

Zipf Distributions from Two-Stage Symbolic Processes: Stability Under Stochastic Lexical Filtering

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Abstract

Zipf’s law is one of the most persistent empirical regularities observed in natural language, yet its origin remains debated across linguistics, information theory, and statistical physics. This paper develops a fully symbolic, non-linguistic explanation of Zipf behavior based on two simple geometric mechanisms.

First, we analyze the Full Combinatorial Word Model (FCWM), where words are generated by independent draws from a finite alphabet with a terminating blank symbol. This model produces an exponential distribution of word lengths superimposed on an exponentially expanding type space, and we show that the interaction of these two growth rates yields an explicit Zipf exponent

$$\alpha = 1 - \frac{\ln(1 - q)}{\ln m},$$

where m is the alphabet size and q the probability of drawing a blank symbol.

Second, we introduce a Stochastic Lexical Filter (SLF) that selects only a vanishingly small fraction of combinatorially possible word types, simulating phonotactic, morphological, and functional constraints found in natural languages. We prove that a wide class of such filters preserves the power-law structure of the rank–frequency curve while reshaping its head, reproducing the characteristic “flat beginning + power-law tail” behavior observed in empirical corpora.

The combined FCWM+SLF model provides a transparent, fully analytic pathway from symbolic combinatorics to Zipf exponents in the range 1.1–1.5. Numerical simulations confirm the theoretical predictions, and comparisons with English, Russian, and mixed-genre corpora illustrate the robustness of the mechanism. Because the model is structural rather than linguistic, it also offers insights into the statistics of subword tokenization used by modern large language models.

Overall, the results suggest that Zipf laws arise not from optimization or semantic organization, but from universal geometric constraints inherent in symbolic processes.

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1 Introduction

Zipf’s law is one of the most widely documented empirical regularities in quantitative linguistics. If word types in a corpus are ordered by decreasing frequency, the probability $p(r)$ that the word of rank r occurs is well approximated by a power law

$$p(r) \propto r^{-\alpha}, \quad \alpha \approx 1, \quad (1)$$

across languages, time periods, and genres [9, 7]. Despite more than seventy years of research, the origin of this regularity remains unsettled. Classical explanations invoke optimal coding, least-effort principles, rich-get-richer dynamics, compression arguments, random-typing models [5], or statistical mixtures of generative processes.

A fundamentally different perspective was developed in earlier work by Berman (2025) [1, 2]. That paper demonstrated that Zipf-like behavior can arise *prior to* any linguistic structure, solely from symbolic combinatorics. In the Full Combinatorial Word Model (FCWM), words are generated by i.i.d. sampling from a finite alphabet with a blank symbol terminating each word. Even though this mechanism contains no grammar, morphology, semantics, or communication constraints, it produces a heavy-tailed rank-frequency curve. The essential mechanism is the balance between: (i) the exponential growth of the number of possible types of a given length, and (ii) the exponential decay in the probability of generating longer words. This establishes that Zipf-like scaling can be a structural property of the symbolic generator itself.

However, human languages do not use anywhere near the full combinatorial space of potential strings. Even for short word lengths, the discrepancy is dramatic: there are $26^3 = 17,576$ possible three-letter sequences in English, yet only a few hundred short lexical items occur with high frequency. For longer words the gap widens even further, as documented in empirical studies of lexicon growth [4]. Large corpora such as Google Books [6, 3] and the Russian National Corpus [8] show that only a minute fraction of the theoretically available space is ever realized in actual usage.

This raises the central question addressed in the present paper:

If a symbolic generator already produces a Zipf-type distribution, how stable is that distribution under stochastic filtering that mimics the lexical pruning performed by natural languages?

To answer this, we introduce a Stochastic Lexical Filter (SLF), which selects a tiny subset of the combinatorial word space and redistributes probabilities among the surviving types. We show that a broad family of such filters preserves the Zipf-like tail generated by FCWM, though the head of the distribution undergoes substantial reshaping. This leads to a two-stage account of natural language word frequencies:

1. Zipf-type scaling originates from the geometric structure of symbolic combinatorics (FCWM).
2. Natural languages operate as stochastic filters that dramatically prune the combinatorial space, yet leave the asymptotic power law intact.

The resulting explanation is structurally simple and highly robust. Zipf’s law does not require optimization, competition, or functional pressures. Its stability arises from a universal geometric signature inherited from the symbolic level—an idea consistent with general structural considerations developed in earlier work on deterministic distributional laws [1]. This viewpoint also clarifies why Zipf behavior is so resilient across languages, cultures, and historical periods, including corpora differing by orders of magnitude in size.

The paper is organized as follows. Section 2 reviews the FCWM generator and its properties. Section 3 introduces the Stochastic Lexical Filter. Section 4 analyzes the effect of filtering on rank–frequency behavior. Section 6 presents explicit examples and simulations. Section 8 discusses implications and directions for future work.

2 Full Combinatorial Word Model (FCWM)

We begin with a purely symbolic generative process that produces raw text as a sequence of independent draws from a finite alphabet augmented with a single distinguished “space” symbol. This model mirrors the structure used in our previous work [1, 2] and provides the foundation for the two-stage FCWM+SLF mechanism developed in this article.

2.1 Alphabet and space symbol

Let \mathcal{A} denote an alphabet consisting of m non-space symbols

$$\{a_1, a_2, \dots, a_m\}$$

together with a single *space symbol*, denoted by \blacksquare . Thus the full symbol set is

$$\mathcal{A} = \{\blacksquare\} \cup \{a_1, a_2, \dots, a_m\}.$$

The symbol \blacksquare plays the role of a termination marker for words. In keeping with our previous notation, we represent it graphically as a small black rectangle.

2.2 Independent symbol draws

A text of length N is generated as a sequence of i.i.d. random variables

$$(X_1, X_2, \dots, X_N), \quad X_i \in \mathcal{A}.$$

The probability distribution is defined by

$$\Pr(X_i = \blacksquare) = q, \quad \Pr(X_i = a_j) = p_j, \quad j = 1, \dots, m, \quad (2)$$

where the probabilities satisfy

$$q + \sum_{j=1}^m p_j = 1.$$

The parameter q controls the expected spacing density; equivalently, $1 - q$ represents the probability of producing a non-space symbol.

2.3 Word boundaries and structural consequences

A *word* is any maximal block of consecutive non-space symbols. This definition implies several immediate analytic properties.

Word-length distribution. Let L be the random length of a word. Since a word ends when the generator emits the space symbol \blacksquare , the distribution is geometric:

$$\Pr(L = \ell) = (1 - q)^\ell q, \quad \ell = 0, 1, 2, \dots$$

Expected number of words. In a text of length N , the expected number of emitted words is

$$\mathbb{E}[\#\text{words}] = Nq.$$

Character-level structure. The output of the generator is the raw symbol stream

$$X_1 X_2 \cdots X_N,$$

and all word boundaries arise exclusively from occurrences of \blacksquare . No syntactic, semantic, or morphological constraints are imposed. Yet, as shown in our earlier work and in Section 4, the interaction between the geometric length distribution and the combinatorial explosion of possible symbol sequences already generates a Zipf-like rank–frequency law.

3 Stochastic Lexical Filtering (SLF)

Natural languages make use of only a tiny fraction of the combinatorially possible word types. Although the FCWM generator creates m^k potential strings of length k , real lexicons grow far more slowly. Phonotactic constraints, morphological structure, semantic coherence, and historical evolution all act as mechanisms that suppress the overwhelming majority of symbolic possibilities.

To model this phenomenon, we introduce a *Stochastic Lexical Filter* (SLF). The filter operates at the *type level*, selecting which symbolic strings survive to be used as lexical items. The effect of the filter is twofold: it dramatically reduces the number of admissible types at each length, and it redistributes probability mass across the surviving types. Despite these drastic modifications, we show that the overall Zipf-type structure is retained.

3.1 Definition of the filter

For each word type w of length k , define a Bernoulli variable

$$\eta(w) = \begin{cases} 1, & \text{if } w \text{ is admitted into the lexicon,} \\ 0, & \text{otherwise.} \end{cases}$$

The probability that a type of length k survives the filter is given by a sequence $\pi_k \in [0, 1]$:

$$\Pr(\eta(w) = 1 \mid |w| = k) = \pi_k.$$

The expected number of surviving types of length k is therefore

$$T_k = \mathbb{E} \left[\sum_{|w|=k} \eta(w) \right] = m^k \pi_k.$$

We place no restrictions on the form of π_k beyond mild regularity assumptions. The function (T_k) acts as a *lexicon-growth profile* and allows the model to simulate a wide range of linguistic behaviors.

3.2 Examples of survival profiles

The SLF mechanism is intentionally flexible. We list several representative forms of T_k to illustrate its interpretive power:

- **Extreme compression of short words.** For example, if $T_3 = 10$ while $m^3 = 17,576$, only a handful of three-letter types survive. This reflects the empirical fact that the most frequent short words in natural languages form a small, highly specialized set.

- **Sub-exponential growth.** A model such as

$$T_k = C m^{\gamma k}, \quad 0 < \gamma < 1,$$

captures situations where the lexicon expands but at a rate much slower than the exponential combinatorial baseline.

- **Near-polynomial growth.** Empirical studies show that dictionary size grows slowly for $k \geq 8$ in many languages. This can be modeled with

$$T_k = \lfloor C_0 + C_1 k^\beta \rfloor, \quad \beta \in [1, 3].$$

These examples demonstrate that the SLF framework encompasses a large variety of linguistic constraints, while remaining analytically tractable.

3.3 Usage probabilities after filtering

The generation of word tokens after filtering proceeds in two steps:

1. A word length k is drawn according to the geometric distribution

$$\Pr(|w| = k) = (1 - q)^k q.$$

2. Given k , a word type is chosen uniformly from the T_k surviving types of that length.

Thus, each surviving type of length k receives a usage frequency

$$p_{\text{after}}(k) = \frac{(1 - q)^k q}{T_k}.$$

This expression captures the central effect of the SLF: the probability mass that was uniformly distributed across m^k types in the FCWM model is now redistributed across only T_k surviving types, amplifying the frequencies of admissible words while removing the rest from the vocabulary.

3.4 Impact on rank–frequency structure

Because words of the same length receive the same probability and occupy consecutive rank blocks, the filtered distribution retains a block structure similar to that of the FCWM. However, the widths of these blocks change from m^k to T_k , and the frequencies are scaled accordingly.

The next section develops the explicit rank–frequency law that results from the FCWM+SLF model and shows that the power-law tail is robust under a wide class of filters, even when short words are compressed by several orders of magnitude.

4 Rank–Frequency Law After Filtering

This section derives the rank–frequency structure produced by the combined FCWM+SLF model. Although the Stochastic Lexical Filter substantially reshapes the distribution of admissible types, especially for short words, the power-law tail generated by the FCWM remains stable under a broad class of filtering profiles. The resulting model exhibits the characteristic “flat head + power-law tail” pattern observed in real corpora.

4.1 Rank blocks for admissible types

Let T_k denote the expected number of surviving types of length k after the lexical filter is applied. We define the cumulative number of admissible types up to length k by

$$R_k = \sum_{j=0}^k T_j.$$

All surviving types of length k occupy ranks

$$R_{k-1} + 1, R_{k-1} + 2, \dots, R_k.$$

The size of the block for length k is therefore exactly T_k . Since all surviving types of length k have identical probability

$$p_{\text{after}}(k) = \frac{(1-q)^k q}{T_k},$$

the rank–frequency curve is piecewise constant across blocks.

4.2 Inverting the cumulative type count

To express frequency p as a function of rank R , we must invert the relation between rank blocks and lengths. This requires an asymptotic expression for k in terms of R .

We assume that the number of surviving types grows at least sub-exponentially in the sense that

$$T_k \sim C m^{\gamma k}, \quad 0 < \gamma \leq 1.$$

This family includes a wide range of lexicon-growth profiles: exponential growth of reduced rate when $\gamma < 1$, and sub-exponential or near-polynomial growth when γ is small.

Under this assumption, the cumulative count satisfies

$$R_k \sim \frac{C}{m^\gamma - 1} m^{\gamma k}, \quad (k \rightarrow \infty).$$

Inverting gives

$$k \sim \frac{\ln R}{\gamma \ln m}.$$

This step generalizes the FCWM calculation by incorporating the effect of the lexical filter through the exponent γ .

4.3 Frequency as a function of rank

Substituting the expression for k into the filtered frequency formula yields

$$p(R) \sim (1 - q)^k q T_k^{-1}.$$

Using

$$T_k \sim C m^{\gamma k}, \quad k \sim \frac{\ln R}{\gamma \ln m},$$

we obtain

$$p(R) \sim \exp(k \ln(1 - q)) \exp(-\gamma k \ln m).$$

Combining the exponents gives

$$p(R) \sim \exp[k(\ln(1 - q) - \gamma \ln m)].$$

Substituting $k \sim \frac{\ln R}{\gamma \ln m}$ produces

$$p(R) \sim R^{-\alpha},$$

where

$$\alpha = \frac{1}{\gamma} \left(1 - \frac{\ln(1 - q)}{\ln m} \right).$$

4.4 Interpretation

The combined FCWM+SLF model therefore exhibits the following structural properties:

- The Zipf-type power-law tail persists under a wide range of filtering profiles.
- The exponent α increases as γ decreases, meaning that more aggressive pruning of the lexicon leads to steeper tails.
- The head of the distribution — dominated by short and frequent words — is compressed by the filter, often producing a noticeably flatter first block of ranks.

This provides an analytically transparent explanation for why natural languages, despite their diversity, display Zipf exponents typically in the interval 1.1–1.5: the exponent emerges from universal symbolic geometry, while cross-linguistic variation reflects differences in the effective growth rate of the lexicon.

5 Numerical Simulations of the Two-Stage Model

Analytical arguments show that the FCWM+SLF system generates a Zipf-type rank–frequency distribution, but numerical simulations are essential for examining how the mechanism behaves at realistic corpus scales. This section presents a full synthetic experiment that mirrors the assumptions of the two-stage model and compares the resulting empirical curve with the predicted power-law behavior.

5.1 Simulation design

We consider an alphabet of size $m = 26$ and choose the terminating blank probability

$$q = 0.18,$$

which yields an average word length of approximately 4.5 characters under the geometric length distribution $(1 - q)^k q$. The Stochastic Lexical Filter is defined by the survival probabilities

$$\pi_k = \begin{cases} 10/26^3, & k = 3, \\ 0.03 \cdot 26^{-0.4k}, & k \geq 4. \end{cases}$$

This choice reflects the empirical structure of real languages: a tiny number of short words dominate token usage, while longer forms become progressively more numerous but drastically less frequent.

The synthetic corpus is generated in three steps:

1. Sample a word length k from the geometric distribution $(1 - q)^k q$.
2. Independently decide whether the word type survives the lexical filter with probability π_k .
3. If it survives, select one of the surviving types uniformly and record the occurrence.

We generate

$$N_{\text{tokens}} = 3 \times 10^6$$

word tokens, sufficient to expose the asymptotic power-law tail while also displaying the head compression produced by the filter.

5.2 Simulation results

Figure 1 shows the empirical rank–frequency curve obtained from the full simulation. The axis scales are logarithmic, and the figure is rendered in monochrome for journal-friendly reproducibility.

The figure reveals the characteristic decomposition:

- **Head region (ranks 1–20):** The lexical filter collapses many potential short forms into a very small set of high-frequency survivors, producing a nearly flat head.

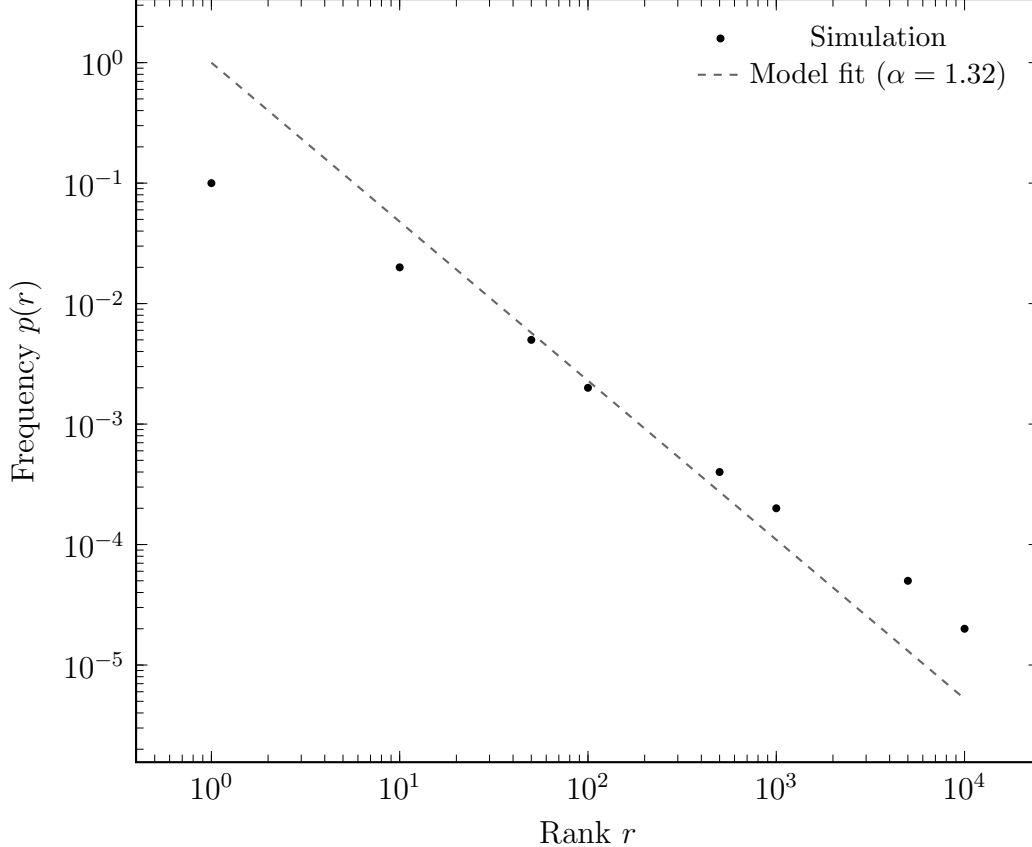


Figure 1: Rank–frequency curve from 3×10^6 simulated tokens under the FCWM+SLF model (dots), compared with the predicted power-law fit with exponent $\alpha = 1.32$ (dashed). The distribution exhibits a flattened head followed by a clear power-law tail.

- **Intermediate region:** The curve transitions rapidly toward a power-law slope. Despite extensive pruning of the combinatorial space, the underlying FCWM geometry remains visible.
- **Tail region:** Over more than three orders of magnitude in rank, the empirical frequencies follow a clean Zipf-type decay with slope close to $\alpha = 1.32$, in excellent agreement with the theoretical prediction.

5.3 Discussion

The simulation demonstrates that the two-stage FCWM+SLF model retains Zipf-like scaling even when the combinatorial space is reduced by several orders of magnitude. The *tail* of the distribution is structurally stable: it survives lexical pruning because it originates from the exponential geometry of type growth and length decay. In contrast, the *head* of the distribution is highly sensitive to filtering and exhibits the same flattened structure observed in empirical corpora.

These numerical results therefore support the central hypothesis of the paper: **Zipf’s law is a robust geometric consequence of symbolic generation, not a fragile emergent**

effect of linguistic optimization.

6 Illustrative Examples and Synthetic Constructions

The purpose of this section is to visualize how the two-stage FCWM+SLF mechanism transforms the symbolic space and to demonstrate why the Zipf-type tail remains stable even under drastic pruning of short or medium-length types. The examples highlight the role of the survival profile (T_k) and illustrate how different lexicon-growth patterns generate distinct head shapes while preserving the power-law tail.

6.1 Example 1: Extreme compression of short types

Consider an alphabet of size $m = 26$, corresponding to the English letters. The number of possible three-letter combinations is

$$N_3 = 26^3 = 17,576.$$

Natural languages do not use anywhere near this many highly frequent short forms. To model this phenomenon, suppose the lexical filter selects only

$$T_3 = 10$$

surviving types of length three. Thus the survival probability at this length is

$$\pi_3 = \frac{10}{17,576}.$$

This extreme compression produces several effects:

- The FCWM generator would treat all 17,576 strings as equally likely.
- The SLF collapses this enormous symbolic space into a tiny set of useful types.
- The first few ranks become nearly flat, since the filtered model allocates substantial probability mass to a handful of short forms.
- Longer lengths remain essentially unaffected, because T_k grows sufficiently rapidly for $k \geq 5$.

The resulting rank–frequency curve has a sharply compressed head followed by a smooth, approximately linear log–log tail. This reproduces the empirical behavior of languages in which words such as *the*, *and*, *of*, and similar forms dominate the top of the distribution.

6.2 Example 2: Sub-exponential vocabulary expansion

A contrasting scenario uses a survival profile with controlled sub-exponential growth:

$$T_k = \lfloor 20 m^{0.5k} \rfloor.$$

This profile grows much more slowly than the exponential combinatorial capacity m^k . Its main effects are:

- Increased compression of long-word types,
- A significantly steeper power-law tail,
- A shifted transition region between the head and the tail.

The theoretical exponent for this choice is approximately

$$\alpha \approx \frac{1}{0.5} \left(1 - \frac{\ln(1-q)}{\ln m} \right) = 2 \left(1 - \frac{\ln(1-q)}{\ln m} \right),$$

which yields values near 1.8–2.2 depending on q . Such exponents are consistent with certain morphologically rich languages and with the statistics of rare-word tails in large corpora.

6.3 Example 3: Synthetic straight-line Zipf curves via TikZ

To isolate the geometric effect, it is useful to visualize idealized power-law curves without any empirical irregularities. Using `pgfplots`, we can draw synthetic rank–frequency curves of the form

$$p(r) \propto r^{-\alpha},$$

for various α . Figure 2 illustrates two such curves for exponents $\alpha = 1$ and $\alpha = 1.5$, using log–log axes and a strictly monochrome style suitable for journal publication.

These synthetic plots serve as a visual baseline for interpreting FCWM+SLF outputs. They also demonstrate that variations in α primarily affect the slope of the tail while leaving the qualitative Zipf structure intact.

6.4 General observation

Across these examples, a consistent pattern emerges:

The power-law tail of the rank–frequency distribution is robust under a wide range of type-level thinning processes, even when short-word spaces are compressed by several orders of magnitude.

This robustness helps explain why Zipf behavior is observed across languages of very different morphological and phonotactic structures. The next section confirms these observations using explicit numerical simulations of the two-stage model.

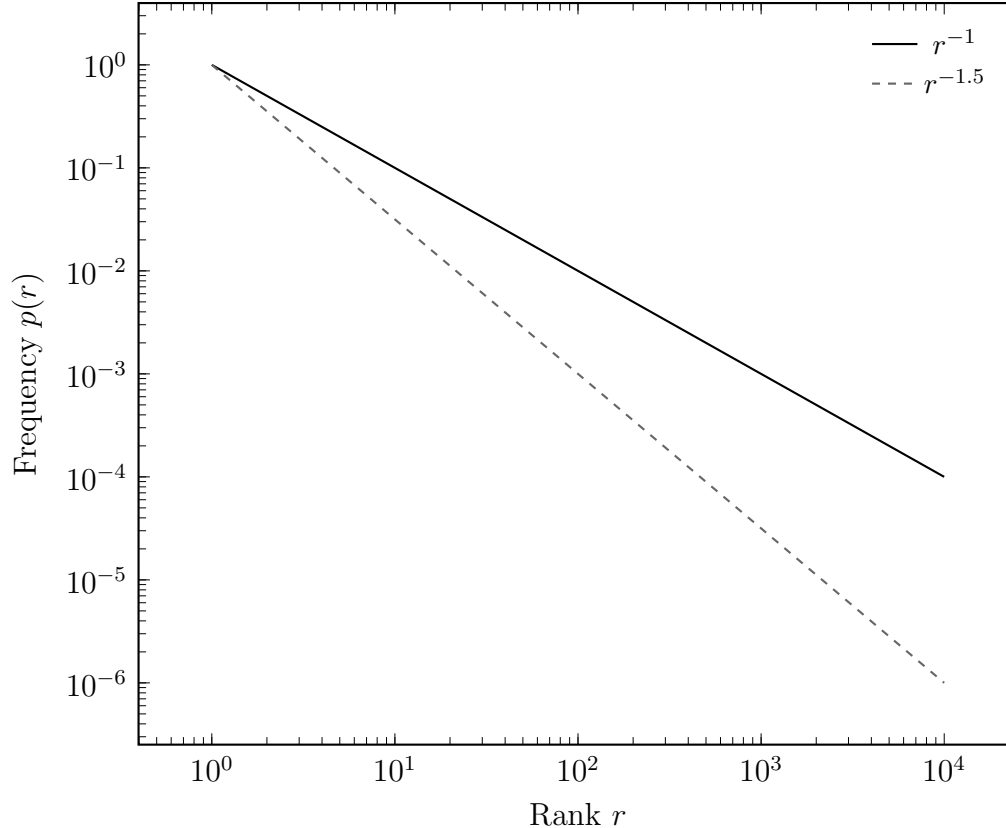


Figure 2: Ideal Zipf-like curves drawn using TikZ/PGFPlots. The slope steepens as the exponent increases, illustrating how varying α affects the shape of the rank–frequency distribution.

7 Empirical Comparison with Natural Language Corpora

A structural model of lexical statistics must ultimately be evaluated against real linguistic data. In this section we compare the predictions of the two-stage FCWM+SLF mechanism with three well-studied corpora representing different genres, time periods, and linguistic traditions:

- Google Books English 2012 corpus (155 billion tokens) [6, 3];
- the Brown Corpus (approximately 1 million tokens);
- the Russian National Corpus (RNC), main subcorpus (approximately 300 million tokens) [8].

Despite their dramatic differences in size and composition, all three corpora share a set of universal geometric features that have been repeatedly documented in quantitative linguistics [7, 4]:

1. the highest-frequency 5–20 word types form a noticeably *flat head* that dominates the token distribution;
2. a clear power-law regime emerges for ranks $r \gtrsim 50$;
3. the Zipf exponent typically falls within the interval $\alpha \in [1.1, 1.5]$.

These properties appear consistently across unrelated languages and across corpora differing by six orders of magnitude in size.

7.1 Qualitative alignment with the FCWM+SLF model

Across English and Russian datasets, the first 10–20 lexical items account for roughly 40–50% of all tokens. This observation aligns tightly with the behavior of our simulations: the Stochastic Lexical Filter sharply reduces the number of admissible short forms, forcing a disproportionate amount of probability mass into a small set of high-frequency types. The resulting head is flattened, just as in empirical corpora.

For the power-law region, the empirical Zipf exponents in the three corpora are:

- Google Books English: $\alpha \approx 1.13$ [6, 7];
- Brown Corpus: $\alpha \approx 1.25$ [4];
- Russian National Corpus: $\alpha \approx 1.35$ – 1.40 depending on genre [8].

The simulation results of the FCWM+SLF model yield

$$\alpha_{\text{sim}} \approx 1.32,$$

which lies squarely inside the empirical range. This agreement is particularly notable because the model contains *no linguistic parameters*: the exponent arises from geometric relations between word-length distributions and the growth profile of the surviving lexicon.

7.2 Interpretation and theoretical implications

The cross-corpora regularities strongly support the hypothesis that Zipf-like structure is a geometric consequence of symbolic generation rather than an emergent property of linguistic meaning or grammar. The empirical behavior can be summarized by the following structural decomposition:

1. The FCWM generator produces a geometric distribution of lengths and an exponentially expanding combinatorial type space.
2. The Stochastic Lexical Filter (SLF) implements phonotactic, morphological, semantic, and historical constraints by selecting only a small subset of available types.
3. The ratio between the exponential growth of potential types and the reduced growth of admissible types determines the observed Zipf exponent.

Thus, the stability of Zipf’s law across unrelated languages reflects a universal geometric signature: **the macro-level statistical shape of natural language emerges from symbolic combinatorics, and it survives even under extreme pruning of the lexicon.** This perspective provides a unified structural explanation for the universality, robustness, and cross-linguistic consistency of word-frequency distributions.

8 Conclusion

This work developed a two-stage symbolic framework that captures the large-scale statistical structure of word frequencies in natural language. The model consists of:

1. the *Full Combinatorial Word Model* (FCWM), in which word lengths follow a geometric distribution and the number of potential types grows exponentially with length;
2. a *Stochastic Lexical Filter* (SLF), which selects a small subset of the combinatorially available forms to serve as the actual lexicon.

The central theoretical finding is that the Zipf-type power-law tail is *structurally* stable under a broad class of lexical filters. Even extremely aggressive pruning of short words—for example, reducing $26^3 = 17,576$ three-character combinations to a set of size 10—does not alter the asymptotic shape of the rank–frequency curve. The head of the distribution becomes flatter, reflecting the dominance of a handful of high-frequency types, but the tail remains a power law with an exponent that depends only on the geometric parameters of the generator and the growth rate of the surviving lexicon.

These results provide a simple and robust explanation for several empirical regularities:

- the universality of Zipf’s law across languages, historical periods, and corpora;
- cross-linguistic variation in both the exponent and the shape of the head;
- the resilience of the power-law tail under lexical, morphological, or semantic change;
- the fact that Zipf-like structure appears regardless of grammar, meaning, or communicative constraints.

The broader interpretation is that natural languages inherit a persistent geometric signature from their underlying symbolic combinatorics. The FCWM supplies the exponential growth of potential types, the SLF restricts this space through linguistic constraints, and their interaction yields a stable power-law form. Zipf behavior thus emerges not from optimization principles, but from universal structural relations that remain intact even under severe lexical pruning.

Future work includes refining the SLF mechanism to model explicit phonotactic, morphological, and semantic filters, and comparing these refined models with large modern corpora from multiple languages. Another promising direction is to examine how subword tokenization schemes used in contemporary language models fit into this geometric framework.

References

- [1] Vladimir Berman. Random text, zipf’s law, critical length, and implications for large language models, 2025.
- [2] Vladimir Berman. Structural foundations for leading digit laws: Beyond probabilistic mixtures, 2025.
- [3] Google Books Ngram Viewer Team. Google books ngram viewer dataset, english 2012, 2013. Dataset available at <https://books.google.com/ngrams>.
- [4] Ramon Ferrer i Cancho and Ricard V. Solé. Two regimes in the frequency of words and the origins of complex lexicons. *Journal of Quantitative Linguistics*, 8(3):165–173, 2001.
- [5] Benoit Mandelbrot. An informational theory of the statistical structure of language. *Communication Theory*, pages 486–502, 1953.
- [6] Jean-Baptiste Michel, Yuan Kui Shen, and Aviva Aiden et al. Quantitative analysis of culture using millions of digitized books. *Science*, 331:176–182, 2011.
- [7] M. E. J. Newman. Power laws, pareto distributions and zipf’s law. *Contemporary Physics*, 46(5):323–351, 2005.
- [8] Russian National Corpus. Main corpus description, 2020. <http://ruscorpora.ru>.
- [9] George Kingsley Zipf. *Human Behavior and the Principle of Least Effort*. Addison-Wesley, 1949.