Fibroblast Cultures and Dermatoglyphics: The Topology of Two Planar Patterns

Tom Elsdale and Frances Wasoff
Medical Research Council, Clinical and Population Cytogenetics Unit, Western General Hospital, Crewe Road, Edinburgh, EH4 2XU, 031-332-2471, Great Britain

Summary. This is a study of two, two dimensional biological patterns — the pattern created in a confluent dish of normal fibroblast and the dermatoglyphic pattern on the primate palm and sole. Both patterns are characterised by a small repertory of different types of interruptions or discontinuities in fields of otherwise parallel aligned elements. Because these discontinuities are invariant under plastic deformations as well as rigid motions, a topological treatment is appropriate. A quantitative topological characterisation shows the pattern in the two systems to be essentially identical. Regarding both systems as exercises in packing elongated elements in the plane subject to certain constraints, both can be modelled by a smooth, planar, non-oriented vector field. In neither case can the development of pattern be accounted for solely in terms of the aggregate of autonomously arising local detail; the whole constrains and influences the local situations. The interrelationship of global and local constraints on packing is quantified by the index theorem, which accounts for the range of patterns that may develop. The study shows that to understand pattern development in these systems, it is necessary to include topological considerations in addition to an analysis of cell behaviour.

Key words: Human – Morphogenesis – Pattern topology – Fibroblasts – Dermatoglyphics.

A close look at the structure of a dense culture of diploid fibroblasts reveals the elongated cells packed side by side in parallel arrays; ditches or discontinuities occur where arrays of cells with different orientations meet (Elsdale, 1968, 1973). These characteristic features of the pattern are large compared to the sizes of the individual cells (Elsdale, 1972). Thus a square large enough to include a typical discontinuity in the fibroblast array contains hundreds if not thousands of cells. Fields of this size are too large to be appreciated solely in terms of the interactions of the individual cells, the local form building activities in any small area are clearly subordinated to influences generated
over much larger areas. For this reason, an account of the morphogenesis of the fibroblast sheet as the resultant of individual cellular interactions, and hence as the aggregate of autonomously arising local detail, is bound to remain incomplete.

To complete the picture it is necessary to identify and quantify the influences from the whole and their local effects. This raises the problem of how to accommodate both local and global aspects of the form building processes within a single, comprehensive, and quantitative model of pattern development in this system.

The treatment we provide employs mathematics in the first place to quantify features of the pattern. We then show how a theorem in topology can be employed to quantify the reciprocal influence of the whole on local detail. To this extent mathematics is used as a tool to investigate the system. In an appendix the mathematics is presented somewhat more rigorously to develop a model.

The essence of the treatment is to regard pattern development as an exercise in packing elongated elements (the individual fibroblasts) in the plane, and to explore the constraints under which this packing occurs.

It turns out that it is necessary to refer to no more than rather general properties of the cells. This implies that our model may have more general application. With this in mind we have re-investigated human dermatoglyphics. We discover that the loop, the whorl and the triradius are topologically the same as the discontinuities we observe in the fibroblast pattern. Topologically the two superficially different systems are identical and conform to the same model. There is a practical spin-off, for certain existing anomalies in dermatoglyphics are removed under the new treatment.

It appears therefore, that a topological approach reveals certain generalities underlying pattern development. It would be surprising if the methods and insights appropriate to two dimensional examples had no utility in the exploration of more complex situations.

**Material and Methods**

Normal human diploid lung fibroblasts were obtained from 12–18 week foetuses. Cell lines were established in the routine way (Elsdale, 1968) and were maintained in F10 medium, with Hepes buffer 10% newborn calf serum, penicillin, streptomycin, and Fungizone. For this investigation, multilayering of the fibroblast sheet was inhibited by the addition of 20 µg/ml collagenase (Boehringer, Mannheim GmbH) to the routine medium. The main purpose of this study was to investigate the way in which densely packed cells organise. Cultures were therefore set up between ¾ and 1⅔ × confluence. Falcon plastic Petri dishes were employed throughout to avoid the introduction of an ordering pattern on cells, as we noted that other brands of dishes provided a biased substratum that influenced the alignment of the cells. To safeguard against setting up a cell density gradient, initial plating was carried out with the dishes placed on a flat, absolutely level, glass plate and the cell suspension poured with a minimum of turbulence; the initial plating density was seen to be uniform over the dish and cell orientation was random. Cultures were fixed at various intervals from one to ten days in a 1:4 solution of methanol and acetone at −20°C and stained with May-Grunwald and Giemsa stains.