while the rest of the specimen above and lateral to the sulcus contracts dorsoventrally. The maximum breadth remains the same when rearranged but lateral expansions occur above and below this level, showing that the smaller specimen had to be expanded laterally in these regions to fit the larger specimen.

The difference between these two specimens is opposite to the findings of Aitken and McKerrow who found that, in general, the breadth and thickness of *G. boueti* increase more rapidly than the length with growth. Here the smaller specimen is the thickest. Possibly this pair represent phenotypic variation which happens to run counter to the statistical trends. Alternatively, the larger specimen is more crushed dorsoventrally than the smaller one. In order to check the second possibility, the whole of the University College, Cardiff collection of this species from the locality was examined. Of the 474 specimens which were sufficiently whole, over 55% were found to be crushed and distorted. In cases of doubt, the doubtful specimens were added to the 'uncrushed' ones. Any bias is therefore against the hypothesis of crushing. The direction of crushing in the Cardiff collection is predominantly dorsoventral, suggesting that there was a preferred orientation of these shells in the bed from which they came. Compaction, possibly very slow, of the muddy sediments in which they occurred is a possible cause of the crushing. That the Langton Herring material does not represent an originally living assemblage *in situ* is suggested by the absence of very small individuals. This suggests sorting during transportation, and the fact that some of the serpulids reported by Aitken and McKerrow (1948) cross the closed commissure in several individuals denotes that the brachiopods lay dead upon the bottom while the tubes were secreted.

The comparison of the two specimens used to illustrate the method shows that the *boueti* question could be re-examined with crushing in mind. For instance, does

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EXPLANATION OF PLATE 87

Figs. 1–7. Comparison of two specimens of *Goniorhynchia boueti* (Davidson). 1, the smaller specimen unmodified (× 1·52 approx.). 2, the same with rectilinear grid superimposed. 3, the larger specimen unmodified (× 1·38). 4, the larger specimen with rectilinear grid superimposed. 5, the smaller specimen matched to the larger. 6, the match with the modified grid superimposed. 7, the modified grid alone.

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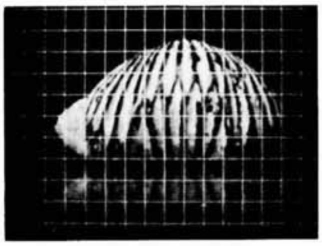

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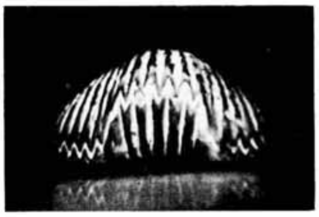

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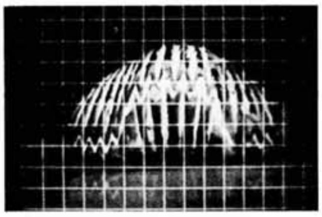

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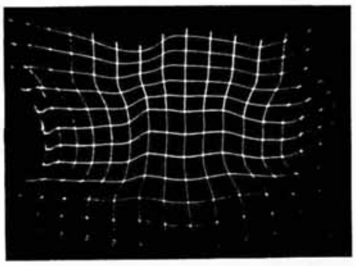

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APPLEBY and JONES, *Goniorhynchia*

the pair compared perhaps indicate that the sulcus is the last part of the anterior part of the shell to give way under increasing crushing? If so, many thinner forms with more widely splayed sulci may not reflect growth characteristics alone.

Micraster

Two Cretaceous echinoids, *Micraster corbovis*, a low zonal type, and *M. coranguinum*, a higher zonal type, were used to demonstrate the technique in use with echinoids. The lower zonal *M. corbovis* (Pl. 88, figs. 1, 2) was matched to the higher *M. coranguinum* (Pl. 88, figs. 3, 4). A good match was reached very rapidly (Pl. 88, fig. 5) and the grid is shown superimposed upon the match and alone in Plate 88, figs. 6, 7 respectively. The two unmodified specimens had been brought to the same length before matching. The modified grid is less variable vertically than horizontally although a relative contraction occurs in the region of the apical disc and below it. This may equally well be interpreted as an expansion posteriorly and anteriorly since the smaller *M. corbovis* has been scaled before matching.

The more important changes occur laterally. The lower zonal form is contracted by as much as a third in the region in front of the apical disc at the level at which the petaloid abulacral areas cease. Posteriorly the elements of the modified grid expand correspondingly. This is in accordance with the posterior shift of the apical disc as set out by Nichols (1959). The modifications between these two forms reveal no new problems, the differences being intimately associated with the verbal and numerical descriptions which have been made from time to time of this group of heart urchins. The main value of the grid in this case is the added impression of the integrated nature of the group as it evolved in accordance with the controlling factors such as depth of burrowing and the migration of the anus to the posterior position. Other views would presumably show the same orderliness but sufficient has been done to show how the system may be applied to echinoids in general.

Variation in the ichthyosaur Stenopterygius

In this example, two specimens of *Stenopterygius quadricissus* (E. Fraas) from the Lias Epsilon 11_4 of Holzmaden, Germany, were scaled to the same length and compared. The smaller (Pl. 89, figs. 1, 2) is 62·5 cm long and the larger (Pl. 89, figs. 3, 4) is 115 cm long. The smaller specimen was matched to the larger and the match is shown with and without the grid superimposed (Pl. 89, figs. 5, 6). The grid alone is shown in Plate 89, fig. 7. Little attention was given to matching the fore limbs because one of these is much displaced in the smaller specimen. The most obvious difference is the general dorsoventral and anteroposterior expansion which is smallest at the head and largest posteriorly. Since this corresponds with an increase in length it is reasonable to correlate it also with the age difference of the two ichthyosaurs. At the next level of detail, the match and the modified grid over it show that

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EXPLANATION OF PLATE 88

Figs. 1–7. Comparison of two forms of *Micraster*. 1, *M. corbovis* unmodified (×0·79). 2, *M. corbovis* unmodified and with rectilinear grid superimposed. 3, *M. coranguinum* unmodified (×0·62). 4, *M. coranguinum* unmodified with rectilinear grid superimposed. 5, *M. corbovis* matched to *M. coranguinum*. 6, *M. corbovis* matched to *M. coranguinum* with modified grid superimposed. 7, the modified grid alone.

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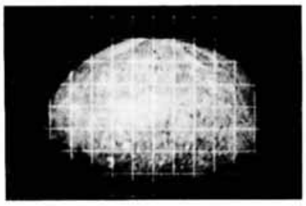

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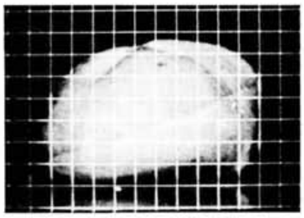

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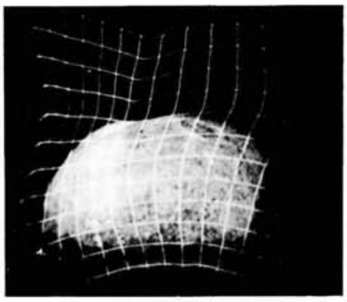

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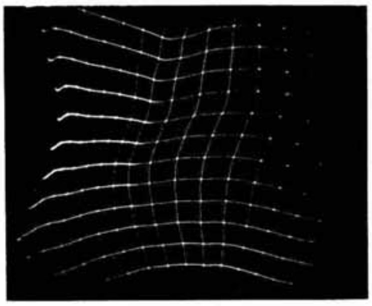

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APPLEBY and JONES, *Micraster*

as the smaller specimen grew, the changes were not uniform. The body behind the skull lengthens and deepens in the dorsal-fin region, the shoulder and caudal regions expand even more, particularly posteriorly, while the posterior dorsal and pelvic regions show minimum expansion. An apparent lack of expansion in the tail-fluke region may be due to different positions of the tail at death. The most important results of measurements, taking the length of the unmodified square as unit of length, are the almost complete absence of absolute contraction or expansion in either horizontal or vertical directions in the orbital region and the absence of posterior growth in the region of the pelvic girdle. In the latter region there is only dorsoventral expansion which is increasing into the caudal region.

The results show general similarities to von Huene's (1922) and McGowan's (1973) findings. McGowan, using three different numerical methods, inferred growth patterns in three species of ichthyosaurs, one of which is *S. quadricissus*. The methods depended on the statistical treatment of chosen variates using the allometric equation $y = bx^a$, ultimately derived from Huxley (1932). The AVR results follow the treatment of surfaces and indicate that relative growth patterns over the whole of the postcranial area are more complex and subtle than normal allometric studies indicate. An examination of von Huene's sketches of a growth series in *S. quadricissus* (von Huene 1922) shows considerable variation in postcranial body proportions and McGowan has superimposed outline drawings taken from Hauff (1953) and BMNH R.4086. These also indicate differences of postcranial dimensions, some of which are mentioned in his paper. Principal among these are tail features and dorsal-fin features. Areas of both tail fin and dorsal fin, expressed as ratios to precaudal body length for a number of specimens, and the higher correlation coefficients for these two features, are reflected in the AVR grid modifications in these areas shown in Plate 89, fig. 6. The lower correlation coefficient for the relationship between the angle of the tail-bend and body length may be due to a combination of a number of factors including developmental increase and greater flexibility in the young as mentioned by McGowan. The peduncle was certainly narrower in the smaller specimens but whether the flexibility was due to the position at death, post-mortem contractions, or later disturbance cannot be decided easily.

Comparison of possible relatives

In contrast to the matching of growth stages in one species, a comparison of relatively closely related hominoids may be made from the series shown, from *Proconsul*, through *Australopithecus*, *Pithecanthropus* (Java man), *Pithecanthropus* (Pekin man), *Homo neanderthalensis* to *H. sapiens* (Cro-Magnon man), in stratigraphical order (Pls. 90, 91). There is no intention here to indicate the precise course

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EXPLANATION OF PLATE 89

Figs. 1–7. Comparison of two growth stages of *Stenopterygius*. 1, *S. quadricissus* (E. Fraas) 62·5 cm long. 2, the same with rectilinear grid superimposed. 3, *S. quadricissus* 115 cm long. 4, as for fig. 3 but with rectilinear grid superimposed. 5, the smaller *S. quadricissus* matched to the larger. 6, the match with the modified grid superimposed. 7, the modified grid alone.


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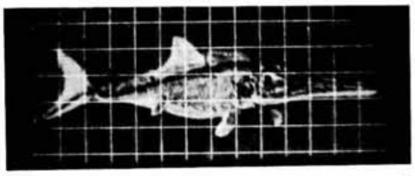
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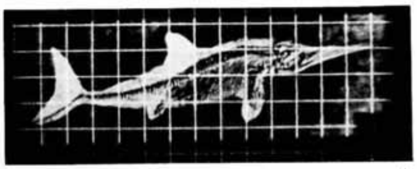
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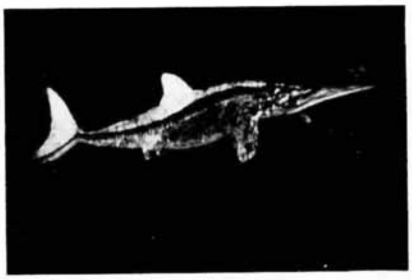
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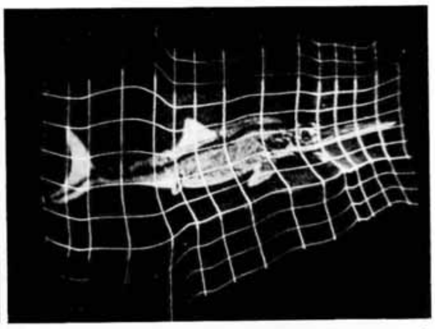
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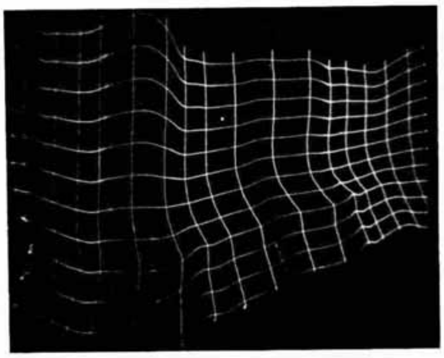
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APPLEBY and JONES, *Stenopterygius*

of evolution in view of the large number of East and North African discoveries. However, the illustrations, taken from skulls and their reconstructions in Romer (1966), after Napier and le Gros Clark; Robinson; McGregor and Weinert, illustrate the method.

Proconsul (Pl. 90, figs. 1, 2) was matched to *Australopithecus* (Pl. 90, figs. 3, 4) to give the composite (Pl. 90, fig. 5) and the grid superimposed (Pl. 90, fig. 6). The grid alone is shown in Plate 90, fig. 7. As the modified grid shows, there is little difference in the shapes of the braincases except for a slight relative elongation from *Proconsul* to *Australopithecus*. Most of the differences lie in the orbital and nasal regions and in the regions of the jaw and dentition. *Australopithecus* matches very well to *Pithecanthropus* from Java (Pl. 90, figs. 8, 9). The match (Pl. 90, fig. 10) and the match and grid and match alone are shown in Plate 90, figs. 11, 12 respectively. The grid as a whole shows a general contraction in the vertical direction which is greater posteriorly than anteriorly but the greatest contraction anteriorly is from the region of the nasal opening to the supra-orbital ridges and slightly above. Posteriorly, the greatest contraction is vertically at the base of the skull. Between and above these two contractions the braincase is considerably expanded, particularly posteriorly, compared with that of *Australopithecus*. When the same procedure is carried out on *Pithecanthropus* from Java and Pekin (Pl. 90, fig. 8 and Pl. 91, fig. 1 respectively) the region of the grid which covers the matched skulls (Pl. 91, figs. 4, 5) is far more linear in all directions, confirming the extremely close apparent similarity between the two forms. There is some slight contraction of the braincase posteriorly in Pekin man and the lower jaw is somewhat contracted vertically. The roof of the skull shows a contraction which may well be a sexual difference. Going on to modify Pekin man so that it fits Neanderthal man (Pl. 91, figs. 6, 7) requires a somewhat different modification, as the grid superimposed on Pekin man shows (Pl. 91, figs. 9, 10). Here, apart from a slight upward tilt of the facial region compared with the braincase, the most linear part of the skull is in the temporal region. Apart from this, the braincase has contracted posteriorly while the facial region and posterior part of the lower jaw have expanded anterolaterally. Finally, modification of Neanderthal to Cro-Magnon man (Pl. 91, figs. 6, 11) shows a slight linear contraction in the facial and nasal regions (Pl. 91, figs. 13–15) and slight relative expansion in the orbital region, but the outstanding features are the further vertical contraction of the upper tooth row, the appearance of the chin emminence, and the much larger increase of the braincase as a whole. It is interesting that braincase expansion is greatest at the beginning and end of this series.

EXPLANATION OF PLATE 90

Figs. 1–12. Phylogenetic variation in relatively closely related hominoids. 1, *Proconsul*. 2, the same with rectilinear grid superimposed. 3, *Australopithecus*. 4, *Australopithecus* with rectilinear grid superimposed. 5, *Proconsul* matched to *Australopithecus*. 6, the match with the modified grid superimposed. 7, the modified grid alone. 8, *Pithecanthropus* from Java. 9, *Pithecanthropus* from Java with rectilinear grid superimposed. 10, *Australopithecus* matched to *Pithecanthropus* from Java. 11, *Australopithecus* matched to *Pithecanthropus* with the modified grid superimposed. 12, the modified grid alone.

PLATE 90

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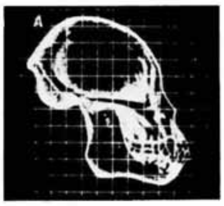

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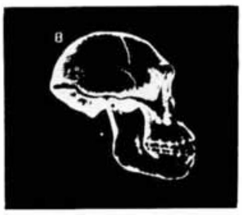

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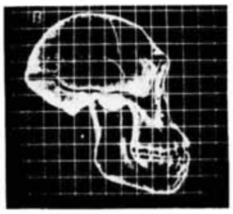

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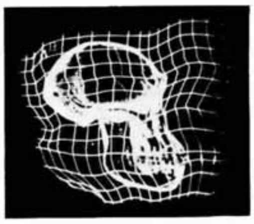

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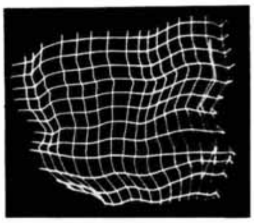

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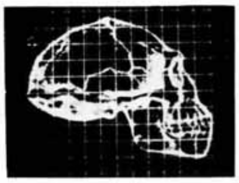

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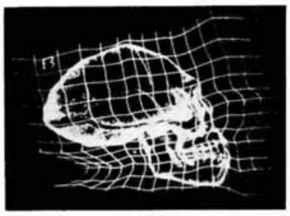

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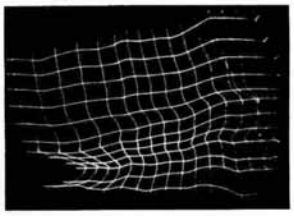

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APPLEBY and JONES, hominoid skulls

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EXPLANATION OF PLATE 91

Figs. 1-15. Phylogenetic variation in relatively closely related hominoids (continued). 1, *Pithecanthropus* from Pekin. 2, the same with rectilinear grid superimposed. 3, *Pithecanthropus* from Java matched to *Pithecanthropus* from Pekin. 4, the match with modified grid superimposed. 5, the modified grid alone. 6, Neanderthal man. 7, Neanderthal man with rectilinear grid superimposed. 8, Pekin man matched to Neanderthal man. 9, Pekin man matched to Neanderthal man with the modified grid superimposed. 10, the modified grid alone. 11, Cro-Magnon man. 12, Cro-Magnon man with rectilinear grid superimposed. 13, Neanderthal man matched to Cro-Magnon man. 14, Neanderthal man matched to Cro-Magnon man with the modified grid superimposed. 15, the modified grid alone.


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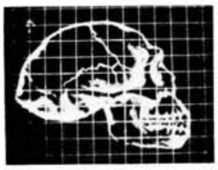
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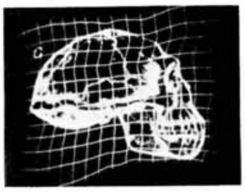
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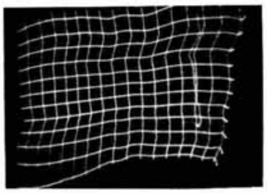
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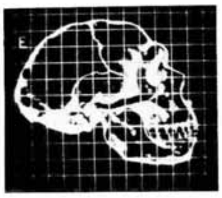

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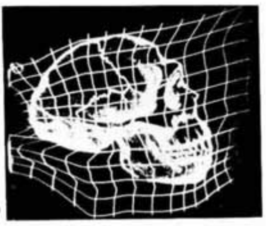
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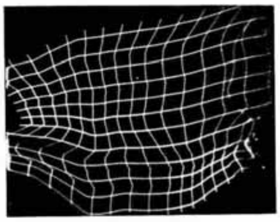
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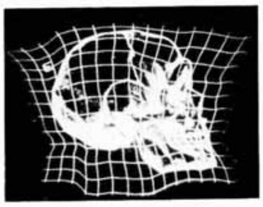
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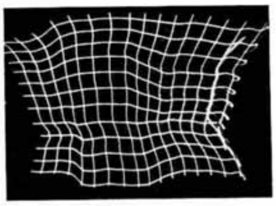
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