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Geometric Measurement Analysis Versus Fourier Series Analysis for Shape Characterization Using the Gastropod Shell (*Trivia*) as an Example [1]

Elisabeth Dommergues,[1] Jean-Louis Dommergues,[1] Françoise Magniez,[1] Pascal Neige,[1] and Eric P. Verrecchia[2]

INTRODUCTION

Varied and efficient methods have been developed to describe and quantify natural objects. The most common ones use superimposition techniques (e.g. Procrustes methods; Bookstein, 1991), decomposition into harmonics (Fourier series and functions, wavelets; Anstey and Delmet, 1973; Christopher and Waters, 1974; Gevirtz, 1976; Lestrel, 1997; Toubin and others, 1999; Verrecchia, Van Grootel, and Guillemet, 1996; Younger and Ehrlich, 1977), analysis of spiral functions (e.g. Raup parameters; Raup, 1961, 1966; Tursch, 1998), and combinations of parameters from elementary geometry (e.g. circularity index, lengthening; Coster and Chermant, 1989; Schmidt-Kittler, 1986; Viriot, Chaline, and Schaaf, 1990). In general, these methods are used independently of one another, without evaluation of their respective efficiencies. This paper compares two of these techniques (Fourier descriptors and combinations of elementary geometric parameters) using image analysis of *Trivia* shells.

The example studied was a cowry-like shell called *Trivia* (*Gasteropoda*, *Prosobranchia*, *Triviidae*). Although the soft parts, color, number of ribs, and shell shape allow for present-day species to be distinguished (Lebour, 1933; Pelseneer, 1926, 1932), only the number of ribs and the shape can be used to differentiate fossil taxa. Moreover, *Trivia* species are only distinguishable by subtle variations in their shape that are difficult to describe with qualitative methods (Tursch, 1992). The opaque outer whorl entirely hides the spire, making its characterization impossible using rolling parameters (e.g. Raup's parameters). The shells in the

[1]UMR CNRS 5561-Biogéosciences, Centre des Sciences de la Terre, Université de Bourgogne, 6 boulevard Gabriel, F-21000 Dijon, France; e-mail: jldommer@u-bourgogne.fr
[2]Institut de Géologie, Université de Neuchâtel, rue Emile Argand 11, 2007 Neuchâtel, Switzerland.

shape of coffee beans are poorly suited for recognition with landmarks and therefore, the Procrustes-type methods cannot be used to compare their morphologies. Nevertheless, the morphologic variations of *Trivia* can be quantified by geometric variables obtained from 2D image analysis of their outlines. This study deals with present-day known taxa, which should allow for a test of the methods before their application to fossil taxa.

METHODS

The analysis was carried out using 365 adult *Trivia* shells from French coastlines. Five taxa can be differentiated by their geographical provenance (Atlantic Ocean or Mediterranean Sea) and by some of their ornamental traits (ribbed or smooth dorsal area, spotted or unspotted dorsal area; Fig. 1). All these criteria are independent of the shell outline measurements used for morphometric analysis.

The present geometric approach used combinations of distances, perimeters, and areas, as well as Fourier descriptors (using Fourier series). The variables retained are defined in such a way as to describe the shape independently of the size. For each shell, three outlines were obtained using camera lucida drawings, utilizing a standard orientation procedure. The 3D morphology of the shell was represented by three orthogonal 2D images (dorsal, lateral and apical outlines; Fig. 2(A)). The

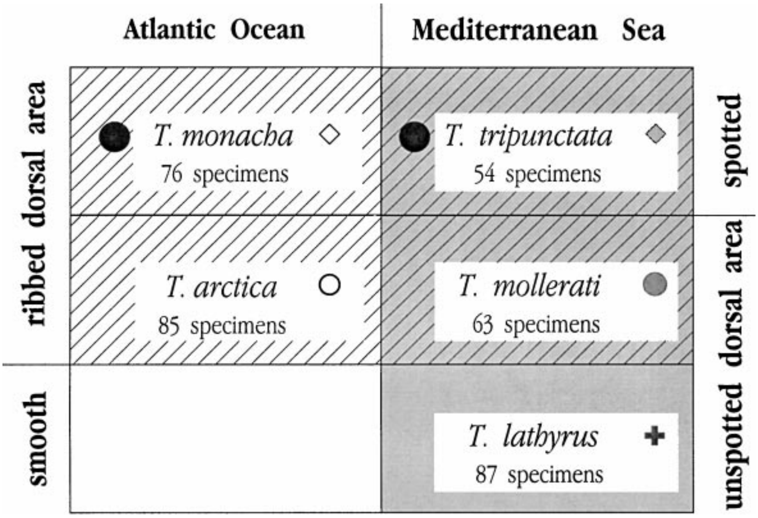
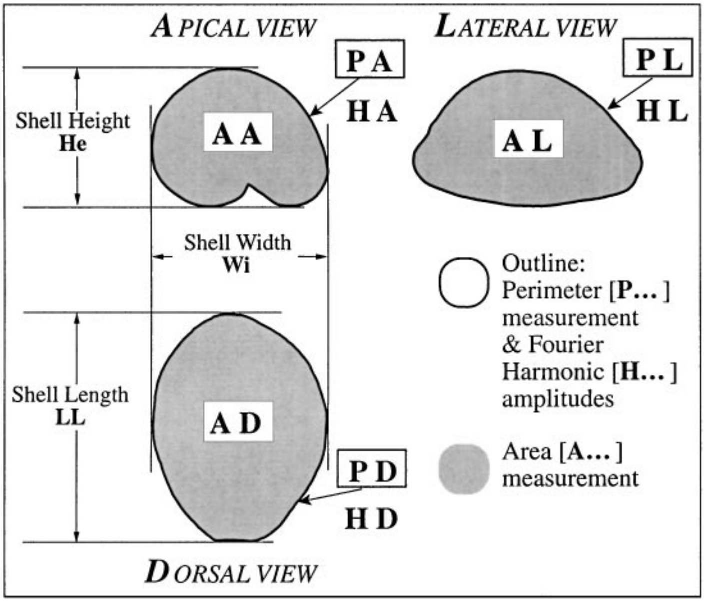


Figure 1. Diagram showing the ornamental traits and geographical origins used in the definition of the five taxa of *Trivia* analyzed. Striped boxes symbolize ribbed dorsal area, black dots symbolize spotted dorsal area, grey boxes symbolize Mediterranean origin.

A



B

Computed variable	Symbol	Formula
Height vs. Width (%)	**He/Wi**	100*He/Wi
Width vs. shell Length (%)	**Wi/LL**	100*Wi/LL
Shell Length vs. Height (%)	**LL/He**	100*LL/He
Dorsal Circularity	**DCir**	PD*PD/AD
Lateral Circularity	**LCir**	PL*PL/AL
Apical Circularity	**ACir**	PA*PA/AA
Dorsal Length index	**LL*LL/AD**	LL*LL/AD
Lateral Height index	**He*He/AL**	He*He/AL
Apical Width index	**Wi*Wi/AA**	Wi*Wi/AA
Lateral area vs. Dorsal area (%)	**AL/AD**	100*AL/AD
Dorsal area vs. Apical area (%)	**AD/AA**	100*AD/AA
Apical area vs. Lateral area (%)	**AA/AL**	100*AA/AL

C

Fourier analysis	Amplitudes of the harmonics
Dorsal view outline	**HD1 to HD8**
Lateral view outline	**HL1 to HL6**
Apical view outline	**HA1 to HA8**

Figure 2. (A) Geometrically defined variables and Fourier harmonic amplitudes used to describe the shells of *Trivia*. (B) Computed variables (12) used to describe the shells of *Trivia*. (C) Fourier harmonic amplitudes (22) used to describe the shells of *Trivia*.

combination of nine elementary geometric parameters measured on these three outlines provided 12 calculated variables (Fig. 2(B)). Fourier descriptors were represented by 22 harmonic amplitudes (the first eight for the dorsal view, the first six for the lateral view, and the first eight for the apical view; Fig. 2(C)). For each view, the cumulative frequency reaches 90%. From this threshold, outline reconstruction performed using inverse Fourier series is sufficient.

Discriminant function analysis (DFA, Forward stepwise procedure) was utilized to compare the accuracy of these two types of geometric approaches used for description and discrimination between taxa. The DFA is relevant because the variables used to describe the shape are independent of ornamentation and biogeographical criteria, which were used to identify the taxa. Scatterplots of the canonical scores for the discriminant functions (root 1 vs. root 2 and root 1 vs. root 3) display the efficiency of the discriminant function, for each of the two groups of variables used. The classification matrix quantifies the post hoc discriminatory power and facilitates the evaluation of both geometrical approaches for describing shape.

RESULTS AND DISCUSSION

The first DFA was computed using the 12 variables obtained from the combination of elementary geometric measurements. These 12 variables were retained and the resulting classification function correctly assigned an average of 72.3% of the specimens to their known species (Table 1(A)). The second DFA used 22 Fourier harmonic amplitudes. Nineteen of them were retained in this analysis and on average 86.6% of specimens were correctly assigned to their known species (Table 1(B)).

The use of Fourier descriptors seems to be more effective than the conventional metrical approach, as used here, to identify the taxa of *Trivia* based on the three shell outlines. The increase in correctly assigned specimens was particularly obvious for the two most difficult taxa to distinguish geometrically (*T. monacha* and *T. tripunctata*) as well as for *T. lathyrus*. There was only a slight increase for *T. arctica* and *T. mollerati*, probably because of their greater gibbosity.

A third DFA combining the two groups of variables (34 in all) was also computed. The 12 elementary geometric variables and 17 of the 22 Fourier amplitudes were retained. An average of 89.6% of the specimens were correctly assigned to their known species (Table 1(C)), which was a better result than for either method separately. The deviation between the discrimination rates of taxa narrows and the five taxa can be identified with almost the same efficiency. The scatterplot for the combination of the two variable groups of canonical scores shows reasonably good discrimination between taxa. Nevertheless, under closer observation, the three classification matrices show that the classification errors computed by each

Table 1. Classification Matrix Showing the Number of Individuals That Are Correctly Classified

Species		% Correct 72.3 (mean)	◇	○	⧫	●	✜	Total
(A) Elementary geometric variables								
T. monacha	◇	64.5	49	6	10	—	11	76
T. arctica	○	74.1	8	63	6	8	—	85
T. tripunctata	⧫	59.3	11	4	32	1	6	54
T. mollerati	●	79.4	—	9	3	50	1	63
T. lathyrus	✜	80.5	5	1	11	—	70	87
Total			73	83	62	59	88	365
		% Correct 86.6 (mean)						
(B) Fourier harmonic amplitudes								
T. monacha	◇	89.5	68	2	4	—	2	76
T. arctica	○	81.2	4	69	4	7	1	85
T. tripunctata	⧫	75.9	8	4	41	—	1	54
T. mollerati	●	87.3	2	4	2	55	—	63
T. lathyrus	✜	95.4	1	—	2	1	83	87
Total			83	79	53	63	87	365
		% Correct 89.6 (mean)						
(C) Elementary geometric variables + Fourier harmonic amplitudes								
T. monacha	◇	89.5	68	1	5	—	2	76
T. arctica	○	87.1	4	74	3	4	—	85
T. tripunctata	⧫	88.9	4	2	48	—	—	54
T. mollerati	●	88.9	—	5	2	56	—	63
T. lathyrus	✜	93.1	2	—	4	—	81	87
Total			78	82	62	60	83	365

Note. Rows: observed classifications. Columns: predicted classifications.

of the two methods are not always related to the same specimens. Moreover, the combination of the two methods only corrects part of the error (Fig. 3). The significance of each variable's contribution depends on the choice of available variables for each analysis. This could explain the slight decrease in discrimination rate for *T. lathyrus* compared to the results obtained using only Fourier descriptors.

CONCLUSIONS

This study on present-day known taxa shows that the morphometrical analysis of the three orthogonal 2D outlines of *Trivia* allows for an independent analysis of such characteristics as anatomy, shell color, etc., which are not preserved during

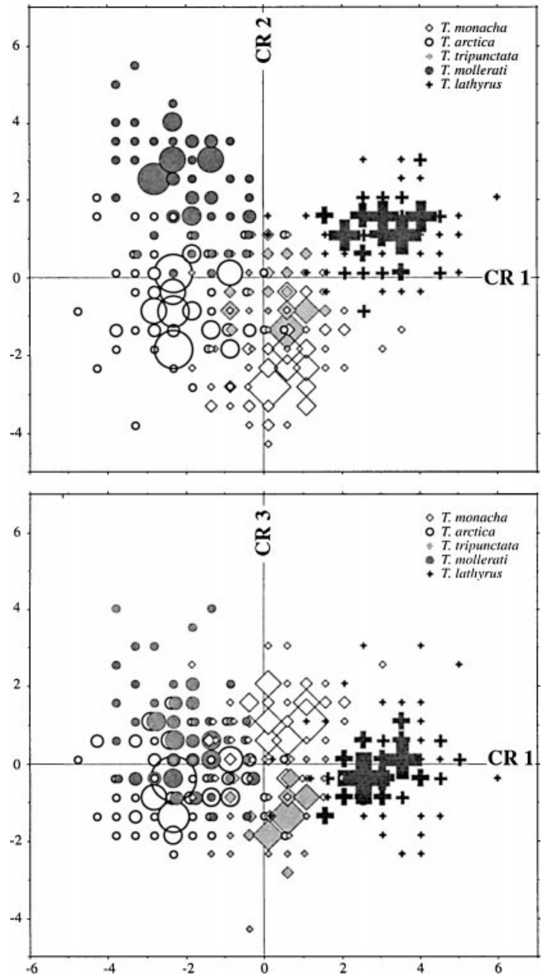


Figure 3. Scatterplot of canonical scores for pairs of discriminant functions computed with the combination of the elementary geometric variables and the Fourier harmonic amplitudes.

fossilization. Therefore, such an outline study, with or without meristic parameters (number of ribs, teeth, etc.), provides a powerful tool for the description and analysis of fossil *Trivia* shells based on quantitative rather than qualitative data.

The DFA showed that both the elementary geometric variables and the Fourier descriptors accentuate the morphological characteristics of each of the five taxa of present-day *Trivia*. Nevertheless, Fourier harmonic analysis is considered the better approach of the two, particularly for discrimination between shapes of *Trivia*, when characterized solely by the shell outlines. The results here are considered encouraging and suggest the initiation of further research to discover more accurate geometrical descriptors, notably in 3D.

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REFERENCES

Anstey, R. L., and Delmet, D. A., 1973, Fourier analysis of zooecial shapes in fossil tubular bryozoans: Geol. Soc. Am. Bull., v. 84, p. 1753–1764.

Bookstein, F. L., 1991, Morphometric tools for landmark data. Geometry and biology: Cambridge University Press, Cambridge, 435 p.

Christopher, R. A., and Waters, J. A., 1974, Fourier series as a quantitative descriptor of miospore shape: J. Paleontol., v. 48, no. 4, p. 697–709.

Coster, M., and Chermant, J. L., 1989, Précis d'analyse d'images: Presses du CNRS, Paris, 560 p.

Gevirtz, J. L., 1976, Fourier analysis of bivalve outlines: Implications on evolution and autecology: J. Math. Geol., v. 8, p. 151–163.

Lebour, M. V., 1933, The British species of *Trivia*: *T. arctica* and *T. monacha*: J. Marine Biol. Assoc. U. K., v. 18, p. 477–484.

Lestrel, P. (ed.), 1997, Fourier descriptors and their application in biological science: Cambridge University Press, Cambridge, 466 p.

Pelseneer, P., 1926, Notes d'embryologie malacologique. Ponte et développement de *Cypraea europaea*, *Triforis perversa* et *Lucina lactea*: Bull. biologique de la France et de la Belgique, v. 60, no. 1, p. 88–112.

Pelseneer, P., 1932, La métamorphose préadulte des Cypraeidae: Bull. biologique de la France et de la Belgique, v. 66, no. 2, p. 149–163.

Raup, D. M., 1961, The geometry of coiling in gastropods: Proc. Nat. Acad. Sci. U.S.A., v. 47, p. 602–609.

Raup, D. M., 1966, Geometric analysis of shell coiling: General problems: J. Paleontol., v. 40, no. 5, p. 1178–1190.

Schmidt-Kittler, N., 1986, Evaluation of occlusal patterns of hypsodont rodent dentitions by shape parameters: Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, v. 173, no. 1, p. 75–98.

Toubin, M., Dumont, C., Verrecchia, E. P., Laligant, O., Diou, A., Truchetet, F., and Abidi, M. A., 1999, Multiscale analysis of shell growth increments using wavelet transform: Comput. Geosci., v. 25, no. 8, p. 877–885.

Tursch, B., 1992, Le désordre des *Oliva*, élégie suivie d'un éloge de la méthode: Apex (hors série), p. 21–28.

Tursch, B., 1998, A simple shell model: Applications and implications: Apex, v. 13, no. 4, p. 161–176.

Verrecchia, E. P., Van Grootel, G., and Guillemet, G., 1996, Classification of Chitinozoa (Llandoverian, Canada) using image analysis: Microsc. Microanal. Microstruct., v. 7, no. 5/6, p. 461–466.

Viriot, L., Chaline, J., and Schaaf, A., 1990, Quantification du gradualisme phylétique de *Mimomys occitanus* à *Mimomys ostramosensis* (Arvicolidae, Rodentia) à l'aide de l'analyse d'images: Comptes-rendus de l'Académie des Sciences Paris, v. 310, série II, p. 1755–1760.

Younger, J. L., and Ehrlich, R., 1977, Fourier biometrics: Harmonic amplitudes as multivariate shape descriptors: Syst. Zool., v. 26, p. 336–342.