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Automated metric profiling and comparison of Ancient Greek verse epics in Hexameter

Oliver Schoisswohl (Vienna) and Evangelos C. Papakitsos (West Attica)

Abstract

This article describes a software tool, named Dactylo, which is capable of performing metrical analysis, alias scansion, of epics written in hexameter. The automated scansion is based on well-known scanning rules of various theoretical works. The development methodology introduces the concept of computerized metric profiling and metric distance, which is a measurement value that reflects the degree of similarity or dissimilarity between different epics. For this purpose, eight renowned epics have been scanned, including Iliad and Odyssey, with plenty of statistical information. Based on these outcomes, these epics can be classified in groups that reflect very well the three periods of their creation, namely Classical, Hellenistic and Late Antiquity. Dactylo demonstrates its ability to produce statistics for hexameter's metric patterns in a massive scale, easily and accurately, becoming so a contribution of Computational Linguistics to the diachronic comparative and quantitative language studies.

1 Introduction

The topic of this article is the computer supported metric profiling and comparison of verse epics in ancient Greek language, written in hexameter, regarding their syllabic distribution. Renowned epics of this category are Iliad and Odyssey (cf. Homer s. a.), Theogony (cf. Hesiod s. a.), Argonautica (cf. Apollonius Rhodius s. a.) and others. All of these poems are written in hexameter, the metric scheme of classical Greek and Latin verse epics that determines the prosodic structure of their verses (cf. Halporn/Ostwald/Rosenmeyer 1980). Namely, this scheme imposes a specific sequence of long and short syllables onto each of the verses, which are arranged in groups that are called "feet". The term originates in the rehearsals of the ancient Greek theatre (cf. Seale 1830), where a person beat time by striking his foot on the ground, according to the rhythmic structure of the poem that is called metre. The metre was selected depending on the two main types of verse: the stichic (like hexameter), which seems to have been recited, or the lyric, which seems to have been sung (cf. Raven 1962). In the case of hexameter, the number of feet per verse denotes the metre of the poem/verse (in other categories of poetry, the scheme is more composite). In this respect, a poem written in hexameter is composed of six feet per verse, each consisting either of two long syllables (long-long), named spondee, or one long and two short (long-short-short), named dactyl (cf. Maas 1962). Thus in hexameter, the actor recited two or three syllables (either a spondee or a dactyl) for every stroke of the foot.

Various principles of metrical syllabification are present in ancient Indo-European poetry, as indicated by the comparison of ancient Greek, Iranian, Latin, Sanskrit, Celtic and Slavic verses (cf. West 1982). Consequently, the study of the various rhythmic structures is a significant topic of classical literature (cf. Laan 1995), including the hexameter (cf. Edwards 1986). A key-activity of the relevant quantitative research is the statistical analysis of the poems and their comparison. For example, in the case of Homeric hexameter, it has been reported that a dactyl is placed 95% at the fifth foot, while the second foot is the least possible place (cf. Papakitsos 2011). Accordingly, the development of computerized tools, like the one presented herein, aims to become a valuable assistance to scholars for saving labour and time.

2   Theoretical framework

In modern poetry, the rhythm is mainly measured by the varying stress/accent on syllables. Namely, an unaccented syllable is short while an accented one is long (cf. Raven 1962). In ancient Greek and Latin poetry though, the rhythm was based on the quantity of syllables, instead of accent (cf. Halporn/Ostwald/Rosenmeyer 1980). The process of determining the metric pattern (or scheme) is called scanning or scansion. Scanning a verse to find its underlying metric pattern is driven by a set of scanning rules (cf. Annis 2006). The rules regarding feet identification are built into the presented software application, named Dactylo. These rules are summarized in Table 1. Words are internally transformed, by means of an auto-adjustment process, in order to facilitate the computerized process.

Other, more complex and/or more specialized rules do exist (cf. Papakitsos 2011). The table of auto-adjustments for analysis is far from complete and currently captures only a small subset of particular phenomena encountered (e. g., contraction). Nevertheless, in the current first iteration of the Dactylo project, a resolution rate of 95% to 99% for the epics scanned delivers a broad enough statistical base for the aggregation of statistical information (see below section: 4. Results and Discussion), such that the developer postpones a refinement of implemented rules, for future iterations of the project.

2.1   Related works

The computerized scansion of hexameter is relatively old, starting with Latin poetry (cf. Ott 1973). These computational efforts were confined neither only to Latin poetry (cf. Mayrhofer 1987) nor to hexameter (cf. Jong and Laan 1996). Some of them may focus on encoding for representing quantitative metrical analyses (cf. Mahoney 2003) or on comparative statistical approaches to rhythmic patterns between poems of different eras (cf. Eder 2007).

The first known computerized system, dedicated to the automated scansion of ancient Greek hexameter, had been implemented in Ada programming language by E. Papakitsos (1992). Its scanning algorithm was based on the statistical distribution of dactyls per verse in Homeric poetry, as defined in theoretical works. The original version could not directly support a Greek keyboard; therefore the second version was implemented in Turbo-Pascal 6 programming language (cf. Papakitsos 2000). Along with the advancement of graphical user interfaces through object-oriented programming, the third version has been implemented in Visual Basic 6.0 programming language (cf. Papakitsos 2009) for corresponding to technological advancements. Mainly targeted to support academic education in the Departments of Classics, the fourth and

last version is implemented in C# programming language (cf. Foti 2013). The same scanning algorithm has been used in another software tool, for exploring the influence of the Pythagorean theories to the structuring of Plato's works (cf. Tsoumaki 2012; Papakitsos and Tsoumaki 2013), after the theoretical and computational work of J. Kennedy (2010; 2011) and by his request. Finally, this system can neither support the direct automated handling of complex phonological phenomena, like synizesis, nor it produces statistical reports that would facilitate comparisons of metrical profiles between different poems.

Rule group	Object	Value and scan	Details and comments
vowel length	η ω	long	
	diphthongs/digraphs	long	
	ε ο	short	
	α ι υ	short or long	dichronae, i. e., can be short or long
	any with ~	long	
syllable quantity	long vowels	long	
	short vowels	short	
	long vowels at end of word, next word starts with vowel	anceps	known as epic correption
	any vowel followed by 2 or more consonants (except below)	long	
	short or anceps vowels followed by exactly 2 consonants of type plosive followed by sonans in the same word (except below)	anceps	includes pairs of any of δ τ θ β π φ γ κ χ followed by any of λ μ ν ρ
	vowels followed by γμ γν δμ δν	long	
	adjacent vowels (e. g., εω)	(may collapse into one) long	This is called *synizesis*. Its implementation in Dactylo is limited to a set of enumerated words such as Πηληϊάδεω in Iliad, I, 1.
	short syllables at the beginning of 5th half foot		This is intended to address a requirement for support of *brevis in arsi*. Short syllables at the beginning of 5th half foot will be accepted as long if they are the last syllable in the word (i. e., potentially preceding a caesura).

Table 1: Hexameter scanning rules in Dactylo

Another software tool, capable of scanning the hexameter, is the expert system of Daniele Fusi (2001; 2002; 2004; 2008; 2015), which can scan other metrical patterns (e. g., elegiacs, trimeters, etc.), as well, in Ancient Greek, Latin and Italian poetry. This comprehensive system covers a wider spectrum of linguistic phenomena, by using different modules for prosody, syntax and metrics. Moreover, the output of it generates report files concerning many linguistic phenomena.

2.2   Research objectives and data

The purpose of this research is to introduce the concept of metric profiling and to show some of the data collected during this work. All data collected (more than those listed in the report) can be made available on request for further investigation. On this ground, the present study has two goals:

- Automatically (through computer software) determine the actual metric patterns of the huge number of verses in classical epics (in total about 67,000) as a sequence of long and short syllables.
- Collect and present statistical information related to the poets' preferences of, or aversions against, the possible patterns that may exist in a hexameter verse, and based on these statistics, compare authors and their works across the timeline.

The types of data analyzed included the following works:

- Iliad (Homer);
- Odyssey (Homer);
- Theogony (Hesiod);
- Works and Days (Hesiod);
- Phaenomena (Aratus Solensis);
- Argonautica (Apollonius Rhodius);
- Fall of Troy/Posthomerica (Quintus Smyrnaeus);
- Dionysiaca (Nonnus of Panopolis).

This selection of works is intended to allow for a comparison of feet distribution, in different periods of Ancient Greek epic poetry; in particular:

- Homer, Hesiod (8th/7th century BCE);
- Aratus Solensis, Apollonius Rhodius (3rd century BCE);
- Quintus Smyrnaeus, Nonnus Of Panopolis (4th/5th century CE).

Based on the distribution patterns of the verses, profiles can be calculated of the relative frequencies of these patterns within the works. These profiles are called metric profiles within this document. Once these profiles have been established, comparison can be performed of profiles of different authors across the centuries, such as to observe and describe the evolution of these preferences from the early days of ancient Greek epic poetry, to their latest days. The source code (these works) was copied into a text editor and saved in UTF-8 encoding. UTF-8 stands for Universal Character Set Transformation-8 bit, and is a character encoding that allows representing all possible characters defined by Unicode, the computing industry standard for encoding most of the world's writing systems. This particular encoding allows the processing of polytonal Greek fonts.

The number of verses available for analysis, along with a few comments, can be seen in Table 2. Hesiod's works are analysed as a compilation of Theogony (as Book 1) and Works and Days (as Book 2). The purpose here is to broaden the statistical base for the calculation of metric profiles, (see below subsection: 3.1 Metric profiling) as both works alone are much shorter than any of Iliad, Odyssey, Argonautica, and Dionysiaca. Even counted together, these Hesiod works

have less than 2,000 verses, so any slight fluctuations or irregularities in the analysis of these works have a larger impact onto the overall results.

Epic	Number of verses	Comments
Iliad	15,683	
Odyssey	12,105	
Hesiod's works	1,853	Assembly of Theogony and of Works and Days. Theogony: "Σημείωση" after verse 929 is not included in this analysis
Phaenomena	1,155	
Argonautica	5,834	
Posthomerica	8,804	
Dionysiaca	21,260	Some apparent errors in line numbering evident in the data source (Perseus Project) have been corrected.

Table 2: Works under analysis

3   Methodology

As outlined above, this study is based on computerized scanning of hexameter. The software tools, developed for this purpose by the name Dactylo, reads verses line by line, scans for the hexameter pattern (i. e., the sequence of long and short syllables compliant with hexameter rules) and outputs the verses along with their determined pattern to simple text files, for further investigation and processing. Before Dactylo scans a text, it is transformed from original Greek characters into an internal format, using Latin characters. This is done primarily for practical reasons, having to do with computing environments of limited or no support for Greek characters. It also facilitates the handling of some grammatical phenomena, like diaeresis and circumflex. As an illustration of this internal transformation, the first few lines of Iliad in original Greek and in transformed versions are given in Table 3.

Each verse is then output along with an identifier and with the determined pattern of long and short syllables, as for example the result for the first verse (0001) of Book 1 (Rhapsody I) of Iliad (IL01):

IL01 0001*OK*mHnin aeide Tea phlhjade0 axilHos*LSSLSSLLLSSLSSLS.

Statistical information, created in the scanning process, comprises:

- Number of verses in the epic (or Book).
- Number of verses for which the metric pattern could not be identified (reported as irregular pattern).
- Number of verses in each of the 32 possible metric patterns (further organized in metric profiles, see below).
- Number of verses for which Dactylo finds more than one matching pattern (see section: Results and Discussion).

Original Greek Text	Latin Transformation
μῆνιν ἄειδε θεὰ Πηληϊάδεω Ἀχιλῆος	mHnin aeide Tea phlhjade0 axilHos
οὐλομένην,ἣ μυρί᾽ Ἀχαιοῖς ἄλγε᾽ ἔθηκε,	oylomenhn h myri axaioIs alge eThke
πολλὰς δ᾽ ἰφθίμους ψυχὰς Ἄϊδι προΐαψεν	pollas d ifTimoys Syxas ajdi projaSen
ἡρώων,αὐτοὺς δὲ ἑλώρια τεῦχε κύνεσσιν	hr00n aytoys de el0ria teYxe kynessin
οἰωνοῖσί τε πᾶσι,Διὸς δ᾽ ἐτελείετο βουλή,	oi0noIsi te pAsi dios d eteleieto boylh
ἐξ οὗ δὴ τὰ πρῶτα διαστήτην ἐρίσαντε	eX oY dh ta prOta diasththn erisante
Ἀτρεΐδης τε ἄναξ ἀνδρῶν καὶ δῖος Ἀχιλλεύς.	atrejdhs te anaX andrOn kai dIos axilleys

Table 3: Internal transformation from Greek to Latin characters

The core consideration is the following: hexameters are built from sequences of 6 feet that each are either 3 syllables building a dactyl (scanning long-short-short), or 2 syllables building a spondee (scanning long-long). The exception is the last foot that has only 2 (never 3) syllables, and scans either long-long or long-short. However, the rhythmic impression of the last foot will always be that of a spondee (long-long) because of the following break at the end of the verse.

3.1   Metric profiling

Looking onto foot one to foot five of a verse, and not distinguishing between long-long and long-short in the last foot, one can distinguish 32 patterns of hexameter (i. e., different combinations of dactyls and spondees). For each of these patterns, one can measure the relative frequency by which that pattern appears in the verses of the text in question. The full metric profile then captures the information of how frequently each pattern occurs in the work, in terms of relative frequencies (percentage of occurrences). Because these frequencies are given in relative (not absolute) values, the concept allows for comparison of profiles of works that differ in length (number of verses). The metric profile is hence a table of 32 numbers that each denotes the percentage of verses in a work that are built to the specific pattern at this table position. Table 4 enumerates and defines the 32 hexameter patterns within the metric profile.

As shown in Table 4 (see below):

- "Pat. id" ("Pattern id") is a sequential numbering of hexameter patterns, from 01 (all dactyls) to 32 (all spondees). The irregular pattern is a hypothetic pattern assigned to verses not successfully scanned as hexameters (for details, see below subsection: 4.1 Irregular patterns).
- "Pattern descriptor" is a combination of D (for a dactyl in this position) and S (for a spondee in this position), terminated by an [x] in the last position (where we don't distinguish between dactyl and spondee).
- "Scanned as" gives the full scan of the pattern as a sequence of LSS (long-short-short) and LL (long-long), with LS possible for the scan of the last foot.

In addition to the full metric profile described above, an additional compact metric profile is also calculated.

Pat. id	Pattern short descriptor	Scanned as	Pat. id	Pattern short descriptor	Scanned as
01	DDDDDx	LSSLSSLSSLSSLSSLx	18	SDDDSx	LLLSSLSSLSSLLLx
02	DDDDSx	LSSLSSLSSLSSLLLx	19	SDDSDx	LLLSSLSSLLLSSx
03	DDDSDx	LSSLSSLSSLLLSSx	20	SDDSSx	LLLSSLSSLLLLx
04	DDDSSx	LSSLSSLSSLLLLx	21	SDSDDx	LLLSSLLLSSLSSLx
05	DDSDDx	LSSLSSLLLSSLSSLx	22	SDSDSx	LLLSSLLLSSLLLx
06	DDSDSx	LSSLSSLLLSSLLLx	23	SDSSDx	LLLSSLLLLLSSx
07	DDSSDx	LSSLSSLLLLLSSx	24	SDSSSx	LLLSSLLLLLLLx
08	DDSSSx	LSSLSSLLLLLLLx	25	SSDDDx	LLLLLSSLSSLSSLx
09	DSDDDx	LSSLLLSSLSSLSSLx	26	SSDDSx	LLLLLSSLSSLLLx
10	DSDDSx	LSSLLLSSLSSLLLx	27	SSDSDx	LLLLLSSLLLSSx
11	DSDSDx	LSSLLLSSLLLSSx	28	SSDSSx	LLLLLSSLLLLLx
12	DSDSSx	LSSLLLSSLLLLLx	29	SSSDDx	LLLLLLLSSLSSLx
13	DSSDDx	LSSLLLLLSSLSSLx	30	SSSDSx	LLLLLLLSSLLLx
14	DSSDSx	LSSLLLLLSSLLLx	31	SSSSDx	LLLLLLLLLSSLx
15	DSSSDx	LSSLLLLLLLSSx	32	SSSSSx	LLLLLLLLLLLx
16	DSSSSx	LSSLLLLLLLLLx	IR	IRREGULAR	Irregular scan
17	SDDDDx	LLLSSLSSLSSLSSLx			

Table 4: Full metric patterns of hexameter

The compact metric profile is a table of six entries, each one giving the percentage of verses by which the 1st, 2nd, 3rd, 4th, 5th, or 6th foot, respectively, in the verses scan long-long (i. e., as a spondee) as opposed to scanning long-short-short (i. e., as a dactyl). The compact metric profile is hence built as defined in Table 5.

Foot id	Short descriptor	Description
01	S*****	spondee in 1st foot
02	*S****	spondee in 2nd foot
03	**S***	spondee in 3rd foot
04	***S**	spondee in 4th foot
05	****S*	spondee in 5th foot
06	*****S	scan of long-long in 6th foot

Table 5: Compact metric patterns

In Table 5:

- "Foot id" identifies the foot (from 1 to 6).
- "Short descriptor" and "Description" correspond to Foot id and show that the pattern has a spondee in the specific foot identified by "Foot id".

Note that in the compact profile, the table maintains the distinction between long-long and long-short in the last (6th) foot of the verse.

3.2 Profile comparison

Once metric profiles have been obtained for the works in scope, it is possible to compare profiles with one another. This can be done on a work-to-work level (e. g., comparison of metric profile of Iliad with metric profile of Odyssey) and on a work-to-part level (e. g., comparison of metric profile of individual Iliad Books with metric profile of the entire Iliad epic). The idea is the following: if metric profiles of two works or parts are found to be very similar, then one might consider assuming that they may have been written by the same author. For this idea, the metric profile is sometimes also thought to be a metric fingerprint (though one will not necessarily give it the same power of proof as, e. g., the fingerprint in criminology). Reversely, if metric profiles of two works are considerably different, one might think of assuming different authors for these works or parts. Whether any such conclusions can indeed be drawn, is outside the scope of judgement of the authors herein.

Within this context, Dactylo introduces a numeric value called the metric distance between two metric profiles. Metric distances have been introduced to help quickly identify works, whose metric profiles are specifically different from the profile of a reference work (larger values of metric distances) or whose metric profiles are specifically similar (smaller values).

3.3 Metric distance

The metric distance is a measurement value that reflects the degree of similarity, or of dissimilarity, between two compared metric profiles, or in other words, between the rhythmic preferences exhibited in these works. The metric distance of a work X under investigation, to a work B taken as base, is a number calculated using the formula:

$$\sqrt{\sum_{i=1}^{33} (x_i - b_i)^2}$$

where $[x_i]$ and $[b_i]$ are the relative frequencies of the i-th pattern within the works (with the irregular pattern picked at i=33). The formula hence calculates the differences of the percentages for all patterns, then squares that number (so as to make the value positive and to make large differences even larger and small differences even smaller), adds up these numbers to a total value and finally scales the result back by taking the square root. The result is a somewhat synthetic number whose actual numeric value is of limited natural meaning, but which can be useful for ordering (ranking) texts by their metric distances from reference texts.

4 Results and discussion

Dactylo provides collected statistical information across all works in the study, in terms of full metric profiles, compact metric profiles and mutual metric distances, solely regarding the

distribution of feet. In the current version, it finds the hexameter pattern for roughly 95% (Homer, Hesiod) to 98% (Apollonius) and 99% (Nonnus) of verses. Before some of this information is presented though, starting with the Dactylo's listings, the nature of failure rate or other irregularities should be firstly commented, considering irregular and multiple hexameter patterns.

4.1   Irregular patterns

Not being able to determine the hexameter scanning of a verse can have the following reasons:

- Incomplete scanning rules built into Dactylo, e. g., with respect to contraction.
- Scanning rules can also be used somewhat inconsistently by ancient authors. For example, in Iliad, the consonant sequence of {sk} at (or after) the end of a syllable will normally cause that syllable to scan long (positional lengthening due to two or more consonants following a vowel). However, if these consonants build the beginning of the name of the river "Skamandros" then the preceding syllable, if built on a short or anceps vowel, will scan short.
- For the epics of Homer (Iliad and Odyssey), research has pointed out for a long time that a number of verses reflect traces of Mycenaean Greek, i. e., a level of the Greek language that is much older than Classical Ancient Greek, and also much older than the Greek language (in any dialect) that was contemporary with Homer's days (approx. 700 BCE). If a verse does not validly scan as hexameter, then it might do so if Mycenaean forms of words, or elements of Mycenaean grammar, were restored to that verse. This is described in some detail in Joachim Latacz: "Troia und Homer" (Latacz 2010). For example, in Mycenaean Greek, some words or syllables used to start with a phoneme that sounded like /w/ which later disappeared in Greek, as a written sign. The Greek alphabet had a letter called DI-GAMMA (written similar to the Latin letter "F") to denote this phoneme. Some of Homer's verses that do not appear to comply with hexameter scanning rules, would turn into valid hexameters if DIGAMMA were re-introduced to words from which it had disappeared (Note: A separate thread of the Dactylo project – not yet documented here – deals more closely with identifying irregular verses in Homer's epics, and with applying "what-if" analysis that examines the results of re-introduction of Mycenaean levels of Greek language for certain words, for example, to see how the outcome is affected if "Ilios" is replaced by "Filios" – with leading DIGAMMA – in all verses where the word is found).
- Editions do also deviate in writing from one another, e. g., the word "ἐς" (preposition with accusative meaning "into", found in the Iliad edition used in this project) scans short, while the same word has been seen in its alternate form "εἰς" in the same place in another edition, scanning long (for centuries, the works had being copied by hand, even when prosodic features had disappeared and words had changed).
- Occasionally, verses have been encountered that are somewhat mis-edited on the web sites from which they have been downloaded for Dactylo, thus introducing errors in the hexameter scan.
- Where none of the above appears to apply, more sophisticated scanning rules are required that are not embedded in Dactylo.

The rate of verses, not validly scanned as hexameters by Dactylo, is in the 5% magnitude for Homer's and Hesiod's works, dropping to 2% for Argonautica and to 1% for Dionysiaca. The statistical base for calculation of metric profiles still appears broad enough, being in the 95% to 99% range of the verses for all works in the analysis. Further improving the Dactylo's hit rate will be subject to future work in the project, if determined to be valuable.

4.2   Multiple patterns

Another slight irregularity is the (rare) occurrence of verses for which Dactylo identifies more than one applicable hexameter pattern. According to the automated scanning, these verses can be pronounced as a hexameter in more than one way. For a number of these verses, it is probable that a trained human speaker might acknowledge only one way of scanning. An example of such a verse is the 3rd one in Rhapsody I of Iliad (IL01 0003):

<p style="text-align:center">πολλὰς δ᾽ ἰφθίμους ψυχὰς Ἄϊδι προΐαψεν</p>

which is scanned in Dactylo's internal transcript as:

- IL01 0003*MULT*pollas d iPTimoys SyKas ajdi projaSen*LLLLLSSLLLLSSLS
- IL01 0003*MULT*pollas d iPTimoys SyKas ajdi projaSen*LLLLLLLSSLSSLS

In the first of above lines, the words "ψυχὰς Ἄϊδι" (in the transformed text written as "SyKas ajdi") are scanned SSLLL, while in the second one they are scanned LLSSL. Both will deliver a valid, yet different, hexameter pattern to the full verse.

These multiple possible patterns is a symptom of shortcomings in Dactylo's scanning capabilities that can be judged by philologists, more competent in hexameter reading than the authors of this document. In the case of a verse with multiple matches, then for calculation of pattern statistics, Dactylo will pick the pattern that is generally more frequent in all of the works in the analysis, though this may not be the best choice in individual cases. For example, the above verse IL01 0003 will be assigned a match with Pattern id 27 (Table 4) and will count the scan as LLLLSSLLLSSLS, because across all works, 27 is encountered more frequently than 29 (the alternate and also preferable scan for this verse). A separate additional output file is created for these verses that lists all possible scans. The number of verses, for which Dactylo finds multiple applicable hexameter patterns, is small. In all of Iliad, 125 verses fall into that group, out of a statistical base of nearly 16,000.

4.3   Dactylo listings

The complete scanning results for the epics can be seen in a number of flat text files. Listings are available for the entire epic, as well as for the individual Books (or songs) that constitute the epic (except for Theogony, as it is a rather short work). The naming convention for the prefix portion of the names of the listings is described in Table 6.

The full file name is constructed by appending a suffix as per Table 7. For example, to inspect the scanning of all verses in Iliad, the listing to be consulted is IL_ALL_OUT_1RESULT.TXT. To review the metric profile of Book 10 (Rhapsody X) of Iliad, the listing to consult is IL10_OUT_4PROFILE.TXT.

Epic	Prefix	Content
Iliad	IL_ALL_OUT_	full Iliad (24 Books)
	ILnn_TR_OUT_	Book nn (from 01 to 24) of Iliad
Odyssey	OD_ALL_OUT	full Odyssey (24 Books)
	ODnn_TR_OUT_	Book nn (from 01 to 24) of Odyssey
(Hesiod)	HE_THEO_OUT_	Theogony
	HE_WORKS_OUT_	Works and Days
Argonautica	ARGO_ALL_OUT_	full Argonautica (4 Books)
	ARGO_nn_OUT_	Book nn (from 01 to 04) of Argonautica
Dionysiaca	DION_ALL_OUT_	full Dionysiaca (48 Books)
	DION_nn_OUT_	Book nn (from 01 to 48) of Dionysiaca

Table 6: Dactylo naming conventions for works

Suffix	Content	Comment
1RESULT.TXT	result listing	all verses along with either their scanning, or an indicator if not scanned correctly
2IRR.TXT	irregular verses	verses for which the valid scheme could not be determined
3DETAIL.TXT	internal diagnostics information	not currently provided for download
4PROFILE.TXT	hexameter profile	profile information in form of the *metric profile* as explained previously
5STAT.TXT	statistics	statistical information
6MULT.TXT	verses with multiple scannings	verses for which Dactylo finds more than one possible hexameter scanning
7BREV.TXT	verses with *brevis in arsi* rule	verses that show a formally short syllable at the position of the 5th half foot; the syllable is however scanned as long

Table 7: Text files produced by Dactylo

4.4   Full metric profiles per epic

In essence, this is a list of the relative frequencies of all 32 hexameter patterns (plus the irregular one) of the verses in these works under investigation (Table 8). The quoted numbers give the percentages of verses in the respective works that match with the pattern designated in the first and second column. In top-down reading, each of the columns shows the full metric profile of the corresponding work. In left-right reading, a comparison for a specific hexameter pattern is enabled between these works.

ID	PATTERN	ILIAD	ODYSSEY	HESIOD	PHAENO-MENA	ARGO-NAUTICA	POST-HOMER	DIONY-SIACA
01	DDDDDX	19.2	18.3	16.9	17.1	21.6	34.5	38.4
02	DDDDSX	1.1	0.88	1.1	3.7	2.5	3.2	0.047
03	DDDSDX	8.6	8.3	6.6	5	6.4	6.8	14.5
04	DDDSSX	0.35	0.38	0.38	0.43	0.017	0.056	0.018
05	DDSDDX	4.1	4	4	6.1	5.7	2.8	2.1
06	DDSDSX	0.22	0.18	0.54	0.87	0.67	0.11	0.009
07	DDSSDX	1.3	1.4	1.5	0.78	0.26	0.16	0.028
08	DDSSSX	0.051	0.041	0.11	0	0	0	0
09	DSDDDX	13.9	14.6	14.7	12.4	19.4	17.5	20.8
10	DSDDSX	0.7	0.78	0.86	3	2.2	1.5	0.042
11	DSDSDX	6.2	6.6	6	4.5	5.5	3.2	8.6
12	DSDSSX	0.3	0.24	0.27	0.17	0.034	0.068	0.009
13	DSSDDX	3	3.6	2.9	5.1	3.8	1.1	0.45
14	DSSDSX	0.18	0.25	0.32	0.61	0.36	0.056	0
15	DSSSDX	0.66	0.78	0.97	0.26	0.085	0.11	0.014
16	DSSSSX	0.076	0.016	0.053	0	0	0	0
17	SDDDDX	13.2	11.4	11.2	11.9	10.8	15.1	9.5
18	SDDDSX	0.92	0.84	0.76	2.9	1.3	1.2	0.004
19	SDDSDX	5.7	6.1	5.3	3.7	2.9	2.7	3.9
20	SDDSSX	0.2	0.26	0.43	0.17	0.017	0.011	0.009
21	SDSDDX	2.8	2.9	3	3.5	2.8	0.77	0.41
22	SDSDSX	0.13	0.099	0	0.35	0.34	0.045	0.004
23	SDSSDX	0.82	0.69	0.81	0.69	0.051	0.045	0.014
24	SDSSSX	0.019	0	0	0	0	0	0
25	SSDDDX	7.2	7.8	9.2	7.8	7.6	5.1	0.047
26	SSDDSX	0.48	0.47	0.38	1.6	1.1	0.49	0
27	SSDSDX	3.4	3.8	3.2	3	1.8	0.9	0.009
28	SSDSSX	0.11	0.14	0.27	0	0	0.011	0
29	SSSDDX	1.1	1.4	1.8	1.3	0.72	0.24	0

ID	PATTERN	ILIAD	ODYSSEY	HESIOD	PHAENO-MENA	ARGO-NAUTICA	POST-HOMER	DIONY-SIACA
30	SSSDSX	0.057	0.049	0.16	0.26	0.068	0	0
31	SSSSDX	0.28	0.31	0.49	0.17	0.051	0.011	0
32	SSSSSX	0.012	0.033	0	0	0	0	0
IR	IRREGULAR	3.7	3.5	5.5	2.5	2.1	2.2	1.1

Table 8: Full metric profiles per epic

Some noticeable observations are the following:

- As it can be seen from Table 8, pattern DDDDDX (called "holodactylic", namely consisting of all dactyls) appears to be the most frequent pattern, because of its much higher relative frequency in Dionysiaca (around 38%) than in any of the other works (around 17% to 21%).
- Pattern DSDDDX (just one spondee in the 2nd foot) holds the second rank in all works, again with highest share in Dionysiaca (around 20%), slightly ahead of Argonautica.
- Comparing Iliad and Odyssey columns, one finds very similar values for practically all hexameter patterns. By and large, the metric profiles of Iliad and Odyssey are the same.
- The Hesiod column is slightly, yet noticeably different from the profiles related to Homer, with Phaenomena and Argonautica again a bit more different, while Posthomerica and Dionysiaca columns show considerably different values.
- Noticeably also, pattern 25 (SSDDDX) that is very frequently used in the other works, is hardly encountered at all (only 0.032%) in Dionysiaca. Similarly, the frequencies for patterns 26 to 32 indicate a strong aversion, in Dionysiaca, against beginning a verse with two spondees. Only 9 (out of more than 21,000 verses) show two consecutive spondees at the beginning.
- Pattern SSSSSX (all spondee, also known as holospondaeus) is unfrequent, yet it does occur four times in Odyssey (thereof twice in Book 22), and twice in Iliad. No occurrence has been found in the other works.

Generally, Dionysiaca uses very few patterns to cover the vast majority of the verses. The top 5 patterns account for 92% of all Dionysiaca verses, followed by 79% in Posthomerica, while for all of the other works, the top 5 patterns cover around 60% of all verses ((a) in Table 9). Reversely, while Dionysiaca don't have any verses in its 10 least used patterns, the other works have several verses also in these patterns, with the older works (Homer and Hesiod) more than Phaenomena and Argonautica ((b) in Table 9).

Epic	(a): Top 5 in %	Epic	(b): Bottom 10 in %
Dionysiaca	91.8	Hesiod works	1.56
Posthomerica	79.0	Odyssey	1.05
Argonautica	65.8	Iliad	1.05
Iliad	62.1	Phainomena	1.03
Odyssey	60.4	Argonautica	0.17
Hesiod works	58.6	Posthomerica	0.12
Phaenomena	55.3	Dionysiaca	0.00

Table 9: Top and bottom patterns per epic

4.5 Compact metric profiles per epic

Table 10 shows the compact metric profiles of the works under investigation. It lists the relative frequencies, in percent, of occurrences of a spondee in each of the six feet of the hexameter scan of the verse. For this statistics, verses with irregular pattern are ignored; only validly scanned verses are taken into account. In top-down reading, each of the columns Iliad, Odyssey, Hesiod, Phaenomena, Argonautica, Posthomer(ica), and Dionysiaca show the compact metric profile of the work. In left-right reading, a comparison for a spondee in a specific position is enabled between these works.

Some noticeable observations:

- As expected, the foot that shows a spondee least frequently is foot 5 in all works. However, both Homer's and Hesiod's works show a spondee in foot 5 in approx. 5% to 6% of their verses, Argonautica and Posthomerica increase this to 7% to 9%, Phaenomena hold the top with nearly 15%, while Dionysiaca exhibit this behaviour extremely rarely (0.1% of verses).
- In foot 6, Homer's epics, Hesiod's texts, Phaenomena, Argonautica and Posthomerica don't seem to bother a lot about the formal length of the last syllable; it will roughly show a 50/50 mix.
- Dionysiaca is very different in that the last syllable is formally long in nearly 87% of verses. In contrast, Dionysiaca show a spondee very rarely in foot 1, foot 2, and foot 3, compared to the other works in analysis.

ID	PATTERN	ILIAD	ODYSSEY	HESIOD	PHAENO-MENA	ARGO-NAUTICA	POST-HOMER	DIONY-SIACA
01	SXXXXX	37.85	37.5	39.29	38.36	30.05	27.23	14.05
02	XSXXXX	39.1	42.23	44.08	41.2	43.45	30.99	30.29
03	XXSXXX	15.31	16.26	17.64	20.6	15.15	5.6	3.01

ID	PATTERN	ILIAD	ODYSSEY	HESIOD	PHAENO-MENA	ARGO-NAUTICA	POST-HOMER	DIONY-SIACA
04	XXXSXX	29.14	30.06	28.04	19.44	17.48	14.41	27.44
05	XXXXSX	5.12	4.83	5.99	14.47	8.75	6.79	0.14
06	XXXXXS	49.75	47.47	49.28	53.9	41.37	43.17	86.97

Table 10: Compact metric profiles per epic

4.6   Mutual metric distances

Table 11 gives the mutual metric distances (distances of full metric profiles) for the works in analysis, where values given are metric distances of the full metric profile of an epic, against the metric profile of a base work (given in the leftmost column).

BASE	Iliad	Odyssey	Hesiod	Phaenomena	Argonautica	Posthomer	Dionysiaca
ILIAD	0	2.5	4.7	7.6	8.4	17.4	23.8
ODYSSEY	2.5	0	3.6	7.5	8.2	18.7	24.5
HESIOD	4.7	3.6	0	7.3	8.9	20	26.7
PHAENOMENA	7.6	7.5	7.3	0	9.2	20	28.2
ARGONAUTICA	8.4	8.2	8.9	9.2	0	14.9	21.6
POSTHOMER	17.4	18.7	20	20	14.9	0	13.8
DIONYSIACA	23.8	24.5	26.7	28.2	21.6	13.8	0

Table 11: Mutal metric distances of epics

The numeric value of the metric distance is quite synthetic and does not carry much natural meaning, other than allowing to order works by their metric distances. Obviously, values around 2 are small distances, 4 and 8 appear still a "near" yet a bit larger distance, while works with considerably different metric profiles show distances beyond 20 (as a reminder here: the purpose of this numeric value is to compare and sort distances of different works against a base work).

Some noticeable observations:

- Table 11 appears to suggest that there is a group of works with the smallest mutual metric distances of less than 5, consisting of Iliad, Odyssey, and Hesiod's works. Iliad and Odyssey are the works that are closest to each other, in terms of metric profiles, with Hesiod very slightly different. Taking Odyssey as a base, Hesiod is only very slightly more distant than Iliad. However, that statistical base for Hesiod is small (less than 2,000 verses) so the numbers in the profiles related to Hesiod are less reliable than those for the other authors.

- Extending this group by Phaenomena and Argonautica gives a group of works with all mutual metric distances less than 10, whereby Phaenomena and Argonautica are no closer than 7 to any other work in the group.
- The rest of the works (Posthomerica and Dionysiaca) show a mutual metric distance of approx. 14, and are no closer than 15 (and up to 28) to any other work in the study. Dionysiaca is the work with biggest metric distances to other works in this study.

Based on metric distances, one would sort of group Iliad, Odyssey, and Hesiod's works in one group, then see Phaenomena and Argonautica in a second group, and finally Posthomerica and Dionysiaca in a third group. These groups would reflect very well the three periods of creation of these works.

4.7   Metric profiles of Iliad and Odyssey

It should be interesting to review the metric profiles of the 24 individual Iliad and 24 individual Odyssey Books, and compare them to the overall profile of the respective epic, taken across all 24 Books. Thus, one can identify Books that are considerably distant from the average and then examine whether this information correlates with current views on a single poet's ("Homer") authorship of these Books. To make identification easier of Books, whose metric profiles are particularly similar or dissimilar from the profile of the entire epic's average, Table 12 is presented below, including the metric distances of Books from the entire respective epic.

The Books of Iliad ((a) in Table 12) near the left top of its respective columns are most distant from the Iliad average ([IL_ALL = 0]), while the Books near the right bottom are most similar to the average. Similarly for Odyssey ((b) in Table 12), the metric distances of Books are compared to the average ([OD_ALL = 0]). Readers are kindly asked to remember that the numeric value of the metric distance is of no particular meaning in reality; it is just used for comparison (ranking) purposes.

Some noticeable observations:

- Of all Iliad's Books, Book 2 is the one whose profile differs most from the average Iliad's profile. For example, the relative frequency of the most frequent pattern (DDDDDX, meaning foot 1 through foot 5 are all dactyls) is only around 13.7%, as opposed to 18.9% of the entire Iliad's epic. The frequency for many of the other patterns is also noticeably different from the average profile. This may have to do with the ships' catalogue within Book 2, which includes many names of individuals and places that, to some degree, pre-determine the metric patterns of the verses where they appear.
- The profiles of Books 21, 19, 12, and 9 follow Book 2, in descending order, regarding their metric distance from the Iliad's average.
- In contrast, Book 10 shows a metric profile very similar to the average Iliad profile. This is noticeable as Book 10 is generally considered a later addition to the epic, not written by Homer (e. g., see the comment of Iliad's translation for Book 10 from Schadewaldt 1975: 158f.). So a bigger metric distance of the metric profile of Book 10 from Iliad's average would have been expected, while in fact it cannot be observed in the table of metric distances. If someone was to take metric profiles as being able to indicate identity or diversity

of authors (i. e., as metric fingerprints), the conclusion would be that Book 10 appears to have been written by the same author as most of the rest of Iliad.

- Odyssey Book 9 appears to be standing out a bit, in terms of differing from the average Odyssey's profile. With approx. 14%, it shows a remarkably low rate for pattern 01 (all dactyls). Also, Odyssey Book 9 shows an approx. 7.6% rate for the irregular pattern (i. e., verses whose hexameter scanning could not be determined by Dactylo), the by far highest rate among all the Books in this analysis.

(a): ILIAD [IL_ALL = 0]				(b): ODYSSEY [OD_ALL = 0]			
Book	Distance	Book	Distance	Book	Distance	Book	Distance
IL02	7.00	IL14	4.06	OD09	6.70	OD11	4.42
IL21	6.03	IL13	3.89	OD01	5.87	OD19	4.41
IL19	5.69	IL20	3.89	OD22	5.68	OD03	4.20
IL12	5.46	IL01	3.87	OD18	5.65	OD15	4.15
IL09	5.26	IL24	3.83	OD21	5.64	OD07	4.07
IL03	5.17	IL15	3.37	OD14	5.59	OD06	4.06
IL16	4.75	IL10	3.21	OD12	4.85	OD17	3.80
IL08	4.69	IL11	3.19	OD23	4.82	OD02	3.70
IL04	4.60	IL06	2.76	OD10	4.68	OD08	3.67
IL07	4.39	IL17	2.72	OD05	4.56	OD04	3.30
IL22	4.38	IL23	2.02	OD16	4.53	OD24	3.08
IL18	4.20	IL05	1.73	OD13	4.43	OD20	3.08

Table 12: Metric distances of Homeric Books

5   Conclusions

Dactylo has demonstrated its ability to produce statistics of hexameter's feet distribution in a massive scale, easily and very accurately. One outcome of the work described in this document is the full listing of all of the epics in the study, presenting all verses along with their feet distribution that have been determined through scanning, or with an indication if that pattern could not be determined. For Homer's works, it appears also interesting to establish and then to compare the profiles of the individual Books of the epics with the average profile of the epic. The next question (outside the scope of this document) would be to examine what conclusions can be drawn from similarities or dissimilarities of these profiles. For each of these statistics, some initial noticeable observations have been also listed. The authors would be interested in learning, from readers that would be interested in acquiring the full listing of statistics, about other interesting findings in the collected numbers, as well as of possible conclusions and/or explanations.

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