Is language evolution grinding to a halt?:
Exploring the life and death of words in English fiction

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The Google Books corpus contains millions of books in a variety of languages. Due to its incredible
volume and its free availability, it is a treasure trove for linguistic research. In a previous work, we
found the unfiltered English data sets from both the 2009 and 2012 versions of the corpus are both
heavily saturated with scientific literature, as is the 2009 version of the English Fiction data set.
Fortunately, the 2012 version of English Fiction is consistent with fiction and shows promise as an
indicator of the evolution of the English language as used by the general public. In this paper, we
first critique a method used by authors of an earlier work to determine the birth and death rates
of words in a given linguistic data set. We show that this earlier method produces an artificial
surge in the death rate at the end of the observed period of time. In order to avoid this boundary
effect in our own analysis of asymmetries in language dynamics, we examine the volume of word
flux across various relative frequency thresholds for the 2012 English Fiction data set. We then use
the contributions of the words crossing these thresholds to the Jensen-Shannon divergence between
consecutive decades to resolve the major driving factors behind the flux.

I. INTRODUCTION

The incredible volume and free availability of the
Google Books corpus[1,2] make it an an exceptional
candidate for linguistic research. In a previous work[3],
we explored the dynamics of the English and English Fiction
data sets from both versions of the corpus, and we
showed that the unfiltered 2009 and 2012 English data
sets are both heavily influenced by scientific texts. In
releasing the original data set, Michel et al. [1] warned
that 2009 version the English Fiction contained non-
fiction material, including scholarly articles about fictional works. Critically, we observed in [3] that this data
set is in fact increasingly dominated over the last several
decades by scientific literature with medical research
language being especially prevalent. It is therefore not
an appriate data set for analysis. The 2012 version
of English Fiction is improved in the respect that it appears
to robustly represent fiction.

In this paper, in order to avoid bias from scientific journals, we limit our analysis to the 2012 version of the
English Fiction data set. Fig. 1 shows the total number of 1-grams for this data set between 1800 and 2000. An
exponential increase in volume is apparent over time with notable exceptions during wartime when the total volume decreases. (This effect is clearest during the American Civil War and both World Wars.)

FIG. 1: The logarithms of the total 1-gram counts for the Google Books corpus 2012 English Fiction data set. An exponential increase in volume is apparent over time with notable exceptions during wartime when the total volume decreases. (This effect is clearest during the American Civil War and both World Wars.)

Many researchers have carried out broad analyses of the Google Books corpus, examining properties and
dynamics of entire languages. These include analyses of Zipf’s and Heaps’ laws as applied to the corpus[4], the
rates of verb regularization[1], rates of word “birth” and “death” and durations of cultural memory[5], as well as
an observed decrease in the need for new words in several languages[6]. However, many of the studies were performed before the release of the second version and did not appear to take into account the substantial effects of scientific literature on the data sets.

The example of word “birth” and “death” rates[5] is of particular interest due to the intuitive narrative of decreased rates of introduction to vocabularies over time and increased rates of disposal. Both observations can be explained in part by the wide availability
of spell-checking software and, hence, decreased competition between alternate spellings. However, we observe that boundary effects arise from the methods employed in that paper. In particular, death rates (as defined by the authors) tend to increase as the last recorded time period is approached. (We demonstrate this in Section II.) Therefore, while the conclusions drawn by the authors may be essentially correct, we must nonetheless take them with a grain of salt.

We do not, however, dispute that asymmetry exists in the changes in word use. In our earlier work [3], we observed this asymmetry in the contributions to the statistical divergences between decades with most large contributions being accounted for by words whose relative frequencies had increased. In this paper, we apply a similar information-theoretic approach to examine this effect.

We structure the remainder of the paper as follows. In Section II, we critique a method from a related work [5] which examines the birth and death rates of words in a data set. In Section III, we recall and confirm a similar apparent bias toward increased usage rates of words from our previous paper. We then measure the flux of words across various relative frequency boundaries (in both directions) in the second English Fiction data set. Furthermore, we describe the use of the largest contributions to the Jensen-Shannon divergence between successive decades from among the words crossing each boundary as signals to highlight the specific dynamics of word grown and decay over time. In Section IV, we display examples of these highlights and explore the factors contributing to the observed disparities between growth and decay. We offer concluding remarks in Section V summarizing the implications of our findings.

II. CRITIQUE OF A RELATED WORK

In a related paper [6], Petersen et al. examined the birth and death rates of words over time for various data sets in the first version of the Google Books corpus. They defined the birth year and death year of an individual word as the first and last year, respectively, that the given word appeared above one twentieth its median relative frequency. Excluded from considerations were words appearing in only one year and words appearing for the first time before 1700. (The latter exclusion focuses the analysis on recent words.) The rates of word birth and death, respectively, were found by normalizing the numbers of births and deaths counted by the total number of unique words in a given year.

Results typical to all data sets included decreased birth rates and increased death rates over time. As noted in the previous section, these results are not implausible. The very specific nature of the experiment—particularly the multiple temporal restrictions on the words included in the analysis, the reliance on a particular proportion of each word’s median frequency, and the ignoring of all but the first and last crossings over this threshold—raise questions as to the robustness of the method. ( Granted, the authors of the paper do state that the results are qualitatively similar when one tenth the median frequency is used as a threshold.)

Ignoring all but the first and last crossings, in particular, appears to cause problems. A boundary effect can arise when the death of a word is defined as the last observed occurrence of a given word above its threshold. To demonstrate this, we recreate the described analysis for the second version of English Fiction.

We note that in our analyses, the relative frequencies are coarse-grained at the level of decades. Excluded are words appearing in only one decade (rather than year) and words appearing before the 1820s (instead of 1700). Again, this more recent initial cut-off date accounts for the high frequency of OCR errors observed before 1820.

Furthermore, we compare the birth and death rates as observed recently versus historically by performing the analysis with three different endpoints imposed: the 1950s, the 1970s, and the 1990s. We present the results of the recreation in Fig. 2 (c.f. Fig. 2 in [6]).

The observed birth rates are qualitatively similar to those from various data sets (from the 2009 version of the corpus) in the afore-mentioned paper and display spikes in the 1890s and 1920s. The observed death rates with the 1990s boundary (light gray) are also similar, despite the lack of deaths detected during much of the 19th century. (Recall, we ignored words originating prior to 1820.) However, as the later boundary is moved to the 1970s, what was originally a stable region between the 1910s and 1940s turns into a region of gradually increasing word death. As the boundary is moved to the 1950s, the increase in death rate is no longer gradual. This demonstrates a qualitative dependence of the observations of the death rate on when the history of the corpus ends. The results of the experiment depend on when the experiment is performed.

Therefore, while this method provides a good start to analyzing asymmetries in the evolutionary dynamics of a language data set, the results of the method invite supplementation by more comprehensive methods, which we introduce presently.

III. METHODS

We course-grain the relative frequencies in the second English Fiction data set at the level of decades—e.g., between 1820-to-1829 and 1900-to-1999—by averaging the relative frequency of each unique word in a given decade over all years in that decade. (We weight each year equally.) This allows us to conveniently calculate and sort contributions to divergence of individual 1-grams between any two time periods.
FIG. 2: Birth and death rates, with definitions based on a related paper [5], for 2012 version of English Fiction as observed between the 1820s and three different end-of-history boundaries. The observed birth rates are qualitatively similar to those from various (2009) data sets (see Fig. 2 in the afore-mentioned paper) and display spikes in the 1890s and 1920s. The observed death rates with the 1990s boundary (light gray) are also similar, albeit with no deaths detected during much of the 19th century (a result of ignoring words originating prior to 1820). However, as the latter boundary is moved to the 1970s, what was originally a stable region between the 1910s and 1940s turns into a region of gradually increasing word death. As the boundary is moved to the 1950s, the increase in death rate is no longer gradual. This demonstrates a qualitative dependence of the observations of the death rate on when the history of the corpus ends.

A. Statistical divergence between decades

As in our previous paper [3], we examined the dynamics of the 2012 version of English Fiction by calculating contributions to the Jensen-Shannon divergence (JSD) between the distributions of 1-grams in two given decades. We then used these contributions to resolve specific and important signals in dynamics of the language. (This material, which is presented in greater detail in our previous work, is outlined in sufficient detail below.)

Given a language with 1-gram distributions \( P \) in the first decade and \( Q \) in second, the JSD between \( P \) and \( Q \) can be expressed as

\[
D_{JS}(P||Q) = H(M) - \frac{1}{2}(H(P) + H(Q)),
\]

where \( M = \frac{1}{2}(P + Q) \) is a mixed distribution of the two years, and \( H(P) = -\sum p_i \log_2 p_i \) is the Shannon entropy [8] of the original distribution. The JSD is symmetric and bounded between 0 and 1 bit. These bounds are only observed when the distributions are identical and free of overlap, respectively.

The contribution from the \( i \)th word to the divergence between two decades, as derived from Eq. [1] is given by

\[
D_{JS,i}(P||Q) = m_i \cdot \frac{1}{2}(r_i \log r_i + (2 - r_i) \log (2 - r_i)),
\]

where \( r_i = p_i/m_i \), so that contribution from an individual word is proportional to both the average frequency of the word and also depends on the ratio between the smaller and average frequencies. To elucidate the second dependency, we reframe the contribution as

\[
D_{JS,i}(P||Q) = m_i C(r_i).
\]

Words with larger average frequencies yield larger contribution signals as do those with smaller ratios, \( r_i \), between the frequencies. A common 1-gram changing subtly can produce a large signal. So can an uncommon or new word given a sufficient shift from one decade to the next. \( C(r_i) \), the proportion of the average frequency contributed to the signal, is concave (up) and symmetric about \( r_i = 1 \), where the frequency remains unchanged yielding no contribution. If a word appears or disappears between two decades (i.e., \( p_i = r_i = 0 \), then the contribution is maximized at precisely the average frequency of the word in question.

B. Exploring asymmetric dynamics

We observed in a previous paper [3] that most large JSD contribution signals are due to words whose relative frequencies increase over time. In this paper, we confirm and explore this effect.

We texture our observations by examining JSD signals due to words crossing various relative frequency thresholds in either direction, as well as the total volume of word flux in either direction across these thresholds. It is both convenient and consistent to record flux over relative frequency thresholds instead of rank thresholds. To demonstrate this consistency, we observe in Fig. [3] that rank threshold boundaries correspond to nearly constant relative frequency thresholds, with the exception of the top 1-gram (always the comma), which decreases gradually in relative frequency. For thresholds of \( 10^{-5} \) and below, we omit signals corresponding to references to specific years, since such references would otherwise overwhelm the charts for these thresholds.

IV. RESULTS AND DISCUSSION

As seen in Fig. [4] more than half of the JSD between a typical given decade and the next is due to contributions from words increasing in relative usage frequency. The
JSDs between 1820s, 1840s, and 1970s and their successive decades are the only exceptions. Moreover, when the time differential is increased to three decades, no exceptions remain. This confirms asymmetry exists between signals for words increasing and decreasing in relative use. We note relative extrema of the inter-decade JSD in the vicinity of major conflicts. Between the 1860s and successive decades, words on the rise contribute substantially to the JSD. This is consistent with words not relatively popular during wartime (specifically the American Civil War) being used more frequently in peacetime. A similar tendency holds for the JSD between the 1910s (World War I) and the 1920s. This is not as apparent in the JSD between the 1910s and the 1940s, possibly because the 1940s coincide with World War II. The absolute maximum for the single-decade curve corresponds to the divergence between the 1950s and 1960s. This suggests a strong effect from social movements. (For the 3-decade split, the absolute peak comes from the JSD between the 1940s and 1970s.)

We next consider flux across relative frequency thresholds of powers of 10 from $10^{-2}$ down to $10^{-6}$. In Fig. 3, we display the volume of flux of words in both directions across relative frequency thresholds of powers of 10 from $10^{-4}$ down to $10^{-7}$. Flux across the $10^{-2}$ boundary between consecutive decades is almost nonexistent during the observed period. Between the 1820s and 1830s, the semicolon falls below the threshold. Between the 1840s and 1850s, “I” rises above the boundary. Between the 1910s and 1920s, “was” rises across. This is the entirety of the flux across $10^{-2}$, which shows the regime of words above this frequency (roughly the top 10 words) is quite stable. The eleven words above threshold in the 1990s in decreasing order of frequency are: the comma “,”, the period “.”, “the”, quotation marks, “to”, “and”, “of”, “a”, “T”, “in”, and “was”.

The set of words with relative frequencies above $10^{-3}$ (roughly to the top 100 words) is also fairly stable. The flux of words across this boundary between consecutive decades is entirely captured by Fig. 4. Parentheses drop in (relative frequency of) use between the 1840s and 1850s and cross back over the threshold after the American Civil War (between the 1860s and 1870s). The same is true for before and after World War II (between the 1930s and 1940s and between the 1940s and 1950s,

![Figure 3](image1.png)

**FIG. 3:** Rank threshold boundaries correspond to nearly constant relative frequency threshold boundaries over many orders of magnitude, with the exception of the top 1-gram (always a comma), which decreases in relative frequency. This demonstrates the general consistency of recording measurements related to flux across either type of boundary.

![Figure 4](image2.png)

**FIG. 4:** Percent of JSD in English Fiction (version 2) due to words increasing in relative frequency of use. The JSD between successive decades is nearly always more than half. The only exceptions are between the 1820s, 1840s, and 1970s, and their successive decades. When the distance between time periods is increased to 3 decades, no exceptions remain. The JSD between successive decades also shows peaks in the vicinity of major conflicts.

![Figure 5](image3.png)

**FIG. 5:** Total number of words ($\log_{10}$) crossing relative frequency thresholds of $10^{-4}$, $10^{-5}$, $10^{-6}$, and $10^{-7}$ in both directions between each decade and the next decade. For each threshold, the upward and downward flux roughly cancel. For either direction of flux, there appears to be little qualitative difference between the three smallest thresholds for which the downward flux between the 1950s and the 1960s is a minimum, the downward flux increases over the next two pairs of consecutive decades, then it dips again between the 1980s and 1990s. For the highest threshold, the increase between the 1960s and 1970s and the next pair of decades is more noticeable for the upward flux, as is the decrease between the last two pairs of decades.
FIG. 6: Words crossing relative frequency threshold of $10^{-3}$ between consecutive decades. Signals for each pair of decades are sorted and weighted by contribution to the JSD between those decades. Bars pointing to the right represent words that rose above the threshold between decades. Bars pointing left represent words that fell. In parentheses in each title is the total percent of the JSD between the given pair of decades that is accounted for by flux over the $10^{-3}$ threshold.

respectively). Beyond these, the flux is entirely due to proper words (not punctuation). For example, “made” fluctuates up and down over this threshold repeatedly over the course of a century. (Between the 1870s and the 1880s, “made,” which sees slight increased use, is the only word to cross the threshold. The most crossings is 12, which occurs between the first two decades.) Also, “great” struggled over the first 5 decades and eventually failed to remain great by this measure. “Mr.” fluctuated across the threshold between the 1830s and 1910s. More recently (since the 1930s), “They” has been making its paces up and down across the threshold.

For each threshold between $10^{-4}$ and $10^{-7}$, the upward and downward flux roughly cancel, which is consistent with Fig. 3. For both upward and downward flux, there appears to be little qualitative difference between the three smallest thresholds. For these thresholds, the downward flux between the 1950s and the 1960s is a minimum, the downward flux increases over the next two pairs of consecutive decades, then it dips again between the 1980s and 1990s. For the highest threshold, the increase between the 1960s and 1970s and the next pair of decades is more noticeable for the upward flux, as is the decrease between the last two pairs of decades.

In the experiment recreated in Fig. 2, the word birth rate initially exceeds the death rate by three orders of
FIG. 7: Words crossing relative frequency threshold of $10^{-4}$ between the given decades. Signals for each pair of decades are sorted and weighted by contribution to the JSD between those decades. Bars pointing to the right represent words that rose above the threshold between decades. Bars pointing left represent words that fell. (The first signal is the asterisk “*”.)

FIG. 8: Words crossing relative frequency threshold of $10^{-4}$ between the given decades. Signals for each pair of decades are sorted and weighted by contribution to the JSD between those decades. Bars pointing to the right represent words that rose above the threshold between decades. Bars pointing left represent words that fell.
FIG. 9: Words (not counting references to years) crossing relative frequency threshold of $10^{-5}$ between the given decades. Signals for each pair of decades are sorted and weighted by contribution to the JSD between those decades. Bars pointing to the right represent words that rose above the threshold between decades. Bars pointing left represent words that fell.

FIG. 10: Words (not counting references to years) crossing relative frequency threshold of $10^{-5}$ between the given decades. Signals for each pair of decades are sorted and weighted by contribution to the JSD between those decades. Bars pointing to the right represent words that rose above the threshold between decades. Bars pointing left represent words that fell.
FIG. 11: Words (not counting references to years) crossing relative frequency threshold of $10^{-6}$ between the given decades. Signals for each pair of decades are sorted and weighted by contribution to the JSD between those decades. Bars pointing to the right represent words that rose above the threshold between decades. Bars pointing left represent words that fell.

FIG. 12: Words (not counting references to years) crossing relative frequency threshold of $10^{-6}$ between the given decades. Signals for each pair of decades are sorted and weighted by contribution to the JSD between those decades. Bars pointing to the right represent words that rose above the threshold between decades. Bars pointing left represent words that fell.
FIG. 13: Words crossing relative frequency threshold of $10^{-4}$ between the given decades. Signals for each pair of decades are sorted and weighted by contribution to the JSD between those decades. Bars pointing to the right represent words that rose above the threshold between decades. Bars pointing left represent words that fell.

FIG. 14: Words (not counting references to years) crossing relative frequency threshold of $10^{-5}$ between the given decades. Signals for each pair of decades are sorted and weighted by contribution to the JSD between those decades. Bars pointing to the right represent words that rose above the threshold between decades. Bars pointing left represent words that fell.
To address the fluxuations during the last couple of decades, we begin by displaying in Fig. 7 the top 60 flux words between the 1970s and the 1980s sorted by contributions to the JSD between those decades. Note that this pair of decades corresponds to both a dip (below 50%) in the proportion of rising word contributions to the JSD and to an increase in the volume of downward flux (as well as upward flux for high thresholds). In Fig. 8, we show all 55 flux words between the 1980s and the 1990s.

Between each pair of decades, we see reduced relative use of particularly British words, including “England” between the first two decades and “King,” “George,” and “Sir” between the latter two. We also see reduced use of more formal-sounding words, such as “character,” “manner,” and “general” between the first two decades and “suppose,” “indeed,” and “hardly” between the latter two. Increasing are physical and emotional words. Those between the first two decades include “stared,” “breath,” “realized,” “shoulder” and “shoulders,” “coffee,” “guess,” “pain,” and “sorry.” Between the latter two, we see “chest,” “skin,” “whispered,” “hit,” “throat,” “control,” and “lives.” Also included are “phone” and “parents.”

FIG. 15: Words (not counting references to years) crossing relative frequency threshold of $10^{-5}$ between the given decades. Signals for each pair of decades are sorted and weighted by contribution to the JSD between those decades. Bars pointing to the right represent words that rose above the threshold between decades. Bars pointing left represent words that fell. magnitude, and this gap declines gradually over the next two centuries. However, with respect to words fluxuating across relative frequency thresholds in opposite directions, we see no strong evidence of asymmetry during any long period of time. With respect to total contributions to the JSD between consecutive decades, there is typically some bias toward toward words with increased relative use as seen in Fig. 4, but the difference need never be described in orders of magnitude.

In Figs. 9 and 10, we display the top 60 flux words, not counting references to years, across the $10^{-5}$ threshold between the same decades. Many of the words declining below the threshold between the 1970s and 1980s are unusual spellings such as “tho,” proper names like “Balzac,” or words from non-English languages like “une.” Also included is the word “Negroes.” Increasing across this threshold between the first two decades are a plethora of mostly female proper names, with “Jessica” and “Megan” leading. Also seen are “KGB” and “jeans.” (“KGB” decreases in the 1990s, as does “Russians.”) Increasing between the 1980s and 1990s are a few proper names; however, most of the signals here are social and sexual in nature. These include “lesbian” and “lesbians,” “AIDS,” and “gender” in the top positions. Also included are both “homosexuality” and the more general “sexuality.” We also see “girlfriend,” “boyfriend,” “feminist,” and “sexy.”

For contrast and amusement, we show in Fig. 12 the flux across a threshold of $10^{-6}$ between the 1980s and 1990s (again, not counting years). In particular, while increases in “HIV” and “bisexual” make the list (similarly to many signals in Fig. 10), as do “fax,” “laptop,” and “Internet,” a great swath of the signals are accounted for by one franchise. Note increases in “Picard,” “TNG,” “Sisko,” and “DS9.” These latter signals should serve
as a reminder that the word distributions in the corpus, even for fiction, do not always resemble the contents of normal conversations (at least not for the general population). However, we do observe signals arising at this threshold from factors external to the imaginings of specific authors. It would therefore be premature to dismiss the contributions at this threshold because of an apparent overabundance of “Star Trek.” In fact, since “The Next Generation” and “Deep Space 9” aired precisely during these two decades, an abundance of “Star Trek” novels in the English Fiction data set is actually quite encouraging, because these novels do exist, are available in English, and are (clearly) fiction.

For consistency, we also include the flux (omitting years) across this threshold between the 1970s and 1980s in Fig. 11. While not particularly topical, we do see “AIDS” increase above this threshold a decade prior to its increase over $10^{-5}$ as seen in Fig. 10.

The texture of the signals changes as we dial down the frequency threshold. We typically find that thresholds of $10^{-4}$ and above produce signals with little to no noise. This is not surprising since this relative frequency roughly corresponds to rank threshold for the 1000 most common words (see Fig. 3) in the data set. Using a threshold of $10^{-5}$ (fewer than 10,000 words fall above this frequency in any given decade), we see some noise (mostly in the form of familiar names), but still observe many valuable signals. Only when the threshold is reduced to $10^{-6}$ does the overall texture of the signals become questionable as a result of a variety of proper nouns far less familiar than those observed with the previous threshold. However, at this threshold, we also observe several early signals of real social importance.

Curiously, between the 1930s and 1940s the volume of flux across each threshold is not atypical (see Fig. 5). Moreover, the asymmetry between the JSD contributions between those decades is very low. Yet it is obvious that we should expect signals of historical significance between these two decades. In Figs. 13 and 14 we see words crossing the $10^{-4}$ and $10^{-5}$ thresholds, respectively (with references to years omitted in Fig 14). For the higher threshold, only 56 words cross. The most noticeable such words that are more commonly used in the 1940s are “General” and “German.” Also, “killed” appears in this list. Words used less frequently include “pleasure,” “garden,” and “spirit.” For the lower threshold, we see the signals from prolific authors as in our previous paper [3], particularly Upton Sinclair’s character, Lanny Budd. We also see more Nazis (“Nazi” and “Nazis”). In fact, the Lanny Budd series is a war story, meaning even the initial orders-of-magnitude gap between so-called birth and death rates. Rather, the JSD bias toward increased relative use of words is within one order of magnitude, and the flux across thresholds is typically balanced.

In fact, this latter point appears to be a fundamental facet of this data set. As we see in Fig. 3 the number of words above each threshold is roughly constant. This stability of the rank-frequency relation compels the observed balancing act (and is consistent with a stable Zipf law distribution [10]). Previously [3] (Fig. 5d), we have seen the divergence between a given year—e.g., 1880—and a target year tends to increase gradually with the time difference. This is not true when, for example, the target year—e.g., 1940—falls during a major war, in which case we see a spike in divergence. However, as the target year exits this period—e.g. enters the 1950s—the spike settles back into the original gradual growth pattern. It is plausible based on these earlier observations and the observations in this paper that the distribution of the language is self-stabilizing: the overall shape of the distribution does not appear to change drastically with time or with the total volume of the data set. As old words fall out of favor, new words inevitably appear to fill in the gaps.

Furthermore, despite the fact that the divergence between consecutive years has been observed to decay over time, we find no shortage of novel word introductions during the most recent decades (which have the lowest
decade-to-decade JSDs). This apparent dissonance clearly invites further investigation.

Finally, while extremely specific fiction can be of great interest—whether it be in the form of war novels or volumes from the “Star Trek” franchise—vocabulary from these works is more easily studied when placed in proper context. Dialing down the relative frequency threshold across several orders of magnitude helps to capture this distinction. However, further experimentation is invited, since an automatic means of separating specific signals from the more general signals (e.g., “Star Trek” from social movements) could allow both a more intuitive grasp of the linguistic dynamics and might, ideally, allow investigators to hypothesize causal relationships between exogenous and endogenous drivers of the language.

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