Links that speak: The global language network and its association with global fame

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Languages vary enormously in global importance because of historical, demographic, political, and technological forces. However, beyond simple measures of population and economic power, there has been no rigorous quantitative way to define the global influence of languages. Here we use the structure of the networks connecting multilingual speakers and translated texts, as expressed in book translations, multiple language editions of Wikipedia, and Twitter, to provide a concept of language importance that goes beyond simple economic or demographic measures. We find that the structure of these three global language networks (GLNs) is centered on English as a global hub and around a handful of intermediate hub languages, which include Spanish, German, French, Russian, Portuguese, and Chinese. We validate the measure of a language's centrality in the three GLNs by showing that it exhibits a strong correlation with two independent measures of the number of famous people born in the countries associated with that language. These results suggest that the position of a language in the GLN contributes to the visibility of its speakers and the global popularity of the cultural content they produce.

Significance

People have long debated about the global influence of languages. The speculations that fuel this debate, however, rely on measures of language importance—such as income and population—that lack external validation as measures of a language's global influence. Here we introduce a metric of a language's global influence based on its position in the network connecting languages that are co-spoken. We show that the connectivity of a language in this network, after controlling for the number of speakers of a language and their income, remains a strong predictor of a language's influence when validated against two independent measures of the cultural content produced by a language's speakers.


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languages are disproportionately influential because they provide direct and indirect paths of translation among most of the world’s other languages. For example, it is easy for an idea conceived by a Spaniard to reach an Englishman through bilingual speakers of English and Spanish. An idea conceived by a Vietnamese speaker, however, might only reach a Mapudungun speaker in south-central Chile through a circuitous path that connects bilingual speakers of Vietnamese and English, English and Spanish, and Spanish and

Fig. 1. Visualizations of the three GLNs. The three GLNs contain all language connections that involve at least six users (Twitter and Wikipedia) or six translations and that are significant with $P < 0.01$. 

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Mapudungun. In both cases, however, English and Spanish are still involved in the flow of information, indicating that they act as global languages. In the first example, Spanish and English have a direct involvement because communication is flowing among their speakers. In the latter case, the involvement is indirect and emerges from the lack of speakers that can communicate in both Vietnamese and Mapudungun. These indirect connections make multilingual speakers of global languages globally influential, as they mediate the flow of information not only among each other, but also, among people with whom they do not share a language (6).

**Influence of Global Languages**

The position of a language in the global language network is expected to affect the visibility of the content produced by the speakers of a language and also the flow of information among the speakers of different languages. Intuitively, better connected languages should increase the visibility of the content produced by their speakers: if information radiates from the more connected to the less connected languages, it will be easier for an English speaker than for a Nepali speaker to become globally famous.

The position of a language in the GLN, however, also affects the flow of information that is not produced in that language. The degree to which a language is global generates incentives to create content in that language and to translate content produced in less-connected languages into that language. For example, a reporter wishing to disseminate news about a major event around the world has an incentive to translate the news into a global language or to report the news in a global language to begin with (7). The position of a language in the global language network therefore affects the diversity of international information available to its speakers, the speed with which they receive international information, and their ability to disseminate information to the speakers of other languages.

Creating a map linking languages that are likely to be co-spoken is an important step for understanding the relevance of the global language network in the diffusion of information. In this paper, we map three GLNs to develop a metric of the degree to which a language is global and validate these networks by showing that the centrality of a language in the GLN is strongly correlated with the number of famous people born in that language.

**Data**

There is no single GLN because different sets of speakers share different kinds of information across different sets of languages for different purposes. Accordingly, we map three different versions of the GLN using data from Twitter, Wikipedia, and UNESCO’s *Index Translationum* (IT), an international index of printed book translations (8).

Going forward, we note that the resulting networks represent patterns of linguistic coexpression not among the entire human population but among the kinds of speakers and texts that contributed to the respective datasets. The populations are confined to literate speakers and, in turn, to a subset of social media users (Twitter), book translators (Index Translationum), and knowledgeable public-minded specialists (Wikipedia). Additional datasets could be used to map the language networks of other groups as long as these datasets cover the linguistic expression of a large fraction of multilingual speakers. To that extent, monolingual resources, such as the Chinese microblogging service *Sina Weibo*, the Russian social network *VK*, or the Chinese encyclopedia

**Fig. 2.** Similarity of the three independent datasets we use for mapping the GLNs. The top row shows the correlation between the number of expressions for each language across the three datasets: (A) Wikipedia editors in a language and book translations from a language; (B) Twitter users in a language and book translations from a language; and (C) Twitter users and Wikipedia editors. The bottom row shows the correlation between the number of coexpressions for language pairs across different datasets: (D) common Wikipedia editors and book translations; (E) common Twitter users and book translations; and (F) common Twitter users and common Wikipedia editors. In D and E, we symmetrized the book translation network by considering the average of translations from and to a language.

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Baidu Baike, do not represent resources that can be used to map connections between global languages.

The elites that participate in Twitter, Wikipedia, and book translations are not representative of the entire human population, yet they still represent groups that are worthy of study because elites often drive the cultural, political, technological, and economic processes with which observers of global language patterns are concerned.

We compiled our Twitter dataset from more than one billion tweets collected between December 6, 2011, and February 13, 2012. The language of each tweet was detected using the Chromium Compact Language Detector (9), after removing misleading expressions, such as URLs, hashtags, and @ mentions. We used only tweets that the language detector identified with a certainty score higher than 90% (SI Appendix). Our final dataset consists of nearly 550 million tweets in 73 languages generated by more than 17 million unique users, which represented more than 10% of Twitter’s active users at the time the data were collected. Two languages are connected when users that tweet in one language are significantly more likely to also tweet in the other language (Eq. 1).

The Wikipedia dataset was compiled from the edit histories of all Wikipedia language editions as recorded by the end of 2011. After removing edits made by Wikipedia’s maintenance bots and applying the filters described in SI Appendix, the dataset contains 382 million edits in 238 languages by 2.5 million unique editors. Here, two languages are connected when users that edit an article in one Wikipedia language edition are significantly more likely to also edit an article in the edition of the other language (Eq. 1).

The LT dataset consists of 2.2 million translations of printed books published between 1979 and 2011 in 150 countries and more than a thousand languages (SI Appendix). The dataset records translations rather than books, so it does not list books that have not been translated. Moreover, the LT dataset counts each translation separately. For example, LT records 22 independent translations of Tolstoy’s Anna Karenina from Russian to English. In mapping the network, we treat each independent translation separately, and in this case, count 22 translations from Russian to English. Also we note that the source language of a translation recorded by LT can be different from the language in which the book was originally written. For example, at the time we retrieved the data, the LT recorded 15 translations of The Adventures of Tom Sawyer to Catalan, of which only 13 were translated directly from English; the two other translations came from Spanish and Galician versions. This characteristic of the dataset allows us to identify languages that serve as intermediaries for translations.

In all three cases, we collapsed mutually intelligible languages following the ISO 639-3 standard (10). For example, Indonesian and Malaysian were both coded as Malay, and the regional dialects of Arabic are all coded as Arabic. Further information on data preparation procedures can be found in SI Appendix.

Results

Mapping a Global Language Network. We begin our construction of these three GLNs by identifying the links that are statistically significant with respect to the population of speakers expressed in each dataset. By definition, a statistically significant connection is a connection where the probability of finding a speaker, or record, connecting languages i and j is larger than what we would expect based on the prevalence of these languages alone [P(i,j) > P(i)P(j)]. To determine the strength and significance of each connection, we use the standard methods of ϕ correlation and t statistic, which are defined as follows.
Let $M_j$ be the matrix representing the number of common users or number of translations from language $i$ to language $j$. Then the correlation $\phi_{ij}$ between languages $i$ and $j$ is given by

$$\phi_{ij} = \frac{M_i N - M_i M_j}{\sqrt{M_i M_j (N - M_i) (N - M_j)}}$$  \hspace{1cm} [1]$$

where $M_j$ represents the number of multilingual users (or translations) expressed in language $i$ ($M_i = \sum M_j$), and $N$ represents the total number of users or translations in the dataset. $\phi_{ij}$ is positive for pairs of languages that co-occur more often than expected based on their representation in the dataset alone and is negative otherwise. To assess the statistical significance of these correlations, we use the $t$ statistic, which is given by

$$t_{ij} = \frac{\phi_{ij} \sqrt{D - 2}}{\sqrt{1 - \phi_{ij}^2}},$$  \hspace{1cm} [2]$$

where $D - 2$ represents the degrees of freedom of the correlation. Here we consider $D = \max(M_i, M_j)$ as it provides more stringent criteria for finding a correlation than using $D = N$.

Finally, we construct our network by considering only links that are statistically significant with $P < 0.01$ ($t_{ij} > 2.59$ for $D > 20$; one-tailed). Also, we consider only links for which $M_j \geq 6$ to avoid false positives that could emerge due to small statistics. In sum, we discard links when either $t_{ij} \leq 2.59$ (they are statistically insignificant) or $M_j < 6$ (the sample size is too small). We note that, by definition, a null model network would contain no links because none of the links of a null model network would satisfy the statistical significance condition ($t_{ij} > 2.59$). We also note that the book translation GLN is directed, unlike the Twitter and Wikipedia GLNs, because we know the source and target of each translation. For the book translation network we assessed the significance of each directed link separately and kept zero, one, or both directed links between any given pair of languages.

The Structure of Three GLNs. To understand the relative importance of each language, we begin by visualizing the three GLNs (Fig. 1). In this visualization, each node represents a language. Node sizes are proportional to the number of speakers (native plus nonnative) of each language (11). Node colors indicate language families and link colors show the significance of the link (according to its $t$ statistic). Finally, link widths show the total number of co-occurrences or translations ($M_{ij}$).

The three GLNs share a number of features, even though they capture information about the linguistic expression of different communities. First, the representation or number of expression of each language—number of Twitter users, Wikipedia editors, or translations from a language—correlates strongly across the three datasets (Fig. 2 A–C). Moreover, the coexpressions—number of common twitter users, Wikipedia editors, and average number of book translations from and to a language—are also positively correlated across the three datasets (Fig. 2 D–F). This correlation means that a language with a high or low coexpression to another language in one GLN is likely to have a high or low coexpression with that same language in the other GLNs. The positive correlations of expressions and of coexpressions across GLNs suggest that the three networks, although representative of their own respective populations, are similar in terms of the size of the populations observed in them and the strength of their links.

It is interesting to note that the similarities observed between the networks appear to conform to their gradient of formality, defined in terms of the literary capacity required by a speaker to participate of each of these global forums. The book translation network is the most formal (as it involves published authors and professional translators) and Twitter is the least formal (as it consists of short, instant messages that anyone with internet access can write). Wikipedia takes the middle ground between Twitter and book translations in terms of formality, and its GLN takes the middle ground also in terms of similarity. The $R^2$ between the representation of a language in the Wikipedia GLN and in the book translation GLN is 63% and between the Wikipedia GLN and the Twitter GLN is 66%. For coexpressions, the $R^2$ is 41% and 63%, respectively. By contrast, the similarity between the representation of languages in Twitter and book translations is $R^2 = 40\%$, and their similarity in coexpression is only $R^2 = 23\%$, meaning that the Twitter and book translation
networks are the most dissimilar. Finally, we note that compared with the book translation dataset, the two digital datasets (Twitter and Wikipedia) exhibit a larger share of languages associated with developing countries—such as Malay, Filipino, and Swahili—which could indicate that these less formal channels of communication are more inclusive of the populations of developing countries than written books.

The Position of Languages in the GLN. Next, we study the relationship between the position of a language in the GLN and the global cultural influence of its speakers. We measure the position of a language in the GLN using its eigenvector centrality (12); for other centrality measures, see SI Appendix. Eigenvector centrality (which is also the basis for Google’s PageRank algorithm) considers the connectivity of a language as well as that of its neighbors, and that of its neighbors’ neighbors, in an iterative manner. Hence, eigenvector centrality rewards hubs that are connected to hubs.

To measure the global influence of the speakers of a language, we use two datasets that estimate the number of famous people associated with each language. First, we compiled a list of the 4,886 biographies of people who were born between 1800 and 1950 across different languages using the same method used for the Wikipedia dataset. We distributed the contribution of the 1,655 people on this list born between 1800 and 1950 across different languages using the same method used for the Wikipedia dataset (SI Appendix).

The second measure of famous people is based on Human Accomplishment, a published volume listing 3,869 individuals that have made significant contributions to the arts and sciences before 1950 (13). We distributed the contribution of the 1,655 people on this list born between 1800 and 1950 across different languages using the same method used for the Wikipedia dataset (SI Appendix).

SI Appendix. Fig. S5 compares these two independent measures of fame by looking at the correlation between the scores reported in Human Accomplishment and the number of different language editions in which a biography is present in Wikipedia. The correlation between both datasets is mild but significant ($R^2 = 0.25, P < 0.001$). The mild correlation between the two datasets highlights the robustness of results that hold for both datasets: the differences between the two datasets imply that a result obtained for one does not need to hold for the other merely because of the colinearity of the data.

Fig. 3A–C shows the bivariate correlation between the number of famous people measured using the Wikipedia dataset and the eigenvector centrality of that language in the Twitter, Wikipedia, and book translation networks. We only use languages that are present in all three GLNs and that are associated with one or more famous character. The regression table in Fig. 4 compares the effects of several independent variables: the combined effect of its population and income (combined) and the effect eigenvector centrality in each of the GLNs. The variables are introduced sequentially. We use gross domestic product (GDP) to indicate income; see SI Appendix for an explanation of the method used to calculate the population and GDP of a language.

With the exception of the Twitter dataset, the correlation between the number of famous people and the eigenvector centrality of a language is similar to or higher than the correlation observed between the number of famous people and the income and population of the language combined using both nested models (column 1 vs. 6 and 7 and columns 3 and 4 vs.
observed. Future assessments of temporal changes in the structure of the GLNs (which will be possible as data for a longer period of time becomes available) can identify whether English is gaining or losing influence with respect to the languages of rising powers such as India or China. Such changes, as well as the differences between GLNs based on traditional media (printed books) and new media (Twitter and Wikipedia), may help predict a language’s likelihood of global importance, marginalization, and, perhaps in the long term, extinction. GLN centrality can therefore complement current predictions of language processes, which rely mostly on a language’s number of speakers (15).

Discussion
In this paper, we used network science to offer a previously unidentified characterization of a language’s global importance. The GLNs, mapped from millions of online and printed linguistic expressions, reveal that the world’s languages exhibit a hierarchical structure dominated by a central hub, English, and a halo of intermediate hubs, which include other global languages such as German, French, and Spanish. Although languages such as Chinese, Arabic, and Hindi are immensely popular, we document an important sense in which these languages are more peripheral to the world’s network of linguistic influence. For example, the low volume of translations into Arabic, which had been identified as an obstacle to the dissemination of outside knowledge into the Arab world (14), is indicated by our book translation GLN and matched by the peripheral position of Arabic in the Twitter and Wikipedia GLNs.

One might argue that the peripheral position of Chinese, Hindi, and Arabic in the GLNs stems from biases in the datasets used, such as the underrepresentation of these languages and some regional languages to which they connect. However, although these languages may be central in other media, their peripheral role in three global forums of recognized importance—Twitter, Wikipedia, and printed book translations—weakens their claim for global influence. Moreover, Chinese, Hindi, or Arabic would not qualify as global hubs even if their connections to regional languages were better documented in our datasets, because a global language also links distant languages and not just local or regional ones.

The structure of the three GLNs documented here also raises important questions involving the dynamics of the networks observed. Future assessments of temporal changes in the structure of the GLNs (which will be possible as data for a longer period of time becomes available) can identify whether English is gaining or losing influence with respect to the languages of rising powers such as India or China. Such changes, as well as the differences between GLNs based on traditional media (printed books) and new media (Twitter and Wikipedia), may help predict a language’s likelihood of global importance, marginalization, and, perhaps in the long term, extinction. GLN centrality can therefore complement current predictions of language processes, which rely mostly on a language’s number of speakers (15).