Examining the history of Voynich glyphs using phylogenetic methods

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Abstract

Paleographic analytical methods are used in dating manuscripts and discovering information about their geographic origins. The evolution of script traditions is well understood; for example, the features that separate Uncial from Carolingian, Gothic, Beneventan and Humanistic hands (among other traditions) include the shape of script glyphs, the use of serifs and ligatures, and the placement, use, and size of descenders. In this paper, we use phylogenetic network methods to identify manuscript clusters, based on features of the scripts, and compare them with glyphs used in the Voynich manuscript. Results indicate that the Voynich glyphs do not clearly cluster within any single tradition.

Keywords

Latin scripts, clustering, evolutionary methods, Voynich script, scribal hands

1. Introduction

Paleographic analytical methods [1] are used in dating manuscripts and discovering information such as geographic origins. The evolution of script traditions is well understood; for example, the features that separate Uncial from Carolingian, Gothic, Beneventan and Humanistic hands (among other traditions) include the shape of script glyphs, the use of serifs and ligatures, and the placement, use, and size of descenders. In this paper, we use phylogenetic network methods based on the features identified by paleographers to identify manuscript hand clusters, based on features of the scripts, and to use that information to shed light on the writing system of the Voynich manuscript (Beinecke Library MS 408). Phylogenetic methods for culture have been employed to study musical trends [2], language divergence [3], as well as other aspects of culturally transmitted information such as folk tales [4]. They are a flexible means of identifying clusters among items with shared histories and allow investigation of both the strength of clusters (that is, how well defined the cluster is) and which features in a dataset contribute to groupings.

This paper has two aims. The first is to examine the extent to which features traditionally used in paleographic analysis can clearly differentiate between script families across time. Can phylogenetic clustering methods distinguish between Gothic and Carolingian scripts, for example? Second, we use the information about the distribution of script features to identify the most likely origins of the Latin-like letters in the Voynich script. Evidence from parchment dating, along with general features of the Voynich manuscript place it clearly in the 15th Century [5], [6]. Anything we can learn about the manuscript and its characteristics is likely to be helpful in understanding its origins. Note that this paper makes no claim about

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decipherment, and in fact, we do not view these results as bearing in any way on likely form-sound correspondences. Our interest is purely in the *shapes* of the glyphs used in the Voynich writing system. We make no claim about the possible mappings of Voynich glyphs to either phonological systems or to plain-text orthographies [7].

We find that while these methods do allow discrimination between different script styles, they do not clearly place the Voynich script in any one tradition. While the Voynich script groups most closely with Uncial writing, we show that this is an artifact of the clustering method. We discuss the findings further in Section 4 below.

2. Methods and data

2.1. Manuscripts

For this initial proof of concept study, we examined 52 manuscripts, written between c. 700 and 1500, held in Yale University's Beinecke and Cushing Libraries. This was a sample of convenience but one which covers Humanistic; German, English, and Italian Gothic; Minuscule (Carolingian and Beneventan); and Uncial scripts. 30 manuscripts were written in Latin or copied from Latin sources, while the remaining manuscripts were in English, Italian, French, German, or Greek. We also separately coded the 5 Voynich hands identified by Davis [5]. A table of the manuscripts, their languages, dates, and script type is given in Table 1. While this is a sample of convenience, there are enough manuscripts to draw some tentative conclusions.[2]

Table 1
List of manuscripts

MS Title	Date	Style	Language(s)	Origin	MS Category	Link
Beinecke MS 528	900-1000	Beneventan minuscule	Latin	Italy	Religious	https://collections.library.yale.edu/catalog/10269766
Beinecke MS 484.15	990-1010	Beneventan minuscule	Latin	Southern Italy	Religious	https://collections.library.yale.edu/catalog/2004145
Beinecke MS 496	1000-1050	Beneventan minuscule	Latin	Southerin Italy	Religious	https://collections.library.yale.edu/catalog/9998841
Beincecke MS 1157	1075-1099	Beneventan minuscule	Latin	Italy	Lit	https://collections.library.yale.edu/catalog/11179095
Takamiya MS 71	1100-1125	Beneventan minuscule	Latin	Italy	Religious	https://collections.library.yale.edu/catalog/16687977
Marston MS 112	1100-1150	Beneventan minuscule	Latin	Southern Italy	Religious	https://collections.library.yale.edu/catalog/10269827
Beinecke MS 482.55	1200-1210	Beneventan minuscule	Latin	Southern Italy	Religious	https://collections.library.yale.edu/catalog/2004033
Beinecke MS 342	700-750	Carolingian minuscule, early	Latin	France	Religious	https://collections.library.yale.edu/catalog/10269797
Beinecke MS 389	800-900	Carolingian minuscule, early	Latin	Lyons, France	Religious	https://collections.library.yale.edu/catalog/2008129
Beinecke MS 442	875-900	Carolingian minuscule, early	Latin	Northern France	Religious	https://collections.library.yale.edu/catalog/2017751
Beinecke MS 808	1025-1050	Carolingian minuscule, late	Latin	Northern France	Legal/Treaty	https://collections.library.yale.edu/catalog/10958727
Takamiya MS 74	c. 1100	Carolingian minuscule, late	Latin	Italy	Religious	https://collections.library.yale.edu/catalog/16371246
Beinecke MS 729	1100-1150	Carolingian minuscule, late	Latin	Italy	Religious	https://collections.library.yale.edu/catalog/10613745
Beinecke MS 126	1150-1200	Carolingian minuscule, late	Latin	Italy	Religious	https://collections.library.yale.edu/catalog/2055233
Beinecke MS 700	1200-1300	Carolingian minuscule, late	Latin	Italy	Lit	https://collections.library.yale.edu/catalog/9998965
Osborn a1	1275-1299	English gothic	French/Latin/Middle English	Flanders, England	Religious	https://collections.library.yale.edu/catalog/11394852
Beinecke MS 556	1281	English gothic textualis libraria	Latin	England	Astrological	https://brbl-dl.library.yale.edu/vufind/Record/3444251

[2] We performed robustness checks (including bootstrapping the NeighborJoining tree and subsampling of datasets); these did not change the results.

Beinecke MS 220	1300-1310	English gothic textura	Latin	England	Astrological	https://brbl-dl.library.yale.edu/vufind/Record/3592306
Beinecke MS 86	1300-1400	English gothic anglicana	Anglo-Norman French	England	Legal/Treaty	https://collections.library.yale.edu/catalog/11684610
Beinecke MS 62	1391	English gothic secretary script	Latin	England	Legal/Treaty	https://collections.library.yale.edu/catalog/11684595
Takamiya MS 28	1400	English gothic	Middle English	England	Religious	https://collections.library.yale.edu/catalog/16371216
Takamiya MS 46	1400-1425	English gothic bookhand	Latin/Middle English	England	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/4340601
Beinecke MS 84	1400-1500	English gothic bookhand	Latin	England	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/3531430
Beinecke MS 163	1450	**English gothic anglicana**	Latin	England	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/3432728
Takamiya MS 59	**1450**	English gothic cursive bookhand	Middle English	England	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/4428086
Mellon MS 12	1450-1510	English gothic	Latin	England	Medical/Alchemical	https://collections.library.yale.edu/catalog/10935973
Takamiya MS 38	1461-1490	English gothic bookhand	Latin/Middle Engliish	England	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/4428073
Takamiya MS 33	**1475-1499**	**English gothic cursive**	Latin/Middle English	England	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/4428071
Beinecke MS 558	1500-1600	English gothic cursive	English/Latin	England	Astrological	https://brbl-dl.library.yale.edu/vufind/Record/3443765
Beinecke MS 337	**1526**	**English gothic secretatry script**	English	England	Astrological	https://brbl-dl.library.yale.edu/vufind/Record/3436758
Osborn fa7	1575-1600	English gothic cursive	English	England	Astrological	https://brbl-dl.library.yale.edu/vufind/Record/4183851
Beinecke MS 1058	1300-1400	German gothica textualis libraria	Latin	Germany	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/3791809
Beinecke MS 936	1385	German gothic cursive libraria/currens	German	Franconia, Germany	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/3443855
Mellon MS 9	1440	German gothic cursive	German/Latin/Arabic/Czech/Polish	Middle Europe, (Prague?)	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/4040549
Mellon MS 15	1475	German gothic cursive	Latin/German (Middle High)	Germany	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/3444910
Mellon MS 27	1536	German gothic cursive	Latin/German	Germany (Usedom, Pomerania)	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/3443934
Beinecke MS 482.57	1200-1210	Italian gothic littera textualis	Latin	Italy	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/3433100
Beinecke MS 1059	1355-1365	Italian gothic cursive currens	Latin	Florence (?), Italy	Astrological	https://brbl-dl.library.yale.edu/vufind/Record/3522127
Mellon MS 32	c. 1542	Italian gothic rotunda antiquior	Latin	Pisa (?), Northern Italy	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/3522126
Beinecke MS 967	1400	Italian humanist, early	Italian	Italy	Lit	https://collections.library.yale.edu/catalog/2013643
Mellon MS 21	1490	Italian humanist cursive	Latin/Italian	Padua (?), Italy	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/3592296
Beinecke MS 632	1400-1500	Italian southern gothica semitextualis libraria and humanistica cursiva libraria	Latin	Italy	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/3581449
Marson MS 7	1400-1410	Italian humanistic bookhand	Latin	Florence, Italy	Oration	https://collections.library.yale.edu/catalog/10171234
Beinecke MS 76	1450-1476	Italian humanistic bookhand	Italian	Italy	Medical/Alchemical	https://brbl-dl.library.yale.edu/vufind/Record/4762559
Beinecke MS 714	1450-1550	Italian humanist minuscule	Latin/Ancient Greek	Italy	Religious	https://collections.library.yale.edu/catalog/10636663
Beinecke MS 342	700-750	Uncial	Latin	France	Religious	https://collections.library.yale.edu/catalog/10269797

Beinecke MS 440	700	Uncial	Latin	Northern Italy	Religious	https://collections.library.yale.edu/catalog/10269759
Beinecke MS 484.3	800-833	Uncial	Latin	Northern Italy	Religious	https://collections.library.yale.edu/catalog/2004133
Beinecke MS 516	700-750	Uncial	Latin	Northumbria	Religious	https://collections.library.yale.edu/catalog/10269757
Osborn fa33	1393-1394	Italian semi-gothic bookhand	Italian	Italy	Lit	https://collections.library.yale.edu/catalog/10501281
Marson MS 7	1400-1410	Italian semi-gothic	Latin	Florence, Italy	Oration	https://collections.library.yale.edu/catalog/10171234
Marston MS 150	1400-1450	Italian semi-gothic cursive	Latin	Northern Italy or Southern France	Commentary	https://collections.library.yale.edu/catalog/10268435
Beinecke MS 408	c. 1420	unique orthography	??	??		

Script identifications were made by the first author, who has paleographic training; they were also checked by another expert. The library records of many manuscripts contain information about the script (that is, further script identification) which was in agreement with the identifications made here. That is, for each of the manuscripts, we have two or three independent identifications of the script tradition.

2.2. Glyphs and coding

Ten glyphs were coded: the Voynich glyphs which most resemble letters of the Latin[3] alphabet and Arabic numerals in common use:  [EVA 'e'],  [EVA iin],  [EVA 's'],  [EVA 'q'], [EVA 'd'], and  [EVA 'y']. Note that the EVA[4] transcription system is a conversion from Voynichese to Latin letters (for ease of machine readability) but is not a claim about what the Voynich letters actually represent. We match Voynich characters to their nearest Latin equivalent (hence matching with 'c' rather than with its EVA equivalent, 'e'). Because we are comparing glyph shapes with manuscripts written in the Latin alphabet, we cannot compare the most distinctive of Voynichese glyphs, such as the gallows ( ,  ,  , ) or combinations of benches and gallows (such as  or ).

Each *glyph* is coded for a range of features which collectively characterize the script. These features are known as 'characters' in the phylogenetics literature.[5] The features used here were chosen from manuscript studies and paleographical descriptions of scripts; that is, we use the features that paleographers use to analyze script traditions. A total of 110 characters were used. The characters are specific to each glyph (e.g. whether *a* has a ligature joining it to the preceding or following letter, whether it ascends above the midline, whether a foot serif is present, whether the glyph is laterally compressed (taller than it is wide); though some types of features apply to each glyph (e.g. the presence or absence or a ligature), others apply only to specific glyphs (such as whether "4" is written with an open "  " or closed "  " top. Each glyph contributes between 6 and 15 coded characters. Each *feature* is coded as "present", "absent" or "variable" (that is, both present and absent). For example, some glyphs always exhibit ligatures which join them to the following glyph (if present), while others never show this. In some cases, however, the ligature is sometimes present, but sometimes absent (and is coded as such). The features are given in Table 2 below. Features can refer to the *shape* of the letters, their *size*, the *ligatures,* or whether they contain head or foot *serifs.* Note that these

[3] We considered expanding the coding to other scripts with similar characters. To take a few examples, Greek ν resembles Voynich ; Cyrillic o resembles both Latin *o* and Voynich , and Syriac ܕ resembles . However, we restrict comparisons to the Latin alphabet because the Latin system has the greatest number of comparators.

[4] See http://www.voynich.nu/transcr.html under the heading Eva for further information.

[5] This is potentially confusing, since letters in a script are also often referred to as characters. To avoid confusion, in this paper, we only use the term in its phylogenetic meaning, as defined above. We call the letter shapes 'glyphs'.

characters are correlated; that is, the presence of a serif for *m* is likely to co-occur with the presence of a serif for *n*, for example.[6]

Table 2
Characters used in the analysis

Ligature Characters	Serif (and Shape) Characters	Shape Characters	Size Characters
A_lig_a_ ligature	A_serif_foot serif	M_shape_high joint	A_size_ascends above midline
A_lig__a ligature	C_serif_foot serif	N_shape_2 minims	A_size_double story
A_lig_no ligature	I_serif_head serif	N_shape_final "swash"	C_size_ascender
C_lig_c_ligature	I_serif_foot serif	N_shape_no "swash"	C_size_descender
C_lig__c ligature	I_serif_heavy serif	N_shape_left minim slant	I_size_ascender
C_lig_no ligature	M_serif_head serif	N_shape_shoulder	I_size_descender
I_lig_i_ligature	M_serif_foot serif	N_shape_diagonal crossbar	M_size_descender
I_lig__i ligature	N_serif_head serif	N_shape_high joint	M_size_ascends above midline
I_lig_no ligature	N_serif_foot serif	N_shape_right minim uptilt	M_size_right thickness
M_lig_m_ ligature	2_serif_foot serif	O_shape_heavy bottom left	M_size_left thickness
M_lig__m ligature	2_serif_head serif	O_shape_angularity	N_size_ascends above midline
M_lig_no ligature	4_serif_head serif	O_shape_slanted axis	N_size_descender
N_lig_n_ ligature	4_serif_foot serif	O_shape_lateral compression	O_size_ascender
N_lig__n ligature	A_shape_angular counter	2_shape_angular crest	O_size_descender
N_lig_no ligature	A_shape_uncial counter	2_shape_diagonal connector	2_size_ascender
O_lig_o_ligature	A_shape_counter closed	4_shape_open top	2_size_descender
O_lig__o ligature	A_shape_hooked	4_shape_apex form	4_size_ascender
O_lig_no ligature	A_shape_vertical stroke	4_shape_vertical stem	4_size_descender
2_lig_2_ligature	A_shape_lateral compression	4_shape_angular crotch	8_size_heavy bottom
2_lig__2 ligature	A_shape_downcurl	4_shape_single stroke	8_size_heavy top
8_lig_8_ligature	C_shape_angularity	8_shape_right slant	9_size_ascender
8_lig__8 ligature	C_shape_lateral compression	8_shape_left slant	9_size_descender
8_lig_No ligature	C_shape_ball terminal (head)	8_shape_smooth body	9_size_descender+arc
	C_shape_"uptick" head stroke	8_shape_single stroke	
M_shape_final "swash"	C_shape_thin mid-upper arc	8_shape_triangle form	9_shape_foot
M_shape_no "swash"	I_shape_vertical axis	8_shape_ovate	9_shape_closed counter
M_shape_vertical axis	I_shape_"uptick" head stroke	8_shape_vertical compression	9_shape_round loop
M_shape_shoulder	M_shape_3 minims	9_shape_loop stroke	9_shape_small loop

Figure 1 below shows a partial example of the coding table for the numeral 2. Characters were coded in a shared Google sheet and then converted to Nexus format (see, e.g., [8]) for analysis.

[6] Character independence is important for phylogenetic dating and methods that presuppose an evolutionary model (such as a Bayesian analysis with a covarion character evolution model). NeighborNet methods use only distances, not the character information directly. Correlations between characters will inflate distances between groups and could increase the appearance of discrete clusters

Glyph	2_ligature	_2 ligature	ascender	descender	foot serif	head serif	angular crest	diagonal connector
	0	0			0	0	0	0
-	-	-			-	-	-	-
-	-	-			-	-	-	-
-	-	-			-	-	-	-
-	-	-			-	-	-	-
-	-	-			-	-	-	-
-	-	-			-	-	-	-
	0	0			1	1	0	0
	0	0			1	1	0	0
	0	0			1	0	0	0
	0	0			0	1	0	0
	0	0			0	0	0	0
	0	0			1	0	1	1
	0	0			1	0	0	0
-	-	-			-	-	-	-

Figure 1: Example partial coding for the numeral 2.

2.3. Clustering

From the character codes, a pairwise distance matrix was then calculated. This distance matrix lets us see how similar (or different) each manuscript hand is from others in the dataset. Many distance-based clustering methods are available to visualize the relationships between elements in a dataset. A common clustering method is a simple pairwise agglomerative method that pairs the two most similar manuscripts with each other, fuses that node, and takes the mean distance between those two manuscripts and the next closest manuscript to derive a dendrogram. Such methods are useful to gain a sense of the manuscripts that are most similar to one another, but they tend to be misleading if the data are complex.

For this reason, we use neighbor nets [9] as an alternative. Neighbor Nets are a pairwise agglomerative hierarchical clustering method which allows for missing features. The neighbor-joining algorithm clusters by minimizing the distance between each pair, while maximizing the distance between the pair and other characters (unlike the simple pairwise method described in the previous paragraph, which agglomerates the two closest items regardless of their distance from other elements in the dataset). Neighbor-joining thus tends to group together the items that are most distinctive. A Neighbor-network uses the neighbor-joining algorithm but with the difference that when nodes are paired, they are not immediately agglomerated. Nodes can therefore be paired several times, rather than with a single neighbor. The result is a network which illustrates conflicting classification. Where the dataset has little conflicting signal, the result is very treelike. Where there are conflicting classifications, however, Neighbornets are a useful visualization tool (as unlike in tree representations, one can see where a tree is or is not a good fit for the data).

3. Results

3.1. Neighbor Net

Figure 2 shows results from the full dataset, including the five Voynich hands. The labels have a tripartite structure: ms number _ script type (per manuscript identification) _ century of

copying/composition. As can be seen here, some script types clearly cluster (Uncial, Beneventan Minuscule, Carolingian), while others cluster more loosely (Gothic, Humanistic). There is a cluster of German Gothic manuscripts, but English Gothic manuscripts show more variation. While the Voynich hands most closely cluster with Uncial manuscripts, this is probably because both Voynichese and Uncial scripts are quite different from the other scripts here; their similarities stem from the absence of features present in the other scripts. We investigate this further below.

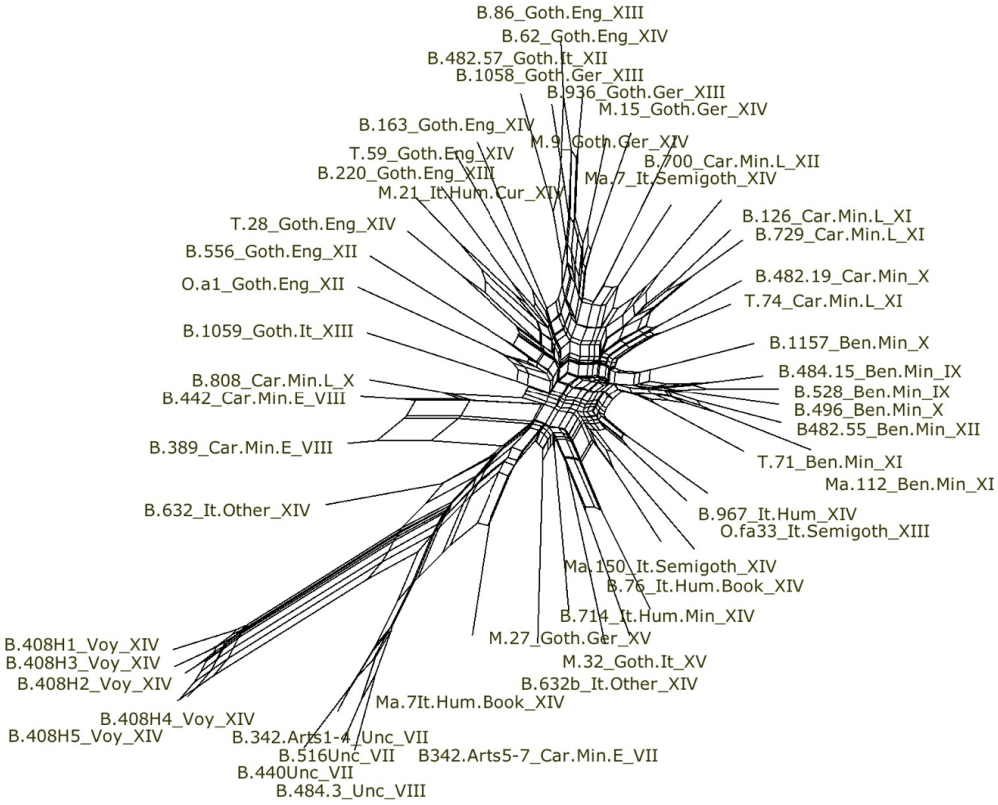

Figure 2: NeighborNet of manuscript clusters

3.2. Types of script characters

In order to investigate the contribution of different types of features to the classification, we plot the values of each set of characters (ligatures, size, shape, and serif characteristics) separately. Figure 3 shows different types of features; size, shape, ligatures, and serifs. Each manuscript appears on the y axis, and the x-axis is the percentage of features of that type attested in the manuscript, multiplied by 10 (for greater ease of viewing and to standardize the scale). So, a manuscript with 0 has no attestation of the feature; one with 10 has every instance of the feature. In practice, a number of these features are variable in manuscripts, or the feature is found for some characters but not others. This gives a range of values which makes the manuscripts (or manuscript hands) distinctive. Voynich hands are at the top of each diagram (in pink), followed by Uncial and the remaining script types in reverse alphabetical order.[7]

All the Voynich hands cluster closely together and differ minimally along the parameters which were coded in this analysis; this is especially apparent from Figure 3. They differ somewhat by serifs, with Hand 5 using fewer serifs than the Voynichese average, and

[7] Due to limitations of space, the panels in Figure 3 are side by side, which renders the manuscript names illegible. However, the individual manuscripts are less important than the overall concentration of values of manuscripts from the same script tradition, and their similarity to the Voynich hands,

Hand 2 using more. Davis' [5] identification of hand differences did not use features that are coded here, the distinction in hands resting on other glyphs or on general features of the hand, such as how spread out the glyphs are. Voynich glyphs have fewer serif features than any of the other scripts in the analysis, one of the features that makes them cluster distinctively in the network in Figure 2 above. Voynich hands have fewer ligatures than the other scripts, with the exception of Uncial scripts. This perhaps suggests that Voynich Latin characters are not drawn from a single script tradition, but rather take features from several.

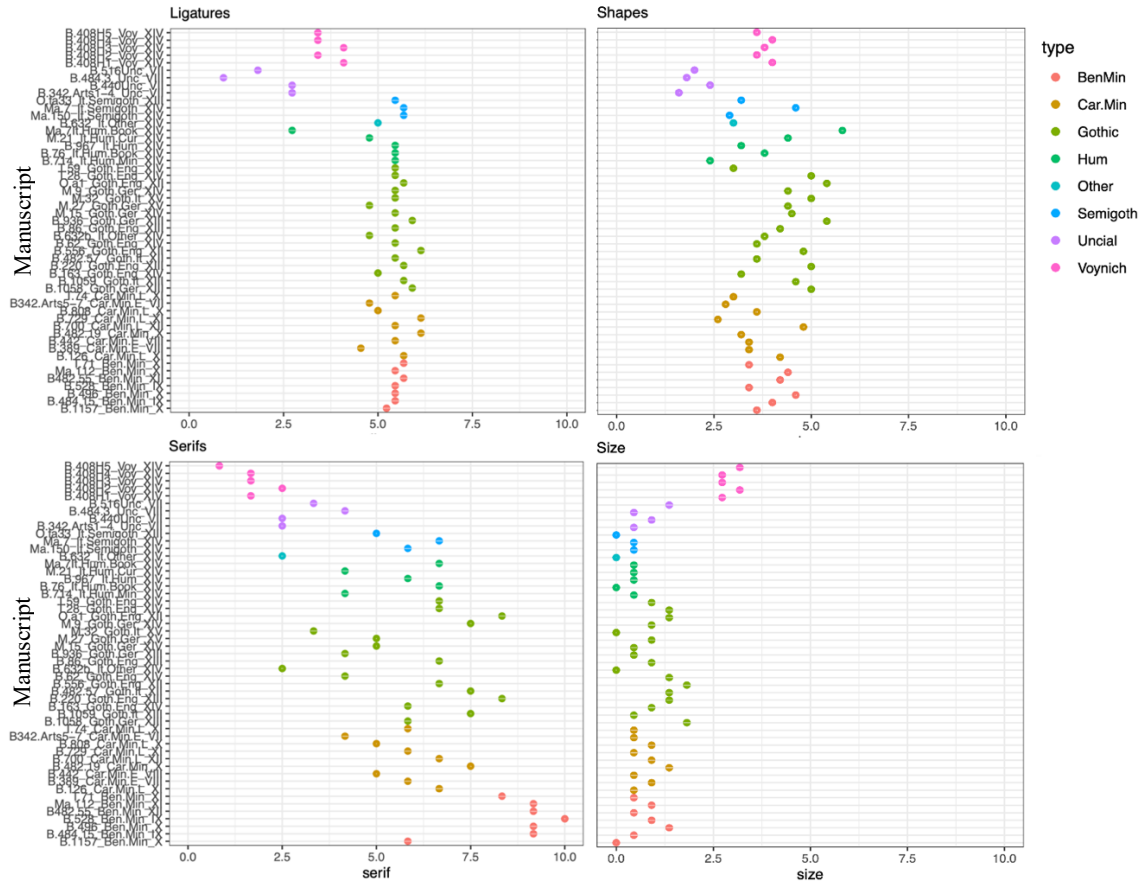

Figure 3: Similarities by feature type

In terms of shape features, Voynich hands appear to be closest to the Beneventan minuscule scripts, while for size features, Voynich glyphs do not overlap with any other script in totality of features.

Space precludes a detailed investigation of individual glyphs. The letters "m" and "n" appear to cluster closely with Uncial variants; "i" is distinct from all other scripts in the sample. The numerals vary more within and between script traditions than the letters do (perhaps unsurprisingly, given that the script traditions are based on the shapes of letters rather than numerals.

4. Conclusions

In conclusion, the features used in manuscript studies can (unsurprisingly) distinguish between manuscript traditions. The Voynich manuscript groups closest to the Uncial tradition, but this is driven by the absence of serifs and the relative lack of use of ligatures; it is not driven by size or shape characteristics. On those grounds, the Voynich hands do not clearly group with

any single tradition, though in shape characteristics it is closest to Beneventan hands. Voynich hands are internally quite consistent on these features. It may be that the features which most distinctively characterize manuscript hands are found in glyphs other than those investigated here.

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