THE UNIVERSITY OF HULL
CARTOGRAPHIC INFORMATION SYSTEMS
RESEARCH GROUP C.I.S.R.G.

DEPARTMENT OF COMPUTER SCIENCE · HULL HU6 7RX · UNITED KINGDOM
TELEPHONE 0482 465295/465951 · FACSIMILE 0482 466666 · TELEX 9312134728 HUG

DR M VISVALINGAM
HONORARY CO-ORDINATOR

Discussion Paper Series Editor: Dr M Visvalingam

C.I.S.R.G. DISCUSSION PAPER 17

Sources of Variability in Cartographers' Deconstruction of Fractals

by

M Visvalingam

Paper presented at the 18 November 1998 Meeting of the British Cartographic Society's Design Group at the University of Glasgow

October 1998

CISRG Discussion Papers

1. Wade, P., Visvalingam, M. and Kirby, G. H. (1986)
   From Line Geometry to Area Topology, 48 pp.
2. Visvalingam, M. (1987)
   Problems in the Design and Implementation of a GKS-based User Interface for a Graphical Information System, 18 pp.
3. Visvalingam, M. (1988)
   Standardising Basic Spatial Units: Problems and Prospects, 19 pp.
4. Whyatt, J. D. and Wade, P. R. (1988)
   The Douglas-Peucker Algorithm for Line Simplification: an introduction with programs, 17 pp.
5. Visvalingam, M. (1988)
   Cartography, Geographical Information Systems and Maps in Perspective, 16 pp.
6. Visvalingam, M. and Whyatt, J. D. (1989)
   The Douglas-Peucker Algorithm for Line Simplification: re-evaluation through visualisation, 35 pp.
7. Visvalingam, M. (1989)
   Trends and Concerns in Digital Cartography, 37 pp.
8. Visvalingam, M. and Whyatt, J. D. (1990)
   Cartographic Algorithms : problems of implementation and evaluation and the impact of digitising errors, 24 pp.
9. Visvalingam, M. (1991)
   Visualisation, VISC and Scientific Insight, 21 pp.
10. Visvalingam, M. and Whyatt, J. D. (1992)
    Line Generalisation by Repeated Elimination of the Smallest Area, 16 pp.
11. Varley, D. A. and Visvalingam, M. (1993)
    Area Topology for Road Extraction and Topographic Data Validation, 34 pp.
12. Visvalingam, M., Varley, D. A., and Wright, C. P. (1993)
    Global dimensions for the recognition of prototypical urban roads in large-scale vector topographic maps, 20 pp.
13. Visvalingam, M., Williamson, P.J. (1993)
    Generalising Roads on Large-Scale Maps: a comparison of two algorithms, 21 pp
14. Visvalingam, M. (1996)
    Approximation, Generalisation and Deconstruction of Planar Curves, 13 pp.
15. Visvalingam, M. and Dowson, K. (1997)
    Algorithms for Sketching Surfaces, 19 pp.
16. Visvalingam, M. and Herbert, S. P. (1998)
    A Computer Science Perspective on Bendsimplification, 18 pp
17. Visvalingam, M. (1998)
    Sources of Variability in Cartographers' Deconstruction of Fractals, 22 pp

Special Issues

1. Visvalingam, M. (ed) (1986)
Research based on Ordnance Survey Small-Scales Digital Data Proceedings of a meeting held as part of the 1986 Annual Conference of the Institute of British Geographers (Reading Jan 1986), **sponsored by the Ordnance Survey**, 79 pp.

2. Visvalingam, M. and Kirby, G. H. (1987)
Director of Research and Development based on Ordnance Survey Small Scales Digital Date, **sponsored by the Ordnance Survey**, 38 pp.

3. Visvalingam, M. and Sekouris, N. M. (1989)
Management of Digital Map Data Using a Relational Database Model, **sponsored by the Ordnance Survey**, 50 pp.

CONTENTS

1. Introduction	1
2. Background	2
3. From algorithmic to human deconstruction of the teragons	4
4. The exercises and method of data collection and analysis	6
5. Some initial reactions	7
6. Initial observations and comments on Exercise 1	7
7. Observations and comments on Exercise 2	15
8. Some implications of the observations	15
9. Conclusion	19
Acknowledgements	21
References	21
Appendix	

1. Introduction

This research was designed for two reasons: firstly, to involve anyone with an interest in cartographic visualisation to participate in eliciting cartographic knowledge and to provide them with the opportunity to contribute their practical knowledge and opinions; and thereby, secondly, to inform the design of algorithms for line generalisation. In the past, there has been some resistance to such mining and codification of expert knowledge. However, many cartographers now welcome highly interactive computer graphics, computer mapping and virtual reality systems as providing them with new opportunities for launching cartography into a new creative age (Collinson, 1997). There is thus a growing willingness to collaborate in projects that could lead to better cartographic software.

Despite nearly 30 years of research on line generalisation algorithms, the available algorithms are still somewhat simplistic. This research, undertaken under the auspices of the BCS Design Group, explored the behavioural tendencies of cartographers engaged in line filtering. The results show that a carefully contrived, even if obviously artificial, exercise on the deconstruction of lines into meaningless forms can prompt cartographers to observe, record and discuss their own cognitive processing. The exercise asked cartographers to provide an abstract representation of a meaningless geometric pattern, corresponding to the first and second generations of the quadric Koch curve. They were asked to select a subset of original points initially. It was hoped that this would help them gauge the degree of generalisation required. By relaxing the constraint of having to use a subset of the original points, they were then encouraged to explore their preferred output form corresponding to the same degree of generalisation. More importantly, the investigation progressively shifted more and more of the research process onto the participants themselves. The author acted as a facilitator - a) providing guidance and independent interpretations to provoke articulation, and b) assuming responsibility for the dissemination of results - with the hope that this will spark off ideas for similar research by other members of the BCS Design Group.

The exercises undertaken are similar to those conducted by Attneave (1954), Marino (1979), White (1983) and numerous other researchers. Although the visual and mathematical comparison of input and filtered lines has been useful for assessing the performance of line generalisation algorithms, Visvalingam and Whyatt (1990) expressed some concern over the conclusions which have been drawn from such surface analysis. Although White's (1983) evidence showed only a 45% agreement between the output of the Douglas-Peucker algorithm and those of cartographers, it has been widely used to endorse the superiority of this algorithm. There was little discussion of what the other cartographers did, let alone why they did so. Prescriptions for knowledge-based generalisation (see papers in Buttenfield and McMaster, 1991) have also tended to focus on the "what and when" of generalisation and re-iterate known guidelines. The belief that manual generalisation is subjective and intuitive has also impeded the deeper probing of the "how and why" of individual practice. Deeper analysis of the results of deconstruction of artificial lines shows that inconsistencies in manual generalisation need not always be the result of subjective ad-hoc decisions; they may reflect justifiable differences in the allocation of priorities.

The paper provides a brief background and the academic motivation for this research. It then briefly describes the nature of the experiment (which is included as Appendix 1) before presenting a classification and discussion of the results. The paper concludes by noting that some approaches adopted by cartographers are not encapsulated within existing algorithms, identifying opportunities for further research.

2. Background

Most algorithms for line generalisation are based on relatively simple geometric reasoning. The widely used Douglas-Peucker algorithm (Douglas and Peucker, 1973) selects points which are furthest from a projected line. More recently, Visvalingam and Whyatt (1993) showed that better results could be achieved through Visvalingam's iterative elimination of triangular geometric features, based on the measured significance of the point at the apex of the triangle. They found that the best measure for 2D lines, such as coastlines, is the area that is lost when a point is dropped. Wang (1996) and Wang and Muller (1998) proposed a more complex geometric process for simplifying bends (i.e. concave or convex sections of lines). This included the context dependent amalgamation of two neighbouring bends, exaggeration of isolated bends and iterative bend elimination using a shape-weighted area tolerance. Visvalingam and Herbert (I998) demonstrated that such complex algorithms do not always produce the intended effect. Indeed, the ArcInfo implementation produces quite unacceptable results. Moreover, as Wang and Muller noted, bend simplification was designed to operate on simple bends and not on complex curves consisting of features within features. Their conclusion ends with " More cartographic rules and ability for line structure recognition are required for enabling more sophisticated generalization operators". Thus, only cursory reference is made to the results from Wang's *bendsimplify* algorithm, investigated more fully elsewhere (Visvalingam and Herbert, 1998).

Visvalingam (1996) suggested that it might be useful to view the Douglas-Peucker, Visvalingam, and other geometric algorithms as providing deconstructions, rather than generalisations of lines. Unlike minimal simplification, both generalisation and deconstruction produce new geometric patterns - i.e. they seek to deviate from the original source line. This is why Visvalingam and Whyatt (1990) rejected McMaster's (1987) mathematical measures of the performance of line generalisation algorithms as misleading and inappropriate, and only appropriate at the level of line approximation. However, deconstruction differs from cartographic generalisation: whereas the latter is knowledge-based, deconstruction is an entirely mechanical cognitive process whose sole aim is to discover unexpected patterns and structures in lines and to study the invariant properties of different deconstructors (Visvalingam, 1996).

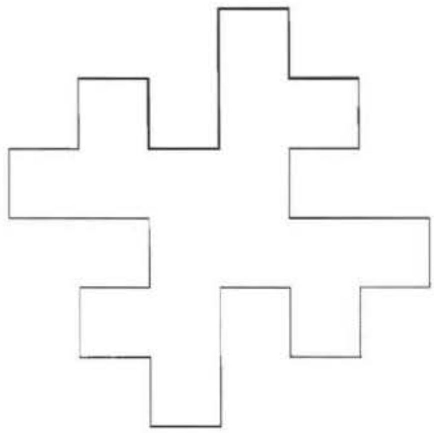


Figure 1 : First generation teragon of the quadric Koch curve

Visvalingam and Brown (I998) and Visvalingam and Herbert (1998) deconstructed pre-fractals or teragons into decogons. Mandelbrot (1987) coined the terms, pre-fractals and teragons, to refer to specific generations of a fractal curve. Visvalingam (1996) used the word ***decogon*** to refer to deconstructed patterns, which had no intrinsic meaning. The exercises force the cartographers to engage in typification and abstraction of the teragons since there is hardly any unnecessary geometric detail at these low levels of fractal generation for minimal simplification. Visvalingam and Brown's decogons (1998) drew attention to the complex symmetry of the first generation quadric Koch curve, shown in Figure 1, produced by the repeated application of a generator pattern (in bold) to the four edges of a square initiator. Visvalingam and Brown (1998) noted four levels of symmetry, namely :

- the 4-fold rotational symmetry around the central axis of rotation (***symmetry 1***). For example, the four partition planes, which originate from this centre and which pass through the four starting points, divide the curve into its repeating components.
- the 2-fold rotational symmetry of the generator around its central point, which is otherwise redundant in defining the generator's shape (***symmetry 2***).
- a further 2-fold rotational symmetry, creating a Z-pattern, in each half of the generator (***symmetry 3)***
- the bilateral mirror symmetry in sections of the curve which give rise to its rectilinear shape (***symmetry 4***)

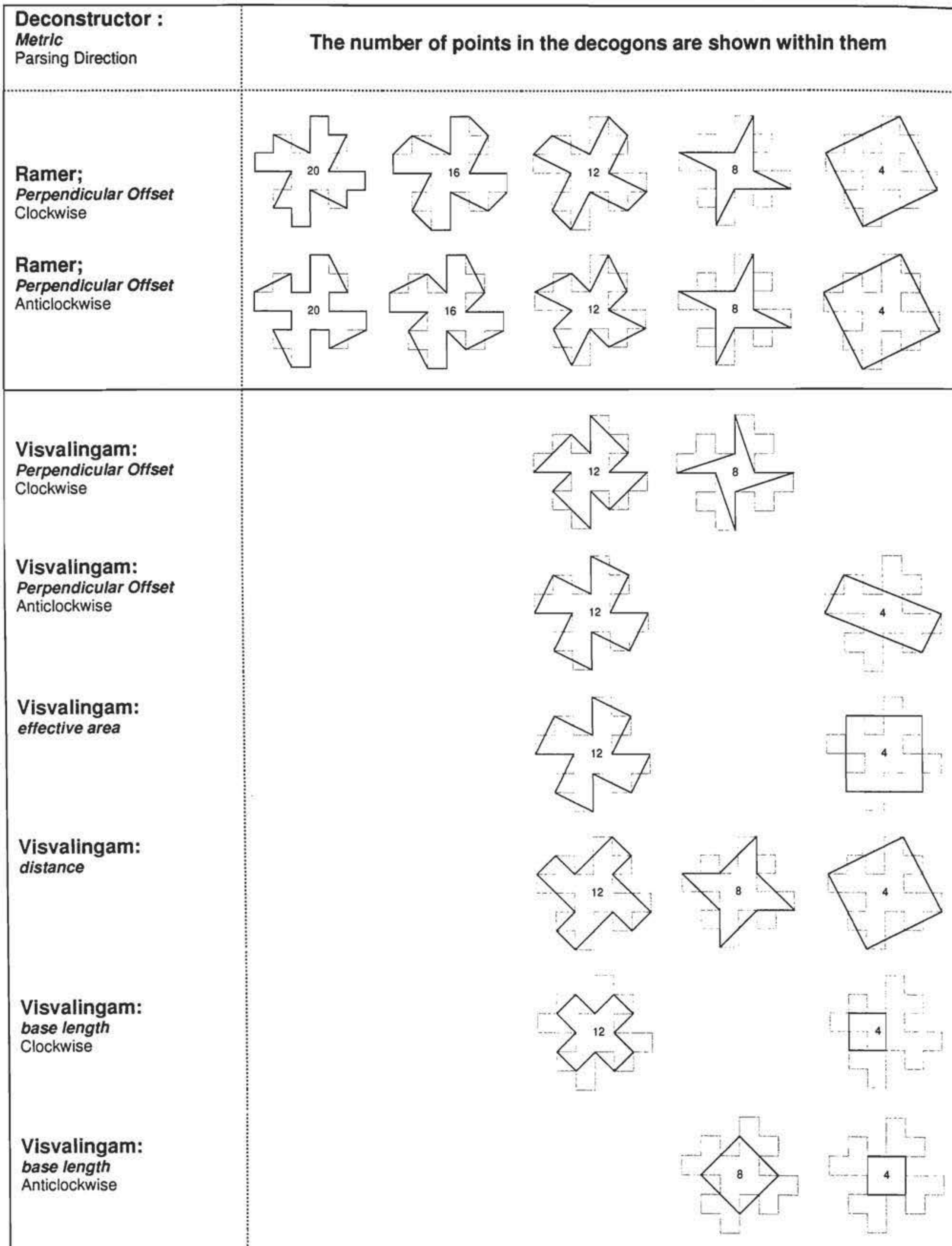


Figure 3 : Decogons produced by the Douglas-Peucker and Visvalingam algorithms
(Source : Visvalingam and Brown, 1999)

The deconstruction of different generations of teragons indicated the types of symmetries that tend to be preserved by different line generalisation algorithms. Visvalingam's algorithm with the area metric appears to best preserve the symmetry of the teragons. Nevertheless, the range of decogons that could be obtained from even simple teragons was quite large and unexpected. The research, reported here, investigated whether cartographers would tend to deconstruct the lines in a more consistent way. Figure 2 classifies the patterns abstracted by algorithms and by people, and provides an index to Figures 3 to 7.

PATTERNS PRODUCED FROM THE LEVEL 1 QUADRIC KOCH CURVE				
by algorithms	**by people**			
Fig 3 : Decogons	Fig 4 : Exploratory Sketches	Fig 5 : Rectilinear Patterns	Fig 6 : Wings & Petals	Fig 7 : Spatial Extent

Figure 2 : Classification of patterns produced by algorithms and by people

3. From algorithmic to human deconstruction of the teragons

Different deconstructors impose a different structure on even relatively simple lines. The rows in Figure 3 list the various algorithmic deconstructors and show the series of decogons output by each. To facilitate comparison, all the decogons in a given column have the same number of points. Only a couple of line filtering algorithms was investigated; Fourier and wavelet analyses, which were not included, are likely to produce other patterns. Wang's (1996) bendsimplify algorithm only extracted the final square initiator shown in the fourth row from the bottom in Figure 3; it used 11 points for depicting a square (Visvalingam and Herbert, 1998). Although all these decogons are equally plausible, the objective of the research was to ascertain whether cartographers would tend to agree on particular decogons or whether they would also output quite dissimilar decogons. It was hoped that the artificial exercise of having to generalise a meaningless geometric pattern would a) provide some insights into the cartographer's cognitive processing of these lines, and b) inform further research into digital line segmentation, structuring and generalisation.

4. The exercises and method of data collection and analysis

Appendix 1 provides a listing of the exercises set. Exercise 1 requires the subject to select 12 out of the 32 points defining the teragon. Similarly, in Exercise 2, they were expected to select 20 to 40 points from the 250-point curve. The exercise is based on that designed by the psychologist Attneave (1954), which was also used by cartographers, such as Marino (1979), White (1983) and several others since then. In this particular set of experiments, sample numbers were specified to enable the participants to get a feel for the required scale of abstraction. It was hoped that having done so, they would then be able to express what they felt was the appropriate solution for that scale in the second part of each exercise.

The exercise was initially undertaken by participants at the British Cartographic Society's Design Group meeting at the 1996 Annual Symposium in September at Reading. Unfortunately, the aspect ratio of the drawings was distorted by the fax machine. However, this seems to have affected only the output of one respondent. Although there were over 25 people at the meeting, only 8 cartographers returned the completed exercise. Two other veteran cartographers, who were not at the Symposium, also undertook this exercise in a less time-constrained fashion. Ten results are by no means representative of the cartographic community and were only treated as indicative. In Tables 1 & 2, the set returned by practising cartographers is referred to by the label **C**. The label **S** refers to 18 student returns; David Forrest from Glasgow University kindly persuaded Diploma level cartography students to attempt this exercise. Not all subjects included explanations for their choice of points.

These results were analysed and interpreted as follows. The first task was to study the figures and tentatively group them into categories. The categories were not pre-defined but were data-driven. The variants within each category were then sub-classed and related, using links in figures and the explanations where possible. Having structured the data, the author tried to deduce the implications of the results. In the meantime, the BCS Design Group members repeated the exercise some 18 months later at their meeting in April 1998 at Southampton. The author was not present. This time, instead of returning their individual solutions, the participants compared and discussed their results. The author presented her interpretation to three of these participants at the September 1998 BCS Symposium. This prompted them to reveal aspects of their behaviour that they had not recorded at Reading in 1996. On reflection, they felt that some patterns seemed to be better than their original ones. This paper, for discussion at the next meeting of the BCS Design Group at Glasgow in November 1998, is restricted to the author's review of the original returns made by individuals in 1996. The 1998 results and discussions (from Southampton and Glasgow) will be reported later so that any consensus view emerging from these discussions do not bias the analysis of independent behaviour.

5. Some initial reactions

Everyone at the meeting attempted the exercise. Some said that they were too embarrassed with the results to hand them in. Some of the comments made by cartographers at Reading are worth noting. Firstly, and most importantly, they felt that the exercise was far too artificial and that it did not relate to how cartographers worked on lines. Some said that they went dizzy parsing the line forwards and backwards, checking the number of points. In comparison to the length of source lines and the number of points to be selected in the exercises undertaken by Marino (1979) and White (1983), Exercise 1 was not at all onerous. Even so, this suggests that the results presented here (and possibly those presented by other authors) may be partial and that some types of cognitive processing of lines (in the non-returns) are perhaps not being detected.

Several cartographers asked the sort of questions they were trained to ask, namely - Why are we doing this? What type of geographic phenomenon does the data refer to? What scale of reduction does the subset represent? Some felt that without such information, the exercise was artificial, meaningless and a waste of time. Some of those, who returned their output, stated that they hoped that their solution was what I was looking for and said that they were looking forward to hearing what the solution should have been. Again, this reflects some uncertainty and discomfort with performing a deconstruction as opposed to a generalisation.

Other cartographers, who were users of mapping software, stated that they found it difficult to project a mental visualisation of target shapes since their normal working practice had made them reliant on the feedback provided by software, which produced curves based on points they input. Without such feedback in a paper exercise, they were unwilling to draw their own curves. These comments are noted here since they provide opportunities for further research into how software may be conditioning cartographic visualisation. This paper itself is more focused on the pattern of results in the returns.

Since most of the non-returns were discarded in the room, they were studied later. Although they were not included in the analysis, some anecdotal reference is made to some of the discarded output later. Scribbles, showing steps in exploring progressive abstraction, have influenced the summary of the results presented here.

6. Initial Observations and Comments on Exercise 1

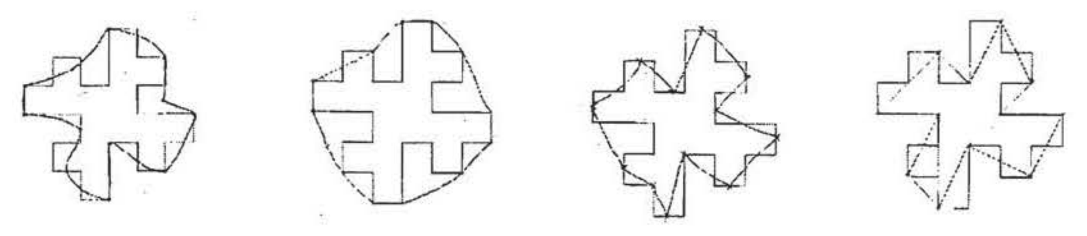
The results from Reading are classified and presented in Figures 4 to 7. Some of the figures have been re-drawn by the author where the originals were either too untidy or where the scanned image was not clear. Table 1 shows the number of times a figure of a particular type was produced. In classifying the results, output with mixed patterns have been assigned where justifiable to the class which it most resembled since the aim of the exercise is to study the types of patterns rather than individual patterns *per se*. Not all subjects gave reasons for why they had chosen a particular pattern, so again the reasons suggested in this paper should be treated as anecdotal even if plausible.

TABLE 1 : Frequency of different patterns produced for Exercise 1

Type of Pattern	Sub-type	Number produced		Comments
		as Fig 1a	as Fig 1b	**KEY S= by students C= by cartographers**
Rectangular				**Being treated as if it were a road**
	Fig 5a	4S + 8C	1S + 1C	Offset cross
	Fig 5b	1C		Figure/ground switch
	Fig 5c		1C	Schematic
	Fig 5d		1S	For smaller scale - shows extent
	Fig 5e		1S	For smaller scale - shows extent
	Fig 5f		1C	Offset road (result may be biased by aspect ratio)
	TOTAL	4S + 9C (13)	3S + 3C (6)	= 19
Wings & Petals				**Emphasis on structure**
	Fig 6a	1S	1C	Retains 3 levels of symmetry
	Fig 6b -c	1S	2S	Examples of free-form sketches
	Fig 6d		1S 3C	Fig 6a rotated to use mid points of edges
	Fig 6e		1S	Tight fitting curve using mid point
	Fig 6f	1S	1S 1C	Free form of Fig 6e
	Fig 6g		5S	Enclosing curved shape
	Fig 4c	3S		Drift towards wings
	TOTAL	6S (6)	10S+5C (15)	= 21

ctd./ ....

Extent				**For display at smaller scale?** Emphasis on overall extent and shape rather than on internal structure
	Fig 7a	1S		Extent using near-redundant points
	Fig 7b	5S	1S	Convex forms
	Fig 7c-e	1S	3S 2C	Concave forms
	TOTAL	7S (7)	4S + 2C (6)	= 13
Unclassified				**Often used by subjects for exploration**
	Fig 4a	1S	1S	Motley of patterns
	Fig 4b	*4S*		Concave and convex (Counted with 7b)
	Fig 4c	*3S*		Drift towards wings (Counted with wings)
	Fig 4d	*1S*		Different wing shapes (Counted with 6b)
	TOTAL	1S	1S	= 2
Reject		1C		Too many points
TOTAL		18S +10C (28)	19S + 10C (28)	= 56



Different forms | Concave and convex outlines | Getting a feel for wings | Different wing shapes

Figure 4 : Evidence of exploration of the teragon for possible patterns

All, except one person, *attempted* to retain the 4-fold rotational symmetry. In general, the figure was being perceived as a whole and the original partition planes were largely ignored. In 10 out 50 figures, subjects appeared to be attempting to use the four parts to explore different patterns. Figure

4a is a good example of such varied exploration. Figure 4b shows a leaning towards a convex rather than concave shape but there were an equal number of people drawing concave shapes. Figure 4c shows a drift towards wings. Figure 4d, shows the exploration of different wing shapes.

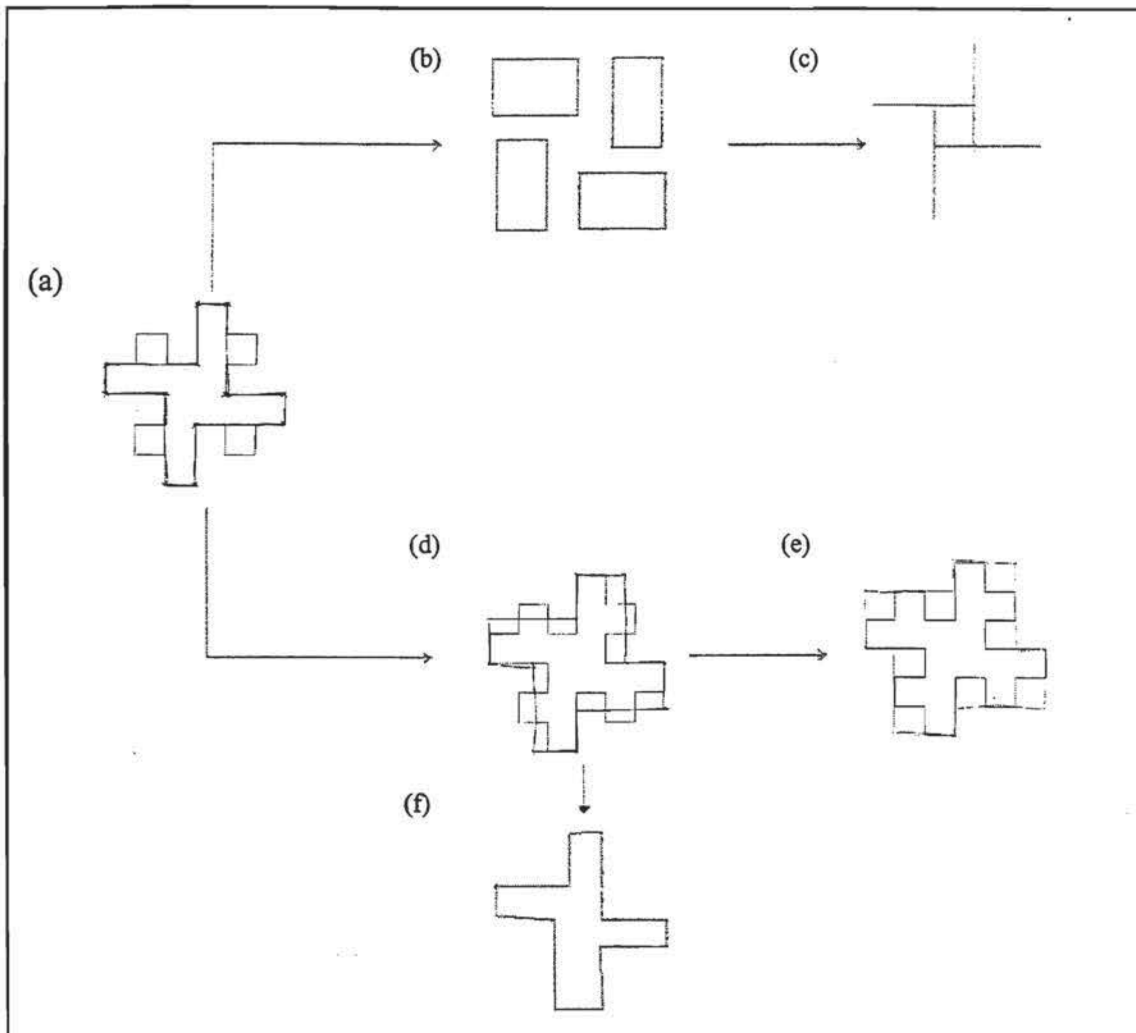


Figure 5 : Preservation of 4-fold symmetry and rectilinearity

Nineteen (of the 56 figures) consisted of rectilinear patterns (Figure 5). The only figure to show a deliberate directional bias was Figure 5f - this orientational bias could be due to the distorted aspect ratio on the faxed figures on which they were originally drawn. Fourteen of the 19 figures corresponded to Figure 5a. Nearly all cartographers, who drew this pattern, produced it during the exploratory phase; only one cartographer produced this as the final rendition. The following reasons were presented in its favour:

1. It is a simpler, "less busy" pattern
2. It omits the smaller juts
3. It retains the biggest branches of the figure
4. It retains the original rectilinear features
5. The original figure resembles a road network

One person included a frame which just fitted the teragon and chose to focus on the background consisting of 4 disjoint parts which were easier to simplify as shown in Figure 5b (which is the complement of Figure 5a). The same cartographer felt that Figure 5c was the best simplification. There was some discomfort with the somewhat awkward offset cross in Figure 5a. Figures 5d and 5e seek to retain the rectangular pattern while showing the extent of the figure (perhaps for display at reduced scale or to make the offset cross look less awkward). The offset cross is clearly being interpreted as on offset junction in Figure 5f but this visualisation may have been induced by the distorted aspect ratio of the faxed figures.

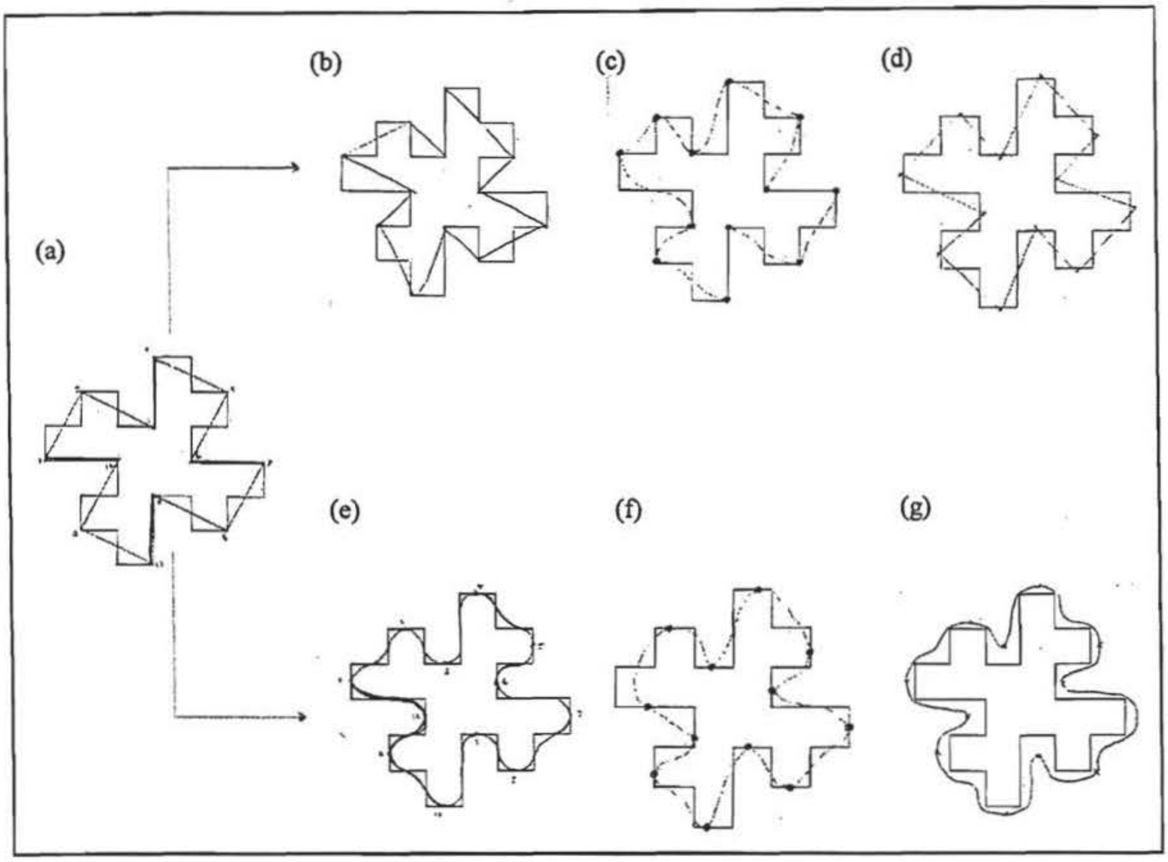


Figure 6 : Different types of wing and petal shapes

All except one person who started with the offset cross (Figure 5a), then chose the wing and petal shapes shown in Figure 6; 21 of the 56 figures were of this type. The subjects stated that they deliberately chose to discount the rectangular shape since the winged shapes were more useful for indicating the main and sub-branches in the structure. Cartographers were clearly aware that this structure could be shown using different shaped wings (e.g. exploration of them in Figure 4d as noted earlier). In their final renditions, the cartographers tended to produce straight edged wings, while the students tended to prefer curvy petal-shapes. But, 12 of the 21 figures used the midpoints on edges, instead of the corner points, in the straight edged and curvy shapes. The cartographers indicated a preference for figures which applied the give and take rule (as in Figure 6a, 6e and 6f). Five students produced the pattern in Figure 6g, which was more concerned with showing the overall shape and extent of the 4-petalled shape, perhaps for display at smaller scale.

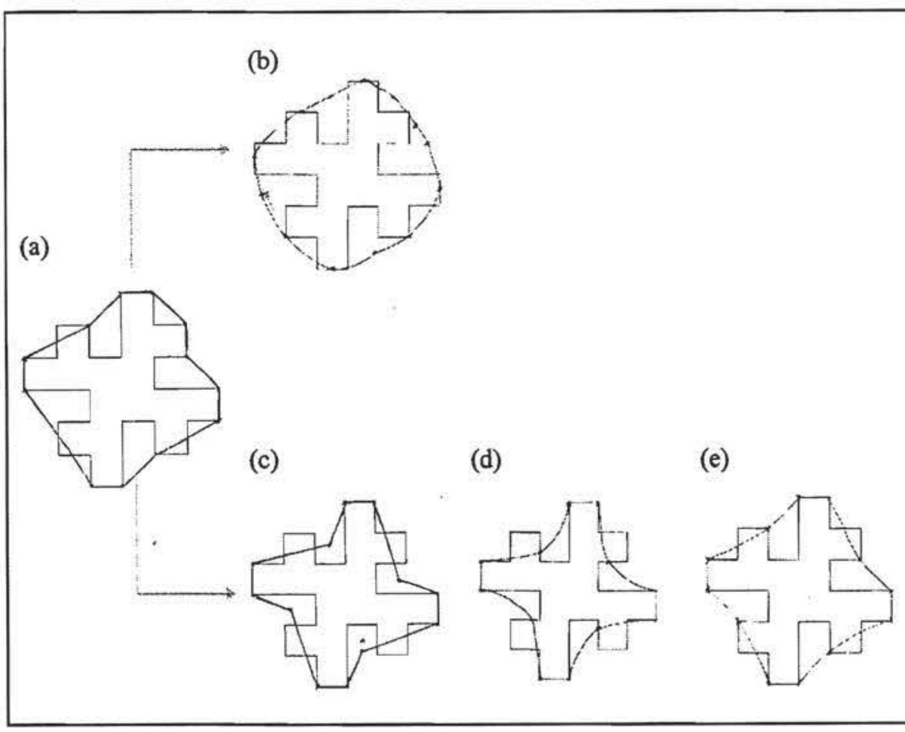


Figure 7 : Convex and concave figures showing the teragon's extent

The shapes In Figure 7 also appear to be more concerned with showing the overall extent of the figure. Here again, opinion was divided between the use of convex and concave forms. Of the 14 shapes in this class, 9 were broadly convex. However, the final preference was for concave figures. One of those who produced the concave form in Figure 7c said that she had attempted to balance the give and take and then adjust the shape as in Figure 7d. Note that Figure 7d could be viewed as a stylised version of the offset cross in Figure 5a, in which the minor branch was omitted. Note also, that many of the patterns in Figure 7 use near-redundant points in preference to information rich points located on curvatures in lines.

TABLE 2 : Frequency of different patterns produced for Exercise 2

Type of Pattern	Sub-type	Number produced: as Fig 2a		Number produced: as Fig 2b		Comments
						KEY S= by students C= by cartographers
Rectangular						**Infuenced by knowledge about fractals?**
	Fig 8a	2S	2C		1C	Level 1 teragon
	Fig 8b	4S		3S	2C	Rotated level 1 teragon
	Fig 8c				1C	Generalised version of Fig 8b.
	Fig 8d			1S		Cross as in Fig 6d
	TOTAL	6S + 2C (8)		4S + 4C (8)		= 16
Wings & Petals						**Emphasis on structure and overall shape**
	Fig 8c			1S		Curved version of Fig 8b
	Fig 8f	5S	3C	2S	1C	Squarish shape for centre
	Fig 8g	6S	1C	5S	1C	Tending to U-shape in centre
	Fig 8h	1S		4S		V-shaped centre
	TOTAL	12S + 4C (16)		12S+ 2C (14)		= 30
Free form						
	Fig 8i		1C			Exploration of structure of figure
	Fig 8j		1C			Similar to Fig 7d
	Fig 8k				2C	Offset cross with centrelines
	TOTAL	3C (3)		2C (2)		= 5
no return			1C	2S	2C	= 5
TOTAL		18S+10C (28)		18S+10C (28)		= 56

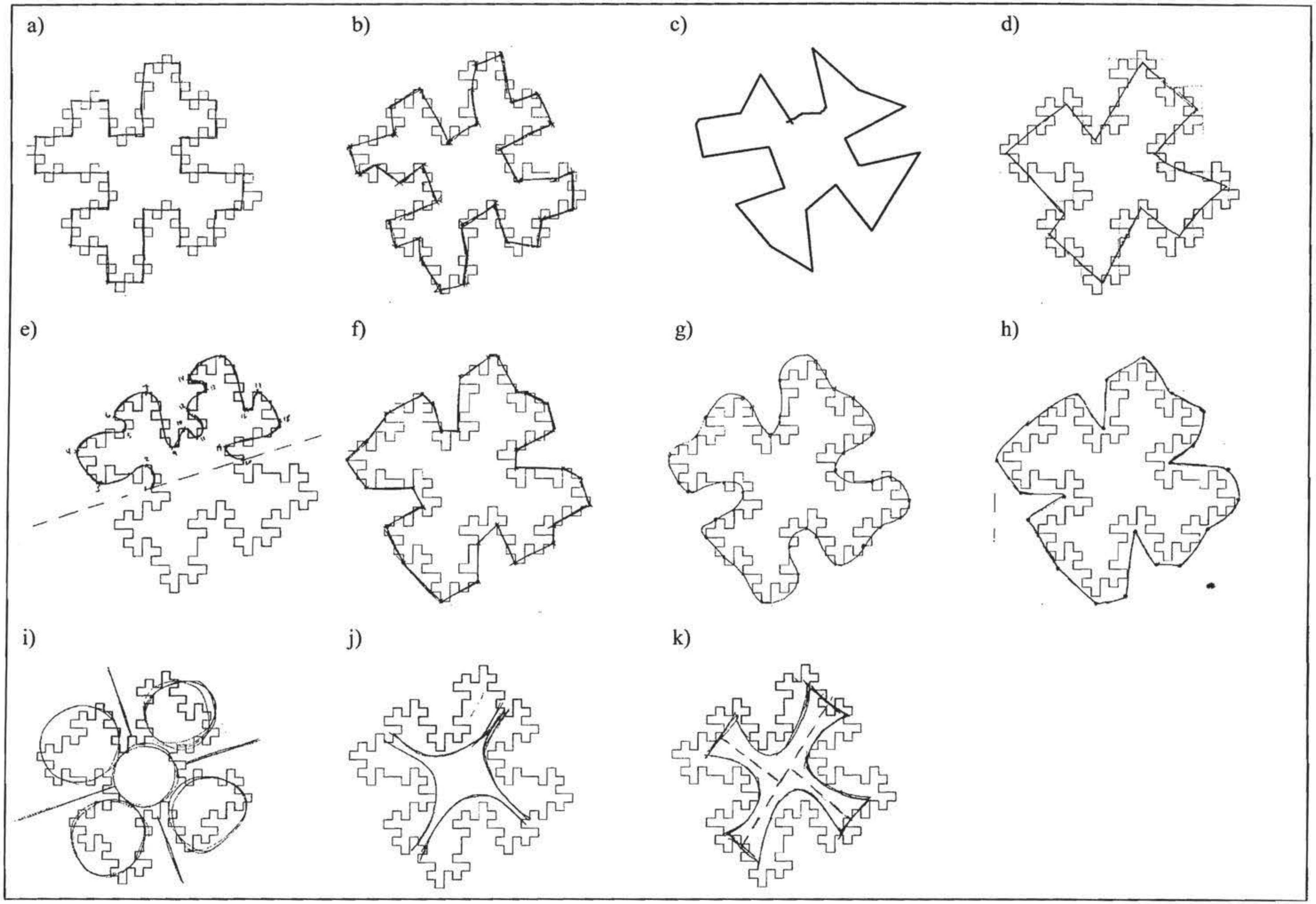


Figure 8 : Patterns emerging from Teragon 2 (see Table 2)

In the final analysis, 15 out of the 28 respondents chose wing and petal shapes for their final rendition. It is interesting that , like the line generalisation algorithms, several respondents decided to sacrifice the level 4 bilateral symmetry in order to preserve the first three levels of symmetry. Some students were also tending to ignore the level 2 symmetry.

7. Observations and Comments on Exercise 2

People had much more difficulty performing a point-based exercise with the second exercise given the line with 256 points. They tended to ignore the specified target range of points and focused on the desired shape instead. Again, the first of the pair, used for exploration, showed mixed patterns but there was an overwhelming convergence towards wing and petal shapes in this exercise. Five people, four of whom were students, abstracted the first generation teragon (Figure 8a) during the exploratory stage; ten considered rotating the shape (Figures 8b and c). Interestingly, Figure 8b is one of the decogons abstracted by the Douglas-Peucker algorithm (Visvalingam and Brown, 1999). One student produced a generalised winged pattern with just 12 points (Figure 8d), showing a re-use of a pattern already encountered in Exercise 1.

There were some variations in the petal shapes but they all have the same orientation as Figures 8b-d. Figure 8e, produced by the same student who produced Figure 6e, shows a tendency to re-use the same strategy. Note that this student's conscious segmentation of the figure involves a rotation of the partition planes and of the figure, which is implicit in many of the other figures. The emergent central square in Figure 8f, produced by 5 students, is noteworthy since it shows an attention to form; this figure was then generalised as shown in Figures 8g and 8h, which correspond to Figure 6g. They show that many students and cartographers preferred to include redundant points to pick out a petal shape and ignore the level 2 symmetry. Two people, one of whom had produced Figures 5a-c, explored the spatial coverage of the figure (Figures 8j and 8k) and then provided stylised abstractions with centrelines. The drawings, which had been discarded by two cartographers, were a cross between Figures 7d and 8j. One of them told the author that she tended to explore patterns using curves and that she found it difficult to fit curves to the level 2 teragon. Although the symbolic shapes are distinctly different, they too have segmented the figure as in Figures 8b-h. The subjects were tending to ignore the low-level rectilinear pattern (which made them think of pixels in remote sensed images) and were focusing more on the overall pattern which has a four winged shape.

8. Some Implications of the Observations

The results indicate that the art of line generalisation is not entirely intuitive and impenetrable. They suggest some of the types of assumptions and cognitive processes responsible for the variations in output in this case study; for example:

1. Despite reassurances to the contrary, there was an initial assumption that there must be a correct answer and that the exercises had been designed to reveal their level of knowledge and competence. There is much more interest in the study now that the participants have grasped the difference between deconstruction and generalisation and see the study as probing the various cognitive processes involved in manual generalisation.

2. The majority of participants were tending to see the closed curves, with or without a bounding box, as an object - i.e. the figure as opposed to the background. Only one cartographer also analysed the figure in terms of spatial coverage, on the one hand, and typifying skeletons at the other. Although cartographic training covers figure-ground relationships and centrelining, the results suggest that most cartographers are selecting a preferred strategy for analysis at the outset. If further tests confirm this, cartographic training should perhaps emphasise different approaches to encourage lateral thinking.

3. Having 'seen' the pattern as figure, there is a tendency to ignore the original partition planes and orientation of the 4-fold symmetry. The spatial coverage of the figure, which was consciously explored in Figure 8i, induced a rotation of the pattern.

4. There was also a very strong urge among some cartographers and students **to mentally map** the seen figure onto known prototypical forms of objects; i.e. to objectify the figure. Nouns, such as roads, islands, lake, built-up area, woodland, wings, cross and swastica, were used in written and verbal descriptions; reference was also made to segmented remote sensed images and to roads. Such semantic labelling could have been induced by the normal practice of selecting a generalisation that was appropriate for a given object. The psychologist Rubin reported in 1915 that we have a tendency to see objects - not the retinal patterns. We see objects even in clouds and in ink blots. The Rorschach ink blot personality test is based on the assumption that perceptual and personality differences tend to affect what we see. Here previous experience is another factor.

5. The process of recognition appears to involve the ***mental projection*** of the prototypical object shape onto the figure, leading to a biased view of the latter, especially in Figure 8h.

6. Equally, the conscious rejection of the rectilinear outline (Figure 8a) in favour of the overall shape of the figure, especially in the case of the level 2 teragon, indicates a capacity to review the output and try another object or form.

7. Those who rejected the rectangular pattern in Figure 5a noted that it violated the give and take rule in cartography. They preferred some of the wing shapes in Figure 6 because they

articulated this rule. Cartographers appear to be using this rule to track the loss of symmetry.

8. Curiously, it appears that the tendency to see a known object involves a disregard for certain types of symmetry and this is especially evident in Figure 8. Figure 6g and Figure 8 show a tendency to place much greater emphasis on the shape of the extruding parts rather than on the detail in the centre. This involves a disregard for the level 2 symmetry that is particularly noticeable in Figures 6g and 8h.

9. Some people were undertaking scale independent generalisation while others were thinking in terms of scale-dependent reduction (Figures 5d and 5e, 6g and Figure 7). Both approaches are valid. However, several of those who assumed a scale reduction not only exaggerated the area of the figure but also used many superfluous points in the extruding parts at the expense of the inner parts.

10. This lends weight to the psychological presumption that figures may be segmented at their inner concavities; for example, outlines of a person and of an aeroplane can be segmented into their component parts using this approach. Figures 6g and 8h, for instance, could be segmented at the apex of the central V-shape into four petals. However, the perception of open curves, such as coastlines, may not be biased in favour of identifying the extrusions and needs to be tested. Even here, the line would be segmented differently if the main aim was to show its extent.

11. The lack of preservation of the two-fold level 2 rotational symmetry may be due to innate distortions in perception and not necessarily due to the conscious use of recalled prototypical object forms. During the review process two professional cartographers, who thought they had returned Figure 6d, offered new information when shown Figure 4. They stressed that it took repeated meticulous checks and conscious effort to preserve the four-fold symmetry. To their surprise, in their initial attempt at abstracting the 4-fold symmetry they had only drawn similar, and not identical, shapes. On closing the curve, they realised that the first and last parts were not identical (as in Figures 4c, 4d, 6c and 6f. They had thought that they were drawing the same pattern. It was only at the stage of self-review that they had noticed the lack of identity, which prompted them to enforce the symmetry at the edit stage prior to handing in the figure. One person suggested that her output might have been different had she rotated the paper as she worked around the curve but was uncertain as to which specific wing-shape she would have chosen.

    There are two factors that may be biasing their perception, namely the orientation of the parts and the involuntary switch of figure and ground. Visvalingam (1996) and Visvalingam and Brown (1999) demonstrated that the triadic Koch curve had its counterpart in the Cesaro curve. It was quite obvious that the orientation of the geometrically identical shapes (e.g. when the paper was rotated) made them appear different. Figure 4d and, to a lesser extent, Figure 6b have orientation dependent shapes. It is interesting that, unlike professional cartographers, students do not appear to have engaged in self-review and edit.

In addition to the orientation-induced perception, there may also be some difficulty in holding a consistent mental image of the figure-ground classification. It is well known that given an ambiguous figure, the brain does not settle for a single interpretation but tends to involuntarily switch between two visual interpretations as it does with the Rubin and Mach figures (Gregory, 1970, p16 and p38). Here, there are three factors that may be facilitating the switch - the linear symbolism, the repeating pattern and local focusing. The perception may have been more stable had the 'island' been shaded. In this context, it is noteworthy that several participants at the 1998 Annual Symposium of the British Cartographic Society at Keele said that they found the up-side down maps of Britain (USDMC, 1998) very disconcerting. It was obvious that there was a need to recreate a mental map of the place in much the same way that one has to consciously learn to use a new keyboard with a different layout.

Even impossible pictures showing normal objects, such as those drawn by Hogarth and by Escher, have to be carefully analysed to detect logical inconsistencies since the eye does not immediately perceive these. When working on the line, people were tending to focus on local sections of the line. The output shape is inevitably dependent upon the shape and orientation of the segment of line being processed, which could also be inducing figure-ground reversals. Where the figure had not been consciously partitioned into identical segments, there would be a tendency to output only similar shapes. Trained cartographers rely on wholistic vision and systematic comparisons during the 'standing back' stage to adjust their tentative shapes, which may have been only similar, into symmetrically identical ones. The behaviour of learners may be suggesting that such evaluative techniques are acquired rather than innate; equally it may be reflecting the fact that professionals work much faster than students, who may not have had enough time for evaluation of their drawings.

12. The results also show that students have a distinct preference for curves while some cartographers are happy to render edges connecting points. The reliance on computer software for fitting curves has already been noted.

13. Individuals tended to stick with a strategy which proved to be successful in Exercise 1. They may have covertly explored other approaches for Exercise 1 and it is hoped that group discussions will provide more information.

14. Although several participants were suspicious that there was perhaps a right answer, which they were missing, the results confirm that there are several equally valid deconstructions of the given line. Not all of these patterns, including Figure 5a, can be derived using existing line deconstruction algorithms. Although the offset cross in Figure 5a was initially rejected by the

cartographers at Reading, some two years later, some cartographers felt that it was the best abstraction. It looks as if the rectilinear pattern may have been biasing recognition after all. If the figure had been interpreted as a road, it would make sense to drop the smallest branch. Although there were two equally sized branches, the Gestalt law on continuance may be justifying the elimination of the orthogonal branch. This constitutes a form of bend simplification. However, neither the *bendsimplify* algorithm (Wang and Muller, 1998) nor its ArcInfo implementation can provide this abstraction (Visvalingam and Herbert, 1998). Also, given teragon 2, the bendsimplify algorithm outputs distorted figures that do not resemble any of the manual deconstructions. There is thus a continuing research opportunity for identifying additional line generalisation algorithms. As pointed out by Brassel and Weibel (1988), significant advances in the design of generalisation algorithms awaits algorithms for segmenting and structuring lines.

This experiment and the results have confirmed that artificial lines may be segmented and structured in a variety of ways as noted by Visvalingam and Brown (1998). Although the semantics associated with natural lines tend to bias consensus towards specific line structuring schemes, the output of different individuals is known to vary. This suggests that like the algorithms for line generalisation, the algorithms for structuring lines may not be universally applicable either and that there would be a requirement for context-dependent techniques. The results point to some of the issues which need to be taken into account in the design of algorithms and in cartographic training.

9. Conclusion

In this collaborative research, undertaken by the BCS Design Group, participants were encouraged to deconstruct (produce meaningless forms) which best represented the patterns, represented by the two simulated lines. Line generalisation algorithms can generate a wide variety of patterns given the same lines. The initial aim of the research was to discover whether cartographers would produce more consistent deconstructions. The research was open-ended and exploratory and was not hypothesis driven. The observations may be no more than anecdotal since sample size is limited. Nevertheless, they are interesting and provide ideas for further research. These observations suggest the following tentative conclusions (the text in parenthesis provides the information on which specific conjectures are based).

1. **Cartographic training appears to be fostering :**

- *A tendency to assume semantic meanings and engage in semantic labelling* (written comments). This tendency **to map** occurs because the practice of generalisation is knowledge-based. This facilitates recognition and exploits the psychological tendency to re-use (project) previously successful solutions when facing new problems.

- *An awareness of the compromises arising from the application of different cartographic guidelines and the need to make choices*, e.g. preservation of the orientation and rectilinearity versus the need to give and take; or, emphasis on structure versus shape and/or coverage (written comments).
- *The subconscious awareness of distortions in perception* - see below (review of output with individuals).
- *Active self-monitoring, review and editing of output, including semantic re-labelling* (review of output with individuals).

2. Potential distortions arising from a perceptual tendency :

- *To focus on extruding parts and to morph the shape to fit the mentally projected form* (output).
- *To see shapes differently on close scrutiny and on taking a holistic view when standing back* (personal discussion). This could be due partly to orientation and partly to figure-ground reversals; the wholistic view takes the island to be the figure, but this classification need not be maintained during local processing.
- *To emphasise the features that continue rather than change direction.* This is well known but was not explicitly stated by respondents.
- *To initially reject figures to which there is an adverse muscular reaction impressing itself as a negative feeling* (personal communication). The offset cross was said to be disconcerting.

3. Some potential inhibitions to creative cartographic visualisation:

- *An assumption that there must be a preferred singular solution* (general verbal articulation). This may have been induced by training.
- *A psychological predisposition to see a closed curve as figure and not ground* (output).
- *A tendency to re-use solutions (forms).* The re-used forms suggest that there is a tendency to re-use (project) known patterns, not necessarily known objects. This may be indicating a re-use of successful strategies without attempting to explore other strategies to discover new possibilities.
- *Over-reliance on software and work-related training* (verbal articulation by non-respondents conditioned to fitting curves).

When these results were shown to a few participants some two years later, they were surprised a) at their initial subconscious behaviour and subsequent change of mind, and b) at the need to monitor subconscious perception-induced behaviour and consciously apply visual logic based on common sense and cartographic precepts. This shows the value of adopting a variety of techniques for knowledge elicitation, such as introspection and thinking aloud on paper, individual retrospection, peer review and dialogues on the psychological and 'cultural' origins of their overt behaviour. These individuals were also interested in the way some of the others had approached the exercises and amazed at just how much even this small set of results revealed about their own inner cognition.

There is a difference between geometric bends and component parts of objects. Minimal simplification may be bend-based; bends were defined by Plazanet (1995) and Wang and Muller (1998) to be geometric convexities and concavities. The hindsight preference for Figure 5a, and other results in this investigation, suggest a preference for sub-part (not bend) elimination to preserve the characteristic shape of the super-parts. Unlike minimal simplification, caricatural generalisation eliminates semantic parts. There is a psychological tendency to see the convex parts of closed figures as component parts (and to project imagined shapes onto these parts). To the author's knowledge, none of the published algorithms articulates line generalisation in such terms. Visvalingam and Herbert (1998) show how the lack of such biasing in ArcInfo's bendsimplification results in very inappropriate shapes. Algorithms developed within Artificial Intelligence, for segmenting curves at their concavities (Hoffman and Richards, 1984), are not suitable for processing complex cartographic lines consisting of a hierarchy of features within features. This remains a research challenge and this study, by the BCS Design Group, has highlighted some behavioural tendencies which could be addressed in further research on segmentation, structuring and scale-free generalisation of lines.

ACKNOWLEDGEMENTS

I would like to thank all those who undertook the exercises on which this study was based. I am particularly grateful to Alan Collinson, Convenor of the BCS Design Group for his enthusiasm and support, and David Forrest of Glasgow University for getting his students to do this exercise. I would also like to extend my thanks to Chris Brown, a PhD student in the Cartographic Information Systems Research Group for providing the data for the two teragons, and Margaret Greenman for her comments on the draft of this paper.

REFERENCES

Attneave F(1954) "Some informational aspects of visual perception", **Psychological Review** 61 (3) 183 - 193.

Buttenfield, B P and McMaster, R B (1991, eds.) **Map Generalization: making rules for knowledge representation,** Longman, UK

Collinson, A (1997) "Virtual Worlds", **The Cartographic J** 34 (2) 117 - 124

Douglas, D H and Peucker, T K (1973) "Algorithms for the reduction of the number of points required to represent a digitised line or its caricature", **The Canadian Cartographer** 10 (2), 112 - 122

Gregory , R L (1970) **The Inteligent Eye**, Weidenfield & Nicolson, London

Hoffman, D D and Richards, W A (1982) "Parts for Recognition", **Cognition** 18, 65 - 96.

Mandelbrot, B (1983) **The Fractal Geometry of Nature**, W.H. Freeman, New York, 3rd edition.

Marino, J S (1979) "Identification of characteristic points along naturally occurring lines : an empirical study", **Canadian cartographer** 16 (1) 70 - 80

McMaster, R B (1987) "Automated line generalisation", **cartographica** 24 (2) 74 - 111

Plazanet, C (1995)"Measurement, characterization and classification for line generalization", **Proceedings of AutoCarto 12**, Bethesda, Md., 59-68

USDMC - The Upside Down map Company Ltd (1998) **Upside Down Maps,** ISBN: 0 952930412

Visvalingam, M (1996) "Approximation, Generalisation and Deconstruction of Planar Curves", Cartographic Information Systems Research Group Discussion Paper 14, University of Hull, 12 pp

Visvalingam, M and Brown, C I (1999) "The Deconstruction of Teragons into Decogons", **Computers & Graphics** 23 (1), in press

Visvalingam, M and Herbert, S P (1998) "A Computer Science perspective on the Bendsimplify algorithm", Cartographic Information Systems Research Group Discussion Paper 16, University of Hull

Visvalingam, M and Whyatt, J D (1990) "The Douglas-Peucker algorithm for line simplification : re-evaluation through visualisation", **Computer Graphics Forum** 9 (3), 213 - 228

Visvalingam, M and Whyatt, J D (1993) "Line generalisation by repeated elimination of points", **The Cartographic Journal** *30* (1), 46 - 51

Wang, Z (1996) "Manual versus automated line generalization", In: **Proceedings of GIS/LIS '96,** Denver, Colorado, 94 - 106.

Wang, Z and Muller, J-C. (1998) "Line generalization based on an analysis of shape characteristics". **Cartography and Geographical Information Systems**, 25 (1) 3-15.

White, E R (1983) "Perceptual evaluation of line generalisaton algorithms", Unpublished Masters Thesis, University of Oklahoma

Appendix 1 : Exercises on Deconstruction

Exercise 1

Figures 1a and 1b are examples of fractals and they consist of 32 points which link lines of equal length. This particular curve is a first generation Quadric Koch island.

Figure 1a

1. Please **select 12 of the marked points in Figure 1a** to provide a simpler representation of the line.

   Since the curves have no real world meanings, you may simplify them as you please and **there is no single correct answer as such**. Indeed, the aim of the exercise is to discover the variety of ways in which curves, such as this Koch curve, may be simplified.

2. Please **note any problems** you have had with this exercise and **explain your choice of points** on the reverse side of Figure 1a

Figure 1b

Having selected 12 points in Figure 1a, you should now have some idea of the level of simplification required.

3. Use Figure 1b to indicate **where you would place 12 points** if you were not constrained to selecting points on the line. If you must draw a smooth curve, then please identify 12 critical points on your curve (i.e points through which curves must pass).

4. Please **indicate your reasons** for departing from your rendering in Figure 1a on the reverse side and note any **difficulties** you have had with this exercise.

Exercise 2

Figures 2a and 2b are second generation Koch islands consisting of 256 points each.

Figure 2a

5. Please **select between 20 to 40 points** on Figure 2a.

   You may find it easier to focus on just half the curve and select between 10 to 20 points.

6. Please **explain your choice of points** on the reverse side. Were there any **new problems**?

Figure 2b

7. Use Figure 2b to indicate how you would provide **a similar level of unconstrained generalisation** of the same figure.

8. Please **explain** your approach on the reverse side.

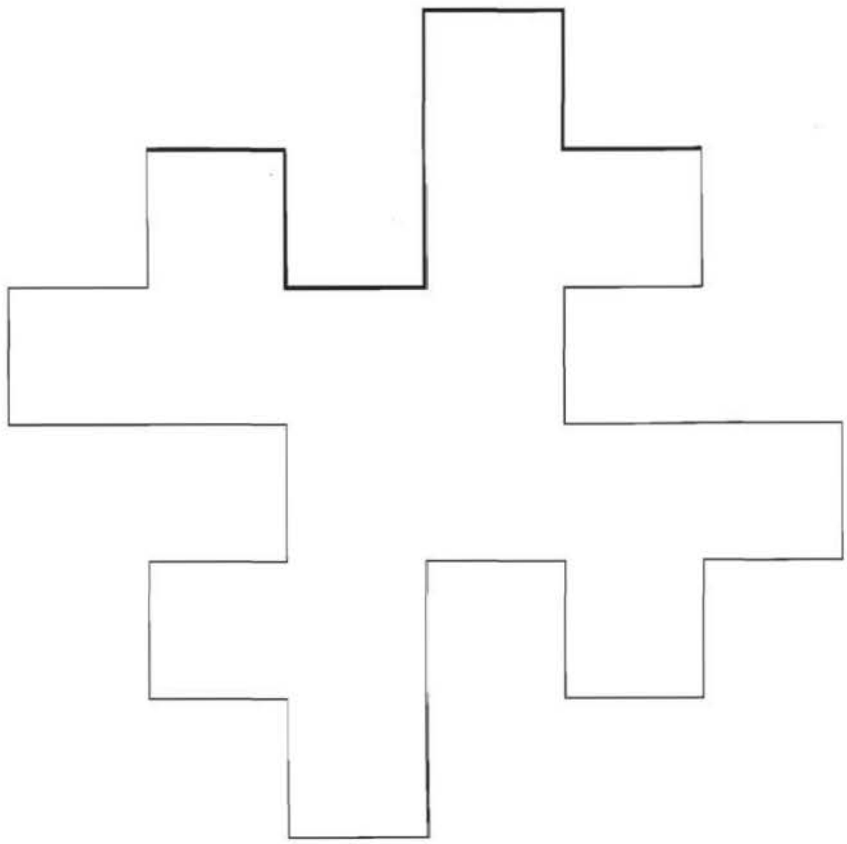


Figure 1a

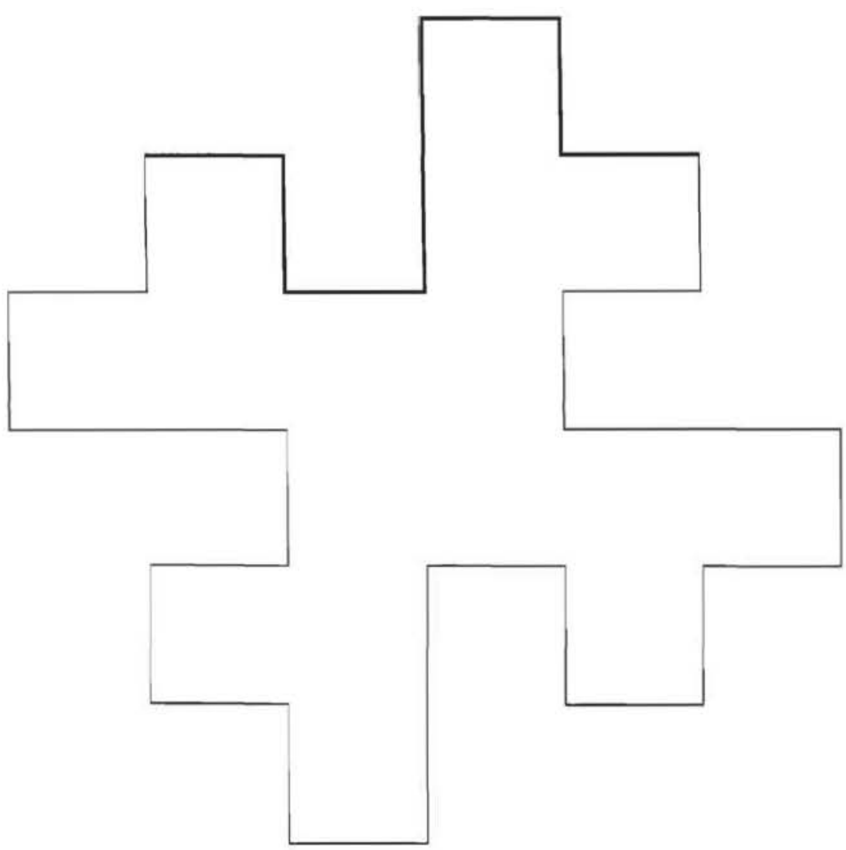


Figure 1b

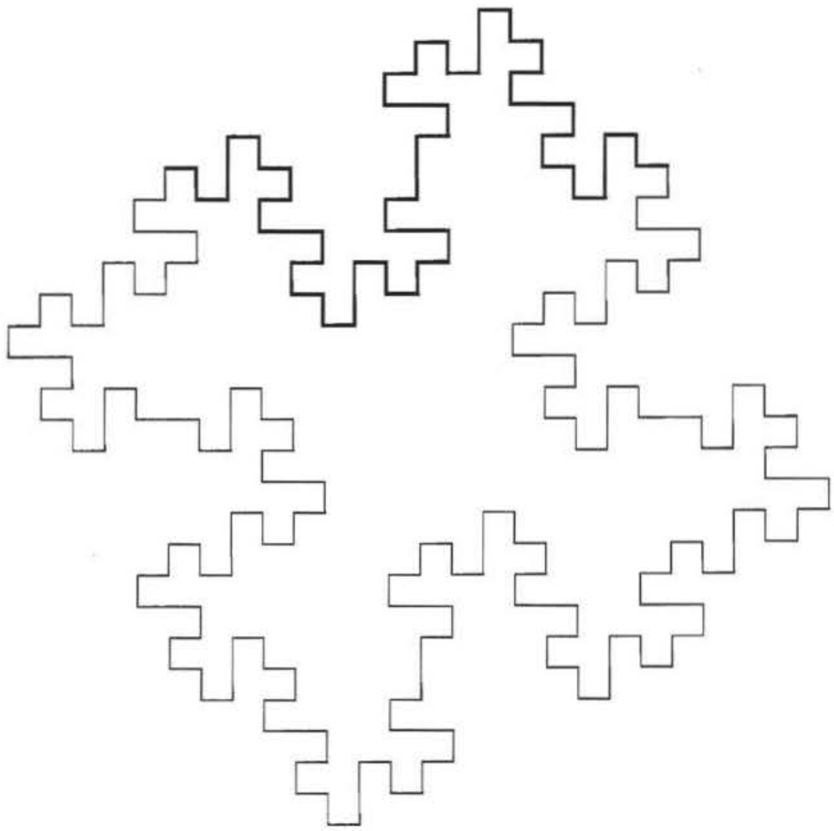


Figure 2a

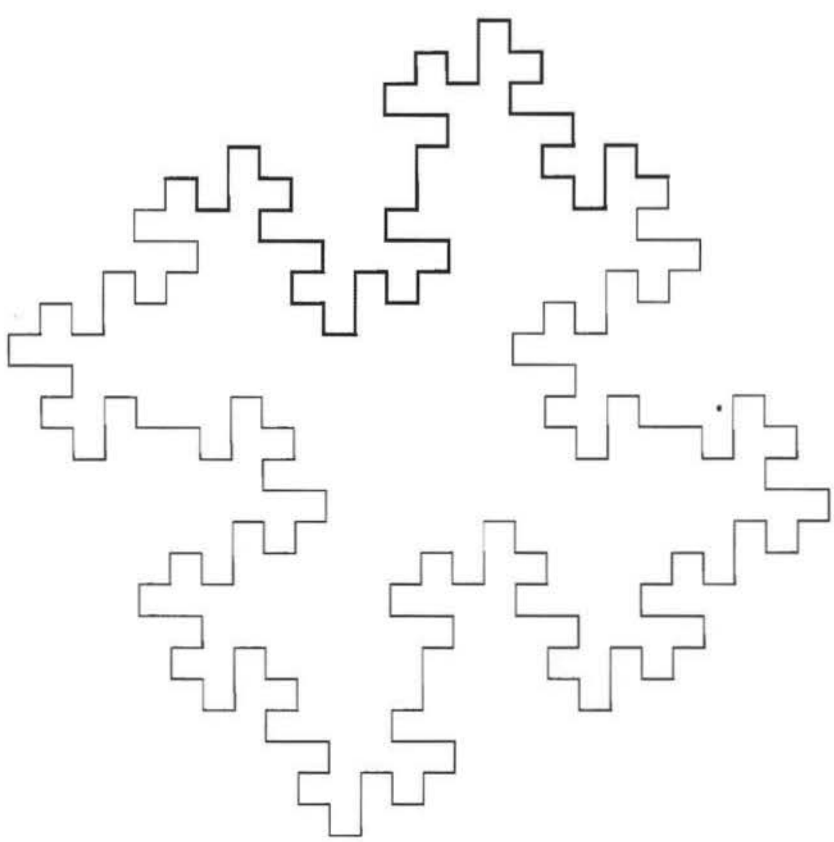


Figure 2b