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FRACTAL DIMENSIONS OF DIFFERENT WRITING SYSTEMS AND THEIR POSSIBLE IMPLICATIONS

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ABSTRACT: The fractal dimension is an indicator of structural complexity. It represents a ratio of the change in the details of a pattern to the change in the scale used for measuring it. In this study, fractal analysis was applied to different writing systems. Each script investigated was considered as a distinct image and its fractal dimension value was estimated by using the box-counting method. Firstly, the presence of characteristic fractal dimensions for Greek, Latin and Cyrillic was established by using different types of fonts to show the validity of such an investigation. Then, possible relationships were sought for between different writing systems by considering their fractal dimensions. It was observed that some scripts with known close relations indeed exhibited relatively close fractal natures in the range of mesh size used in the calculations. Latin and Cyrillic known to be derived from Greek exhibited fractal dimension values rather close to and slightly higher than that of Greek. This might imply the increase in complexity of a writing system as other scripts are developed from it. Arabic and Hebrew, Devanagari and Thai, Armenian and Georgian exhibited quite similar fractal natures to each other, supporting available knowledge/speculations on their kinship. The Korean script, which is known to be developed uniquely, was investigated for obtaining some clues about its possible inspirations. The fractal dimension of the Korean writing system Hangul was determined to be close to those of Devanagari and especially Thai scripts, when the Far East scripts were taken into consideration. On the other hand, the fractal natures of the Old Turkic and Japanese scripts seemed to be less similar to the Korean script. As shown in this study, fractal analysis may be utilized as a helping tool, together with other techniques, in determining the origins and/or relatives of various unknown scripts, or alternately to show that they are irrelevant. Additional information, such as regional and historical relationships between different writing systems may reinforce the implications obtained from investigations carried out by fractal analysis.

Keywords: Writing System, Origin, Fractal Dimension, Korean, Hangul

1. INTRODUCTION

Different writing systems have been developed since ancient times to provide communication among human beings. There are dozens of scripts in use today, the most common one being Latin, deriving from the first true alphabet, Greek. Actually, scripts are classified according to how they indicate vowels and are called true alphabets only when they

treat vowels in the same way as consonants. If vowels are not indicated at all, the writing system is called an abjad and alternatively, in case the vowels are indicated by diacritics or systematic graphic modification of the consonants, the script is named an abugida. The history of writing systems may be extended to ancient Egypt where hieroglyphs were developed to represent syllables beginning with a single consonant followed by a vowel supplied by the user (Haarmann, 2002). These scripts were not used as a system to encode speech. Later, the Proto-Sinaitic script was developed which was probably based on Egyptian hieroglyphs and did not have any characters representing vowels. This, in turn, was developed into the Phoenician script, which was modified to obtain Greek, the parent of most Western alphabets. An important writing system, namely, Aramaic was also adapted from the Phoenician script, later giving rise to some Asian writing systems. Many isolate systems also exist, though some inspirations might have possibly been obtained from these initial examples of scripts. It is not very easy to trace back the exact origins of the numerous existing and already extinct writing systems developed throughout the history of mankind. Additional analysis techniques would be very useful to understand better and comment on the relationships between these various scripts.

Fractal geometry has found widespread use in diverse areas of science to simulate irregular shapes and chaotic movements. Many different applications have benefited from fractal interpretations, providing new perspectives. The possible use of fractal analysis has been investigated in medical science, for various applications including the prediction of future arrhythmic death (Anderson et al., 1997, p. 226-232), development of growth models of cancer cells (Ferreira et al., 1998, p. 569-580), measurement of the complexity of the retinal vasculature (Azemin et al., 2012, p. 194e1-194e4) and prognostic indication of implant success (Sansare et al., 2012, p. 15-23). It has been used to characterize crystalline deposits (Helalizadehet al., 2006, p. 2069-2078), aggregates (Bushell et al., 2002, p. 1-50) and adsorbent surfaces (Tatlier et al., 2001, p. 1545-1555) as well as to detect patterns in process data (Purintrapiban et al., 2003, p. 653-667) and to reveal the deep structural features of images (Zhuang et al., 2004, p. 29-36). Fractal analysis techniques have been used to study space-time variations in the epicentral field of earthquakes (Lunina et al., 2011, p. 351-364). Fractal dimension has also been used as a tool to reflect the roughness of the impact fracture surface (Tang et al., 2012, p. 4777-4781).

Actually, the fractal dimension is one of the most useful tools of fractal geometry. It takes into account how fast a curve, surface or volume changes by measuring with smaller and smaller scales. The fractal dimension increases in value with increasing structural complexity. There exist several types of fractal dimension, of which self-similarity, Hausdorff, compass and box counting may especially be mentioned. Box counting is a practical method that may be applied to any structure in the plane and may be adapted to determine the fractality of three-dimensional structures. It may measure pictures that are not self-similar and this is important since most real-life applications are not self-similar and display fractality only between an upper and lower bound.

There are not many examples in the literature concerning fractal analysis performed to investigate the properties of various writing systems. In one study, fractal analysis of handwriting style was carried out in a pattern matching process in order to be able to differentiate between parts of texts written using different alphabets (Seropian et al., 2004, p. 622-625). In the present study, estimations were made by using the box counting method to determine the fractal dimensions of various scripts. Greek, Latin and Cyrillic were investigated in detail by taking into consideration different fonts used for these systems. The possible use of the fractal approach in classifying different scripts was then discussed.

2. SCRIPTS

The writing systems investigated in this study by fractal analysis are shown below in Figures 1-12. The Greek script shown in Figure 1 is a modified form of Phoenician script and it is the first true alphabet that provides a full representation of one written symbol per sound both for vowels and consonants. It has been used to write Greek, an Indo-European language, since the 8th century BC. It is the ancestor of numerous European and Middle Eastern scripts (Daniels et al., 1996). The Cyrillic script depicted in Figure 2 has been derived from Greek during the 10th century. It is being used to write a number of languages such as Russian, Bulgarian, Serbian and Mongolian. Some of these languages have Indo-European origin and some others have Altaic origin. The latter languages started to use this true alphabet at later periods. Figure 3 represents the Latin script which is used very commonly today in different parts of the world for writing numerous European, American, East Asian and African languages. This true alphabet has evolved from Greek in the 7th century BC.

The Arabic script is given in Figure 4. Actually, it is an abjad since the letters usually represent consonants. It is a descendent of the Aramaic script, which itself has evolved from Phoenician. The Arabic script has been developed in the 4th century for writing Arabic which is an Afro-Asiatic language. Figure 5 represents the Hebrew script, which similar to Arabic has evolved from Aramaic script and is used to write Hebrew, another Afro-Asiatic language. It has been developed in the 3rd century BC as an abjad, consisting only of consonants. Figure 6 shows the Devanagari script which is an abugida used in India and Nepal. It has been developed in the 13th century and is the main script used to write Standard Hindi, Marathi, and Nepali, all Indo-European languages. The Thai script is shown in Figure 7. It is a descendent of the Brahmic script, similar to the Devanagari writing system, which is also believed to be a descendent of Aramaic. Thai script is an abugida, where each consonant may invoke an inherent vowel sound. It has been developed in the 13th century to write the Thai language which belongs to Tai-Kadai language family. The Armenian script shown in Figure 8 was created uniquely in the 5th century, though some Greek influences have been mentioned to be possible. It is a true alphabet developed to write Armenian, an Indo-European language. The Georgian script is given in Figure 9. It is a true alphabet developed in the 5th century to write Georgian and other Kartvelian languages. It may be regarded as a separate system, but there are suggestions that the earlier version has been created by the same person who has created Armenian and might also have been inspired from the Greek writing system. Figure 10 shows the Old Turkic script developed in around the 8th century to record the old Turkish, an Altaic language. This true alphabet is thought to be developed from variants of the Aramaic script, though it has also been suggested to be derived from the Chinese script. The Korean Hangul script is depicted in Figure 11. This is an original system designed for writing the Korean language, which is speculated to have Altaic origins or be a language isolate. Figure 12 shows hiragana, which is one of the basic components of the Japanese writing system, along with katakana and kanji. Actually, this writing system may be called a syllabary, consisting of syllables, and has been developed from Chinese characters in the 5th century for writing the Japanese language, speculated to have Altaic origins.

3. CALCULATION OF THE FRACTAL DIMENSION

The fractal dimensions of different writing systems were estimated by using the box counting method. Firstly, the letters were arranged in tables under similar conditions. For Greek, Latin and Cyrillic, the fonts used were Arial Unicode MS, Courier New, Century, Tahoma and Times New Roman. Different fonts were selected to investigate the effect of different writing styles of the scripts on the fractal dimension values. Extremely different cases, such as those involving handwriting styles were not taken into consideration in this selection. The presence of characteristic fractal dimensions for the scripts was sought for, in order to show the suitability of a fractal analysis. A font size of 22 was utilized in all cases. For all the other scripts investigated, Arial Unicode MS 22 was employed since the use of a large variety of fonts was not generally available for them. The fractal dimension was calculated by considering each script depicted in a table as an image. The script letters were arranged as shown in Figures 1-12 for Greek, Cyrillic, Latin, Arabic, Hebrew, Devanagari, Thai, Armenian, Georgian, Old Turkic, Korean and Japanese, respectively. The figures shown here are reduced in size and written in Arial Unicode MS 12. The mentioned scripts were selected in this study taking into consideration their commonness in use as well as their possible relations with at least one of the other scripts investigated, regarding historical and geographical issues.

In order to calculate the box-counting fractal dimension of an object, the picture is placed on a mesh. The x-axis of the mesh is s where s=1/(number of mesh blocks). The number of blocks that the picture touches (N) is counted. Then, the mesh is resized and the counting process is repeated for a number of times. As a result, the fractal dimension (FD) may be evaluated from

$$N = (1/s)^{FD} \quad (1)$$

When log N is plotted vs. log (1/s), the slope of the straight line fitted to the plotted points represents the fractal dimension value of the structure investigated. Five different mesh sizes, namely, 1/11, 1/16, 1/22, 1/33 and 1/42 were employed in the estimations carried out in this study to determine the fractal dimensions of different writing systems.

Α Β Γ Δ Ε Ζ Η Θ Ι

Κ Λ Μ Ν Ξ Ο Π Ρ Σ

Τ Υ Φ Χ Ψ Ω

Figure 1. Greek script

А Б В Г Д Е Ж З И

Й К Л М Н О П Р С

Т У Ф Х Ц Ч Ш Щ Ъ

Ы Ь Э Ю Я

Figure 2. Cyrillic script

A B C D E F G H I

J K L M N O P Q R

S T U V W X Y Z

Figure 3. Latin script

ا ب ت ث ج ح خ د ذ

ر ز س ش ص ض ط ظ ع

غ ف ق ك ل م ن ه و

ي

Figure 4. Arabic script

א ב ג ד ה ו ז ח ט

י כ ל מ נ ס ע פ צ

ק ר ש ת

Figure 5. Hebrew script

अ आ इ ई उ ऊ ऋ ॠ ऌ

ॡ ए ऐ ओ औ क ख ग घ

ङ च छ ज झ ञ ट ठ ड

ढ ण त थ द ध न प फ

ब भ म य र ल व श ष

स ह

Figure 6. Devanagari script

ก ข ฃ ค ฅ ฆ ง จ ฉ
ช ซ ฌ ญ ฎ ฏ ฐ ฑ ฒ
ณ ด ต ถ ท ธ น บ ป
ผ ฝ พ ฟ ภ ม ย ร ล
ว ศ ษ ส ห ฬ อ ฮ ะ
ั า ำ ิ ี ึ เ- โ- ใ-
ไ- ฤ ฤๅ ฦ ฦๅ

Figure 7. Thai script

Ա Բ Գ Դ Ե Զ Է Ը Թ Ժ
Ի Լ Խ Ծ Կ Հ Ձ Ղ Ճ Մ
Յ Ն Շ Ո Չ Պ Ջ Ռ Ս Վ
Տ Ր Ց Ւ Փ Ք Օ Ֆ

Figure 8. Armenian script

ა ბ გ დ ე ვ ზ თ ი
კ ლ მ ნ ო პ ჟ რ ს
ტ უ ფ ქ ღ ყ შ ჩ ც
ძ წ ჭ ხ ჯ ჰ

Figure 9. Georgian script

Figure 10. Old Turkic script

Figure 11. Korean script

あ か さ た な い き し ち

に う く す つ ぬ え け せ

て ね お こ そ と の は ま

や ら わ ひ み り ゐ ふ む

ゆ る ん へ め れ ゑ ほ も

よ ろ を

Figure 12. Japanese script (hiragana)

4. RESULTS AND DISCUSSIONS

The box-counting fractal dimensions obtained for the Greek, Cyrillic and Latin writing systems, when different fonts were used, are given in Table 1. Figures 1-3 show these writing systems utilizing the Arial Unicode MS font. It may be observed that there was good agreement between the fractal dimensions of the scripts when different fonts were used. The highest fractal dimension was obtained for the Latin script which had an average value of 1.144, taking into consideration the five different fonts used. The standard deviation was equal to 0.0045 in this case. As a result of the estimations, the Cyrillic and Greek scripts exhibited average fractal dimension values of 1.122 and 1.082 with standard deviations of 0.0038 and 0.0032, respectively. The correlation coefficients were between 0.997-0.999, signifying the validity of the mesh size used for the evaluation of the fractal dimension values. It may be observed from Table 1 that the error obtained in the estimations did not exceed 1.4%.

Table 1. Fractal dimensions of Greek, Latin and Cyrillic obtained by using different fonts.

Script	Font	Fractal Dimension
Greek	Arial Unicode	1.085±0.015
	Courier New	1.086±0.014
	Century	1.082±0.012
	Tahoma	1.081±0.012
	Times New Roman	1.078±0.011
	Arial Unicode	1.146±0.015
	Courier New	1.143±0.0067

Latin	Century	1.151±0.012
	Tahoma	1.139±0.0060
	Times New Roman	1.142±0.014
Cyrillic	Arial Unicode	1.124±0.013
	Courier New	1.118±0.014
	Century	1.1270.012
	Tahoma	1.124±0.013
	Times New Roman	1.119±0.0090

Some other writing systems were also investigated by fractal analysis. Their fractal dimensions are depicted in Table 2 for the use of Arial Unicode MS font. The maximum amount of error in the estimations was again equal to about 1.4% for these scripts for which only the utilization of the generalized Arial font could be investigated.

The fractal dimensions of some scripts, which are known to be closely related, revealed similarities. Arabic and Hebrew depicted in Figures 4 and 5, which are both descendants of the Aramaic script, exhibited rather close fractal dimension values of 0.920 and 0.907, respectively. Devanagari and Thai, depicted in Figures 6 and 7, both descendants of the Brahmi script, had fractal dimensions of 1.012 and 0.979, respectively. Armenian and Georgian, depicted in Figures 8 and 9, which are found in the same geography, with also speculations existing about their kinship, exhibited values of 0.924 and 0.960, respectively. These two writing systems are also speculated to be affected by Greek. The Old Turkic script shown in Figure 10 had a fractal dimension of 0.853 which was closest to the Arabic and Hebrew, regarding its quite low fractal dimension value. Actually, the Old Turkic script has been developed from Aramaic similar to Arabic and Hebrew, though some other effects like Chinese have also been proposed, as mentioned before.

Table 2. Fractal dimensions of various scripts obtained by using Arial Unicode MS.

Script	Fractal Dimension
Japanese (hiragana)	1.061±0.013
Devanagari	1.012±0.012
Korean	0.972±0.013
Georgian	0.960±0.011
Arabic	0.920±0.012

Armenian	0.924±0.013
Hebrew	0.908±0.0091
Thai	0.979±0.0083
Old Turkic	0.854±0.0061

The fractal dimension of the Korean script depicted in Figure 11 was estimated to be equal to 0.972. This uniquely developed writing system exhibited a fractal dimension value close to those of the Devanagari and especially Thai scripts, when the Far East scripts were taken into consideration. Some inspirations related to close geographical and historical relations might surely be expected to some degree on the Korean writing system, too. On the other hand, the fractal natures of the Old Turkic and Japanese scripts seemed to be less similar to the Korean script. The Japanese script which is shown in Figure 12 had a higher fractal dimension of 1.061. Actually, it is known that the Japanese writing system is affected by Chinese.

Figure 13 shows the variation of fractal dimensions of different writing systems, which are classified according to their possible kinship with Greek. This investigation aimed to show the possible use of fractal dimensions of writing systems in the prediction of their proximity to other systems. Group 1 represents the scripts that are known to be derived from Greek, namely Latin and Cyrillic, while group 2 indicates those for which there are some speculations that Greek has influenced their creation. Armenian and Georgian are considered in this group. Group 3 represents the scripts that may be regarded as descendants of Aramaic, either directly or indirectly. The scripts directly derived from Aramaic, namely, Arabic and Hebrew, those that are derived from the Aramaic-based Brahmic script, Devanagari and Thai, and Old Turkic which is speculated to be related to Aramaic with additional possible effects, were included in this group. The relationship of these scripts with Greek lies within the fact that Aramaic and Greek are both descendants of the more ancient Phoenician script. Group 4 includes Japanese and Korean writing systems which don’t have any apparent or speculated kinship to Greek.

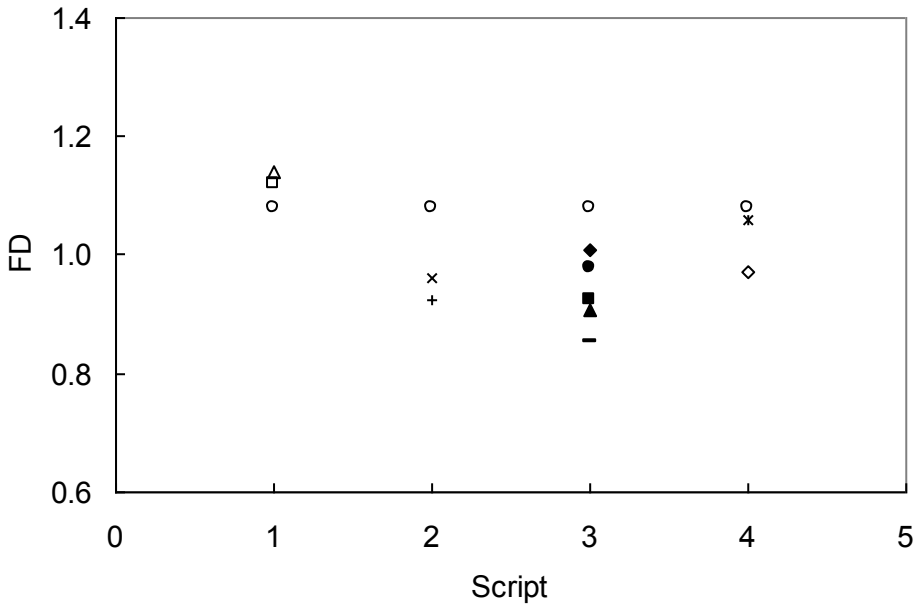

Figure 13. Variation of fractal dimension, as different writing systems, namely, (Δ) Latin, (□) Cyrillic, (x) Georgian, (+) Armenian, (-) Old Turkic, (•) Thai, (♦) Devanagari, (■) Arabic, (▲) Hebrew, (◊) Korean and (∗) Japanese are classified according to their possible kinship with (o) Greek.

It may be observed from Figure 13 that the fractal dimension of Greek was quite close to those of Cyrillic and Latin, derived from it. The results indicated that the fractal dimension of the parent writing system (Greek) was close to and somewhat lower than those of the scripts derived (Latin and Cyrillic) from it. This may be related to the increasing complexity of a script as new writing systems, which are somewhat similar, are developed from it. In case the amount of inspiration is high enough, the fractal dimension values of the scripts may be quite close as observed for Greek, Latin and Cyrillic.

The fractal dimension values of Armenian and Georgian were rather different from Greek not supporting the view that these writing systems were strongly inspired from the Greek script. Armenian and Georgian, on the other hand, had relatively similar fractal dimensions, which might be meaningful, since they have been developed in geographically near places and the initial creator of these writing systems might be the same person. Regarding the writing systems that are descendants of Aramaic, the difference between their

fractal dimensions and that of Greek was rather large, and the closest value to Greek was exhibited by Devanagari. It seems that significant changes occurred in the natures of Greek and Aramaic-derived scripts after being developed from the common parent writing system, the Phoenician.

A rather close value to the fractal dimension of Greek was that of Japanese, which is not actually expected to be much related to it. Surely, the fractal dimension value may not be used alone to judge the proximity and kinship of different writing systems but rather be used in conjunction with additional present knowledge.

5. CONCLUSIONS

The fractal dimensions of various writing systems were estimated by using the box-counting method to obtain information about their complexity. The fractal dimension values might be used as a helping tool for tracing back the historical origins of different scripts and determining their kinship to various systems. Although it is not much possible to get direct information about a script from the magnitude of the fractal dimension value, alone, its relative proximity or irrelevance to another writing system or a group of systems may be revealed. Additional knowledge about the regional and historical relationships between different scripts will also contribute to our decision on this issue.

The fractal dimension may provide an idea about the parent-child relationship for some scripts. For example, Greek had a somewhat lower fractal dimension value than those of the Latin and Cyrillic derived from it. The fractal natures of all these scripts were quite close. It might be concluded that the firm relationships between these writing systems might have resulted in close fractal dimensions. Arabic and Hebrew scripts revealed very close fractal dimension values. These writing systems originated from the same parent writing system, namely, Aramaic, and were born in the same geography. Thus, it is not very surprising that they exhibited very similar fractal dimensions. The fractal natures of the Aramaic/Brahmic-derived Thai and Devanagari scripts were quite similar, too. Historical and geographical relations might affect the proximity of the fractal natures of writing systems to some degree, as also observed from the fractal dimensions of the Armenian and Georgian scripts. These two writing systems did not provide fractal dimensions much close to that of Greek, demonstrating any near relation, as sometimes suggested. It is possible that even if these

writing systems were modeled on Greek, the shapes of the letters were not much affected from it.

In some cases, the script might be very original or rather affected by more than one writing system, such as the Korean and Old Turkic scripts. The Korean Hangul script, which is known as a uniquely developed writing system, exhibited a fractal dimension value close to those of the Devanagari and especially Thai scripts, when only the Far East writing systems were taken into consideration. It should not be surprising that some inspirations were taken from regionally and historically close systems in the development of the Korean script. The fractal natures of the Old Turkic and Japanese scripts seemed to be less similar to the Korean script and the fractal dimension values of these two scripts were not much close to each other, either. The results seemed to indicate the more significant influences of Chinese and Aramaic on the Japanese and Old Turkic scripts, respectively. In this study, the lowest fractal dimension was obtained for Old Turkic which seemed to be rather close to those estimated for Aramaic-derived Arabic and Hebrew scripts.

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