

What We Know About The Voynich Manuscript

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Abstract

The Voynich Manuscript is an undeciphered document from medieval Europe. We present current knowledge about the manuscript's text through a series of questions about its linguistic properties.

1 Introduction

The Voynich manuscript, also referred to as the VMS, is an illustrated medieval folio written in an undeciphered script.

There are several reasons why the study of the manuscript is of interest to the natural language processing community, besides its appeal as a long-enduring unsolved mystery. Since even the basic structure of the text is unknown, it provides a perfect opportunity for the application of unsupervised learning algorithms. Furthermore, while the manuscript has been examined by various scholars, it has much to benefit from attention by a community with the right tools and knowledge of linguistics, text analysis, and machine learning.

This paper presents a review of what is currently known about the VMS, as well as some original observations. Although the manuscript raises several questions about its origin, authorship, the illustrations, etc., we focus on the *text* through questions about its properties. These range from the level of the letter (for example, *are there vowels and consonants?*) to the page (*do pages have topics?*) to the document as a whole (*are the pages in order?*).

* This work was completed while the author was visiting the Information Sciences Institute.

2 Background

2.1 History

From the illustrations – hairstyles and features of the human figures – as well as the shapes of the glyphs, the manuscript is posited to have been created in Europe. Carbon-dating at the University of Arizona has found that the vellum was created in the 15th century, and the McCrone Research Institute has asserted that the ink was added shortly afterwards¹.

The exact history of the VMS is not established. According to Zandbergen (2010), the earliest owner that it can be traced to is Jacobus de Tepenec in Prague in the early 1600s. It is speculated that it was given to him by Emperor Rudolf II, but it is unclear how and from where the manuscript entered Prague.

The VMS appears to have circulated in Prague for some time, before being sent to Athanasius Kircher in Italy in 1665. It remained in Italy until 1912, when it was sold to Wilfrid Voynich, who brought it to America. It was then sold to the bookdealer Kraus, who later donated it to the Yale University library², where it is currently housed.

2.2 Overview

The manuscript is divided into *quires* – sections made out of folded parchment, each of which consists of *folios*, with writing on both sides of each folio (Reeds, 2002). Including blank pages and pages with no text, there are 240 pages, although it is believed that some are missing (Pelling, 2006). 225

¹These results are as yet unpublished. A paper about the carbon-dating experiments is forthcoming in 2011.

²High-resolution scans are available at <http://beinecke.library.yale.edu/digitalibrary/voynich.html>

pages include text, and most are illustrated. The text was probably added after the illustrations, and shows no evidence of scratching or correction.

The text is written left to right in paragraphs that are left-aligned, justified, and divided by whitespace into words. Paragraphs do not span multiple pages.

A few glyphs are ambiguous, since they can be interpreted as a distinct character, or a ligature of two or more other characters. Different transcriptions of the manuscript have been created, depending on various interpretations of the glyphs. We use a machine-readable transcription based on the alphabet proposed by Currier (1976), edited by D’Imperio (1980) and others, made available by the members of the Voynich Manuscript Mailing List (Gillogly and Reeds, 2005) at <http://www.voynich.net/reeds/gillogly/voynich.now>. The Currier transcription maps the characters to the ASCII symbols A-Z, 0-9, and *. Under this transcription, the VMS is comprised of 225 pages, 8114 word types, and 37919 word tokens. Figure 1 shows a sample VMS page and its Currier transcription.

2.3 Manuscript sections

Based on the illustrations, the manuscript has traditionally been divided into six sections: (1) *herbal*, containing drawings of plants; (2) *Astronomical*, containing zodiac-like illustrations; (3) *Biological*, mainly containing drawings of female human figures; (4) *Cosmological*, consisting of circular illustrations; (5) *Pharmaceutical*, containing drawing of small containers and parts of plants, and (6) *Stars* (sometimes referred to as *Recipes*), containing very dense text with drawings of stars in the margins.

Currier (1976) observed from letter and substring frequencies that the text is comprised of two distinct ‘languages’, A and B. Interestingly, the Biological and Stars sections are mainly written in the B language, and the rest mainly in A.

Using a two-state bigram HMM over the entire text, we find that the two word classes induced by EM more or less correspond to the same division – words in pages classified as being in the A language tend to be tagged as one class, and words in B language pages as the other, indicating that the manuscript does indeed contain two different vocabularies (which may be related languages, dialects, or simply different textual domains). In Figure 2, we

Figure 1: Page *f81v* (from the Biological section).



(a) Scan of page

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BAR ZC9 FCC89 ZCF AE 8AE 8AR OE BSC89 ZCF 8AN
OV AE ZCF9 40FC89 OFAM FAT OF AE 2AR OE FAN
OEFAN AE OE ROE 8E 2AM 8AM OEFCC89 OFC89 89FAN
ZCF S89 8AE AE OE89 40FAM OFAN SCCF9 89 OE FAM
8AN 89 8AM SX9 OFAM 8AM OPAN SX9 OFCC89 40F9
FAR 8AM OFAR 40FAN OFAM OE SC89 SCOE EF9 E2
AM OFAN 8AE89 OEOR OE ZCX AE 8AM 40FC8 AE 8AM
SX9 2SC89 4OE 9FOE OR ZC89 ZCC89 4OE FCC89 8AM
8FAN WC89 OE89 9AR OESC9 FAM OFCC9 8AM OEOR
SCX9 8AII89
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BOEZ9 OZ9PCC8 4OB OFCC89 OPC89 OFZC89 4OP9
8ATAJ OZC9 40FCC9 OFCC9 OF9 9FCC9 4OF9 OF9EF9
OES9 F9 8ZOE98 4OE OE S89 ZC89 40FC89 9PC89
SCPC89 EFC8C9 9PC89 9FCC2C9 8SC8 9PC89 9PC89
8AR 9FC8A IB*9 4OP9 9FC89 OF AE 8ZC89 9FCC89
C2CCF9 8AM OFC89 40FCC8 40FC89 ESBS89 40FAE
SC89 OE ZCC9 2AEZQ89 4OVSC89 R SC89 EPAR9
EOR ZC89 4OCC89 OE S9 RZ89 EZC89 8AR S89
BS89 2ZFS89 SC89 OE ZC89 4OESC89 4OFAN ZX9 8E
RAE 40FS89 SC9 OE SCF9 OE ZC89 40FC89 40FC89
SX9 4OF9 2OEFCC9 OE ZC89 4OFAR ZCX9 8C2C89
4OFAR 40FAE 8OE S9 4OQC9 SCFAE SO89 40FC89
EZCP9 4OE89 EPC89 4OPAN EZO 40FC9 EZC89 EZC89
SC89 4OEF9 ESC8AE 4OE OPAR 40FAE 4OE OM SCC9
8AE EO*C89 ZC89 2AE SPC89PAR ZOE 4CF S9 9FAM
OEFAN ZC89 4OF9 8SC89 ROE OE Q89 9PC9 OFSC89
40FAE OFCC9 4OE SCC89 2AE PCOE 8S89 E9 OZC89
40PC89 ZOE SC89 9ZSC9 OE SC9 4OE SC89 PS8 OF9
OE SC89 PAR OM OFC89 8AE ZC9 OEFCOE OEFC889
OF89 8ZCOE O3 OEFCC89 PC89 SCF9 ZXC89 SAE
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OPON OEFOE

(b) Transcription in the Currier alphabet. Paragraph (but not line) breaks are indicated.

illustrate the division of the manuscript pages into the six sections, and show the proportion of words in each page that are classified as the B language.

For coherence, all our experimental results in the rest of this paper are on the B language (which we denote by VMS B) – specifically, the Biological and Stars sections – unless otherwise specified. These sections together contain 43 pages, with 3920 word types, 17597 word tokens, and 35 characters. We compare the VMS’s statistical properties with three natural language texts of similar size: the first 28551 words from the English Wall Street Journal Corpus, 19327 words from the Arabic Quran (in Buckwalter transcription), and 18791 words from the Chinese Sinica Treebank.

3 The Letter

3.1 Are vowels and consonants represented?

If a script is alphabetic, i.e., it uses approximately one character per phoneme, vowel and consonant characters can be separated in a fully unsupervised way. Guy (1991) applies the vowel-consonant separation algorithm of (Sukhotin, 1962) on two pages of the Biological section, and finds that four characters (o, a, c, g) separate out as vowels. However, the separation is not very strong, and several words do not contain these characters.

Another method is to use a two-state bigram HMM (Knight et al., 2006; Goldsmith and Xanthos, 2009) over letters, and induce two clusters of letters with EM. In alphabetic languages like English, the clusters correspond almost perfectly to vowels and consonants. We find that a curious phenomenon occurs with the VMS – the last character of every word is generated by one of the HMM states, and all other characters by another; i.e., the word grammar is a^*b .

There are a few possible interpretations of this. It is possible that the vowels from every word are removed and placed at the end of the word, but this means that even long words have only one vowel, which is unlikely. Further, the number of vowel types would be nearly half the alphabet size. If the script is a syllabary or a logograph, a similar clustering will surface, but given that there are only 35 characters, it is unlikely that each of them represents a syllable or word. A more likely explanation is that the script is an abjad, like the scripts of Semitic lan-

guages, where all or most vowels are omitted. Indeed, we find that a 2-state HMM on Arabic without diacritics and English without vowels learns a similar grammar, a^*b^+ .

3.2 Do letters have cases?

Some characters (F, B, P, V) that appear mainly at paragraphs beginnings are referred to ‘gallows’ – glyphs that are taller and more ornate than others. Among the glyphs, these least resemble Latin, leading to the belief that they are null symbols, which Morningstar (2001) refutes.

Another hypothesis is that gallows are uppercase versions of other characters. We define $\text{BESTSUB}(c)$ to be the character x that produces the highest decrease in unigram word entropy when x is substituted for all instances of c . For English uppercase characters c , $\text{BESTSUB}(c)$ is the lowercase version. However, BESTSUB of the VMS gallows is one of the other gallows! This demonstrates that they are not uppercase versions of other letters, and also that they are contextually similar to one another.

3.3 Is there punctuation?

We define punctuation as symbols that occur only at word edges, whose removal from the word results in an existing word. There are two characters that are only found at the ends of words (Currier κ and \perp), but most of the words produced by removing κ and \perp are not in the vocabulary. Therefore, there is most likely no punctuation, at least in the traditional sense.

4 The Word

4.1 What are the word frequency and length distributions?

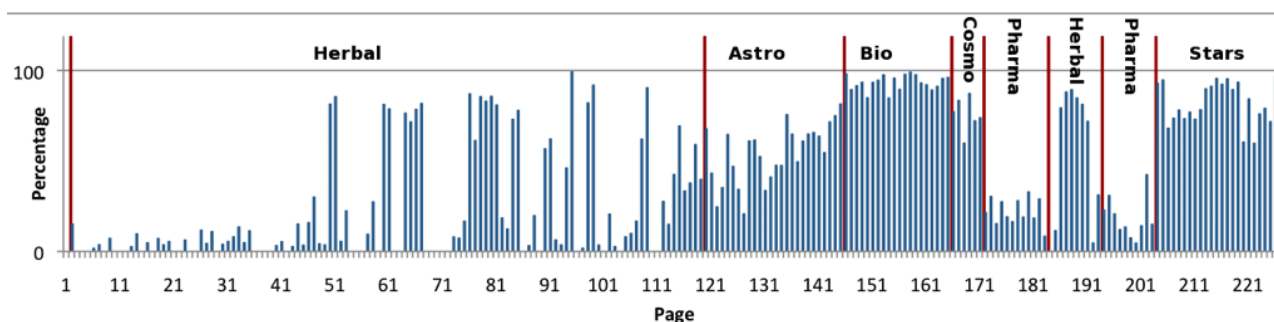
The word frequency distribution follows Zipf’s law, which is a necessary (though not sufficient) test of linguistic plausibility. We also find that the unigram word entropy is comparable to the baseline texts (Table 1).

Table 1: Unigram word entropy in bits.

VMS B	English	Arabic	Chinese
9.666	10.07	9.645	10.31

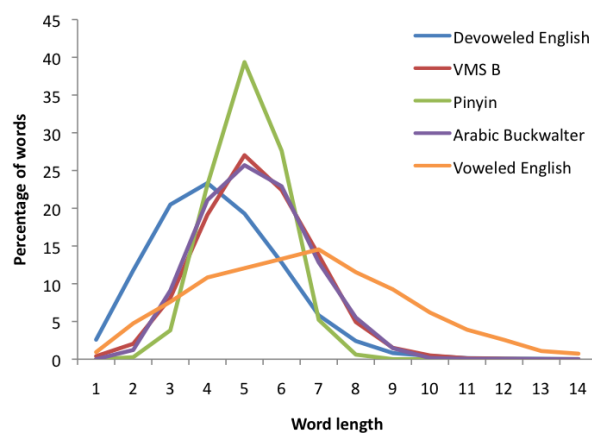
Several works have noted the narrow binomial distribution of word lengths, and contrasted it with

Figure 2: VMS sections, and percentage of word tokens in each page that are tagged as language B by the HMM.



the wide asymmetric distribution of English, Latin, and other European languages. This contributed to speculation that the VMS is not a natural language, but a code or generated by some other stochastic process. However, Stolfi (2005) show that Pinyin Chinese, Tibetan, and Vietnamese word lengths follow a binomial distribution, and we found (Figure 3) that certain scripts that do not contain vowels, like Buckwalter Arabic and devoeled English, have a binomial distribution as well.³ The similarity with devoeled scripts, especially Arabic, reinforces the hypothesis that the VMS script may be an abjad.

Figure 3: Word length distributions (word types).



Landini (2001) found that the VMS follows Zipf’s law of word lengths: there is an inverse relationship between the frequency and length of a word.

³This is an example of why comparison with a range of languages is required before making conclusions about the language-like nature of a text.

4.2 How predictable are letters within a word?

Bennett (1976) notes that the second-order entropy of VMS letters is lower than most European languages. Stolfi (2005) computes the entropy of each character given the left and right contexts and finds that it is low for most of the VMS text, particularly the Biological section, compared to texts in other languages. He also ascertains that spaces between words have extremely low entropy.

We measure the *predictability* of letters, and compare it to English, Arabic, and Pinyin Chinese. Predictability is measured by finding the probabilities over a training set of word types, guessing the most likely letter (the one with the highest probability) at each position in a word in the held-out test set, and counting the proportion of times a guess is correct. Table 2 shows the predictability of letters as unigrams, and given the preceding letter in a word (bigrams). VMS letters are more predictable than other languages, with the predictability increasing sharply given the preceding contexts, similarly to Pinyin.

Table 2: Predictability of letters, averaged over 10-fold cross-validation runs.

	VMS B	English	Arabic	Pinyin
Bigram	40.02%	22.62%	24.78%	38.92%
Unigram	14.65%	11.09%	13.29%	11.20%

Zandbergen (2010) computes the entropies of characters at different positions in words in the Stars section, and finds that the 1st and 2nd characters of a word are more predictable than in Latin or Vulgate, but the 3rd and 4th characters are less predictable.

It has also been observed that word-final characters have much lower entropy compared to most other languages – some characters appear almost exclusively at the ends of words.

4.3 Is there morphological structure?

The above observations suggest that words are made up of morpheme-like chunks. Several hypotheses about VMS word structure have been proposed. Tiltman (1967) proposed a template consisting of roots and suffixes. Stolfi (2005) breaks down the morphology into ‘prefix-midfix-suffix’, where the letters in the midfixes are more or less disjoint from the letters in the suffixes and prefixes. Stolfi later modified this to a ‘core-mantel-crust’ model, where words are composed of three nested layers.

To determine whether VMS words have affixal morphology, we run an unsupervised morphological segmentation algorithm, Linguistica (Goldsmith, 2001), on the VMS text. The MDL-based algorithm segments words into prefix+stem+suffix, and extracts ‘signatures’, sets of affixes that attach to the same set of stems. Table 3 lists a few sample signatures, showing that stems in the same signature tend to have some structural similarities.

Table 3: Some morphological signatures.

Affixes	Stems
OE+, OP+, null+	A3 AD AE AE9 AEOR AJ AM AN AR AT E O O2 OE OJ OM ON OR SAJ SAR SCC9 SCCO SCO2 SO
OE+	BSC28 BSC9 CCC8 COC8CR FAE0E FAK FAU FC8 FC8AM FCC FCC2 FCC9R FCCAE FCCC2 FCCCAR9 FCO9 FCS9 FCZAR FCZC9 OEAR9 OESC9 OF9 OR8 SC29 SC890 SC8R SCX9 SQ9
+89, +9, + C89	4OFCS 4OF CZ 4OFZ 4OPZ 8AES 8AEZ 9FS 9PS EFCS FCS PS PZ OEF S OF OFAES OFCS OFS OFZ

5 Syntax

5.1 Is there word order?

One of the most puzzling features of the VMS is its weak word order. Notably, the text has very few repeated word bigrams or trigrams, which is surprising given that the unigram word entropy is comparable to other languages. Furthermore, there are sequences of two or more repeated words, or repetitions of very similar words. For example, the

first page of the Biological section contains the line
40FCC89 40FCC89 40FC89 40FC89 40FCC89 E89.

We compute the predictability of a word given the previous word (Table 4). Bigram contexts only provide marginal improvement in predictability for the VMS, compared to the other texts. For comparison with a language that has ‘weak word order’, we also compute the same numbers for the first 22766 word tokens of the Hungarian Bible, and find that the *empirical* word order is not that weak after all.

Table 4: Predictability of words (over 10-fold cross-validation) with bigram contexts, compared to unigrams.

	Unigram	Bigram	Improvement
VMS B	2.30%	2.50%	8.85%
English	4.72%	11.9%	151%
Arabic	3.81%	14.2%	252%
Chinese	16.5%	19.8%	19.7%
Hungarian	5.84%	13.0%	123%

5.2 Are there latent word classes?

While there are very few repeated word bigrams, perhaps there are latent classes of words that govern word order. We induce ten word classes using a bigram HMM trained with EM (Figure 4). As with the stems in the morphological signatures, the words in each class show some regularities – although it is hard to quantify the similarities – suggesting that these latent classes are meaningful.

Currier (1976) found that some word-initial characters are affected by the word-final characters of the immediately preceding word. He concludes that the ‘words’ being syllables or digits would explain this phenomenon, although that is unlikely given the rarity of repeated sequences.

We redo the predictability experiments of the previous section, using the last m letters of the previous word to predict the first n letters of the current word. When $n > 2$, improvement in predictability remains low. However, when n is 1 or 2, there is a noticeable improvement when using the last few characters of the previous word as contexts (Table 5).

5.3 Are there long-distance word correlations?

Weak bigram word order can arise if the text is scrambled or is generated by a unigram process. Alternately, the text might have been created by inter-

Figure 6: TF-IDF visualization of page *f108v* in the Stars section.

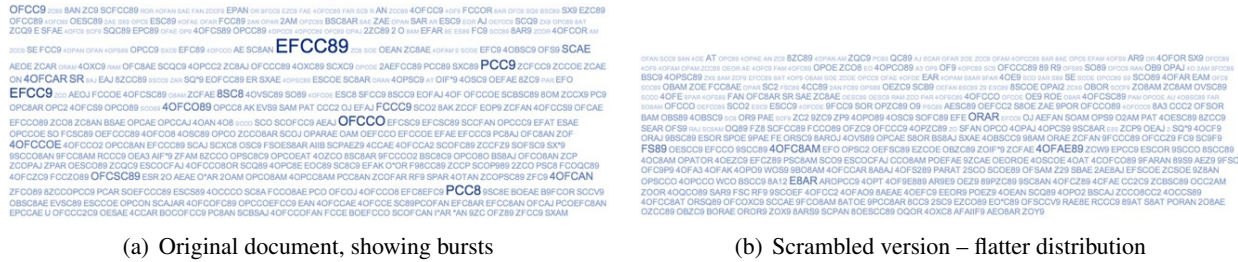


Table 6: Strength of page topics in VMS and other texts, cropped to be of comparable length to the VMS.

	VMS	English	English	Arabic
	B	WSJ	Genesis	Quran
T	7.5	6.3	6.6	7.7
T_{rand}	7.7	6.5	7.1	7.9
$1 - T/T_{rand}$	0.033	0.037	0.069	0.025

is a functional entity” – that is, there are patterns to lines on the page that are uncharacteristic of prose. In particular, certain characters or sequences appear almost exclusively at the beginnings or ends of lines.

Figure 7 shows the distribution of characters at line-edges, relative to their occurrences at word beginnings or endings, confirming Currier’s observation. It is particularly interesting that lower-frequency characters occur more at line-ends, and higher-frequency characters at the beginnings of lines.

Schinner (2007) found that characters show long-range correlations at distances over 72 characters, which is a little over the average line length.

7 The Document

7.1 Are the pages in order?

We measure the similarity between two pages as the cosine similarity over bags of words, and count the proportion of pages P_i where the page P_{i-1} or P_{i+1} is the most similar page to P_i . We denote this measure by ADJPAGESIM. If ADJPAGESIM is high, it indicates that (1) the pages are not independent of each other and (2) the pages are in order.

Table 7 shows ADJPAGESIM for the VMS and other texts. As expected, ADJPAGESIM is close to zero for the VMS with pages scrambled, as well as the WSJ, where each page is an independent article,

and is highest for the VMS, particularly the B pages.

Table 7: ADJPAGESIM for VMS and other texts.

VMS B	38.8%
VMS All	15.6%
VMS B pages scrambled	0%
VMS All pages scrambled	0.444%
WSJ	1.34%
English Genesis	25.0%
Arabic Quran	27.5%

This is a convincing argument for the pages being mostly in order. However, the non-contiguity of the herbal and pharmaceutical sections and the interleaving of the A and B languages indicates that larger chunks of pages were probably re-ordered. In addition, details involving illustrations and ink-transfer across pages point to a few local re-orderings (Pelling, 2006).

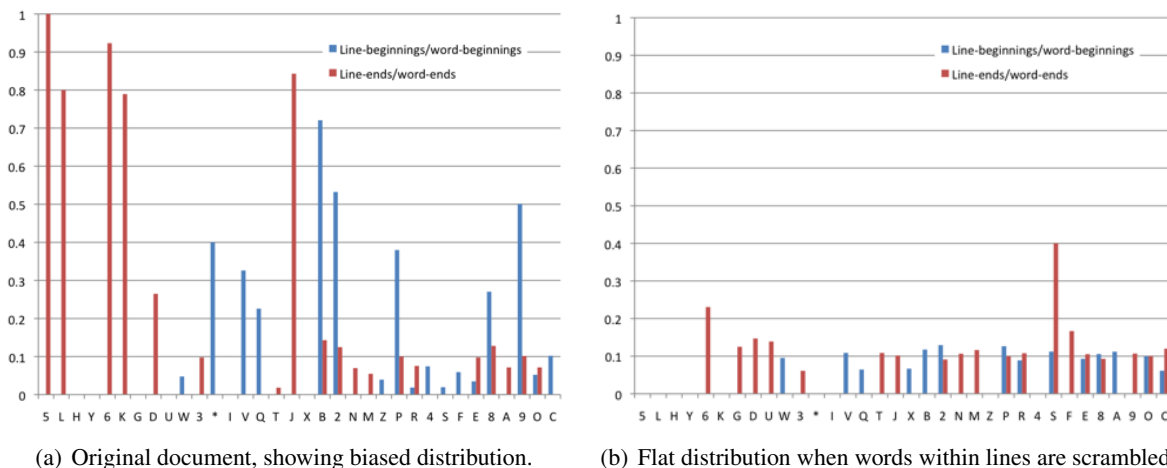
7.2 How many authors were involved?

Currier (1976) observed that the distinction between the A and B languages corresponds to two different types of handwriting, implying at least two authors. He claimed that based on finer handwriting analysis, there may have been as many as eight scribes.

8 Latin, Cipher, or Hoax?

Claims of decipherment of the VMS script have been surfacing for several years, none of which are convincing. Newbold (1928) believed that microscopic irregularities of glyph edges correspond to anagrammed Latin. Feely in 1943 proposed that the script is a code for abbreviated Latin (D’Imperio, 1980). Sherwood (2008) believes that the words are coded anagrams of Italian. Others have hypo-

Figure 7: Proportion of word-edge characters at line-edges for lines that span the width of the page. Characters are in ascending order of their total frequencies.



esized that the script is an encoding of Ukrainian (Stojko, 1978), English (Strong, 1945; Brumbaugh, 1976), or a Flemish Creole (Levitov, 1987). The word length distribution and other properties have invoked decodings into East Asian languages like Manchu (Banasik, 2004). These theories tend to rely on arbitrary anagramming and substitutions, and are not falsifiable or well-defined.

The mysterious properties of the text and its resistance to decoding have led some to conclude that it is a hoax – a nonsensical string made to look vaguely language-like. Rugg (2004) claims that words might have been generated using a ‘Cardan Grille’ – a way to deterministically generate words from a table of morphemes. However, it seems that the Grille emulates a restricted finite state grammar of words over prefixes, midfixes, and suffixes. Such a grammar underlies many affixal languages, including English. Martin (2008) proposes a method of generating VMS text from anagrams of number sequences. Like the previous paper, it only shows that this method *can* create VMS-like words – not that it is the most plausible way of generating the manuscript. It is also likely that the proposed scheme can be used to generate any natural language text.

Schinner (2007) votes for the hoax hypothesis based on his observations about characters showing long-range correlations, and the geometric distribution of the probability of similar words repeating at a fixed distance. These observations only confirm

that the VMS has some properties unlike natural language, but not that it is necessarily a hoax.

9 Conclusion

We have detailed various known properties of the Voynich manuscript text. Some features – the lack of repeated bigrams and the distributions of letters at line-edges – are linguistically aberrant, which others – the word length and frequency distributions, the apparent presence of morphology, and most notably, the presence of page-level topics – conform to natural language-like text.

It is our hope that this paper will motivate research into understanding the manuscript by scholars in computational linguistics. The questions presented here are obviously not exhaustive; a deeper examination of the statistical features of the text in comparison to a number of scripts and languages is needed before any definite conclusions can be made. Such studies may also inspire a quantitative interest in linguistic and textual typologies, and be applicable to the decipherment of other historical scripts.

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