

Circadian Patterns of Wikipedia Editorial Activity: A Demographic Analysis

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Abstract

Wikipedia (WP) as a collaborative, dynamical system of humans is an appropriate subject of social studies. Each single action of the members of this society, i.e., editors, is well recorded and accessible. Using the cumulative data of 34 Wikipedias in different languages, we try to characterize and find the universalities and differences in temporal activity patterns of editors. Based on this data, we estimate the geographical distribution of editors for each WP in the globe. Furthermore we also clarify the differences among different groups of WPs, which originate in the variance of cultural and social features of the communities of editors.

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Introduction

Relying on the data gathered by recently developed information and communication technologies (ICT), studies on social systems has entered into a new era, in which one is able to track and analyze the behavior of a large number of individuals and the interaction between them in details. Among all examples, recent investigations based on cell phone records (calls [1] and text messages [2]) and web-based societies and media (web-pages [3], movie, news and status sharing sites e.g., YouTube.com [4], digg.com [5] and twitter.com [6]) have opened very interesting insights into features of collective and cooperative dynamics of human systems. Wikipedia (WP) as a free, web-base encyclopedia, which is entirely written and edited by volunteers from all around the world, has also attracted attention of many researchers recently [7–10] (for a recent review, see [11]). To study WP, understand and model its evolution [7], coverage [12], conflicts or editorial wars [13,14], user reputation [15] and many other issues, we should obtain basic information about the community of its editors, i.e., their age, education level, nationality, individual editorial patterns, fields of interest and many other aspects. Yet, there has been rare systematic and unbiased studies in this direction. The main barrier here is the privacy issues, which prohibit any attempt to obtain personal data of committed editors.

There are two ways of contributing to Wikipedia. The first way is editing as an unregistered user; in this case all the edits are recognized by the IP address of the editor, and therefore it becomes easy to locate the editor and collect some geographical information about him/her. But most of the editors take a second way which is editing under a registered user name, which hides the real world identity and IP address of the editors and therefore is a much more secure way of contributing. Moreover, contributions of

such serious editors are identified and unified under one single nickname, irrespective of which IP address they use to connect to the network and can be counted as a measure of maturity in the promotion processes. Cohen has extracted geographical data from IP addresses of unregistered editors of English WP, integrated them over time and concluded that about 80% of edits on English WP are originated from few English speaking countries with high Internet penetration rate, i.e., 60% from the USA, 12% from UK, 7% from Canada and 5% from Australia [16]. However, contributions from unregistered editors are limited to less than 10 percent for many WPs (see Table 1). Moreover the rather small sample of unregistered users, is not representing the features of average users, as will be discussed later. Therefore, indirect methods to locate editors or to obtain any kind of information about the community is highly desirable. One of our aims is to show that using the temporal patterns of WP users, conclusions about the geographical distribution of (registered) editors can be drawn.

Recently much effort has been devoted to describe and understand the extreme temporal inhomogeneity of human activities, represented by the burstiness of activities and the fat-tailed distribution of time intervals between events [17]. While the circadian and other periodic characteristics of temporal patterns of human activities cannot account for the whole richness of bursty behavior [18], they remain important for understanding the entire dynamics of the systems. These regularities are induced by circadian and seasonal cycles of the nature [19] on one hand and by cultural aspects on the other one. Consequently, studies on circadian patterns of the Internet traffic have brought interesting information about individual habits of the Internet usage in different societies [20,21]. In this paper our focus is on such cyclic behavior, while investigations on other aspects of temporal

Table 1. Wikipedias Statistics.

WP	Language	M. Country	Speakers	Articles	Edits	Users	Active	IP%	Offset	S. D.
Ar	Arabic	*	255	146	8	368	2433	12	+2 [‡]	2.5
bg	Bulgarian	Bulgaria	9	115	4	89	848	14	2	4.4
ca	Catalan	Andorra	7	337	7	85	1749	6	0	5.2
cs	Czech	CzechRep.	11	192	6	146	2329	9	1	4.3
da	Danish	Denmark	5	147	5	128	1364	10	1	4.3
de	German	Germany	128	1214	91	1205	24519	16	1	5
en	English	-*	600	3609	455	14340	151549	10	-6 [†]	2.7
eo	Esperanto	- [‡]	2	143	3	49	466	6	+1 [▲]	3.5
es	Spanish	-*	460	748	48	1789	15647	26	+1 [△]	4.4
fa	Persian	Iran	110	124	6	217	1890	5	3.5	2.7
fi	Finnish	Finland	5	266	10	175	2060	16	2	4.8
fr	French	France	172	1088	68	1037	16546	14	1	4.5
he	Hebrew	Israel	5	116	11	140	2020	31	2	4.5
hu	Hungarian	Hungary	13	187	10	167	2055	6	1	5.3
id	Indonesian	Indonesia	160	159	5	247	1881	9	8	2.6
it	Italian	Italy	62	790	43	620	8279	18	1	5.6
ja	Japanese	Japan	126	743	37	510	10571	37	9	4.8
ko	Korean	Korea	67	159	7	147	1916	14	9	3.4
lt	Lithuanian	Lithuania	3	131	3	46	497	7	2	4.6
nl	Dutch	Netherlands	20	681	25	381	5125	10	1	5.1
no	Norwegian	Norway	4	297	9	194	2413	8	1	4.7
pl	Polish	Poland	44	793	27	425	5403	14	1	5.2
pt	Portuguese	-*	230	680	25	852	5770	20	0 [§]	4.2
ro	Romanian	Romania	27	158	5	181	1255	7	2	3.6
ru	Russian	Russia	277	699	35	652	12841	16	3	4.3
simple	sim.English	-*	-	69	2	176	746	13	-6 [†]	2.3
sk	Slovak	Slovakia	5	122	3	58	612	7	1	3.7
sl	Slovenian	Slovenia	1	109	2	78	579	4	1	3.8
sr	Serbian	Serbia	11	141	4	81	672	5	1	3.5
sv	Swedish	Sweden	9	392	14	221	3467	14	1	4.5
tr	Turkish	Turkey	75	158	9	337	2499	24	2	4.5
uk	Ukrainian	Ukraine	37	274	6	99	1929	5	2	4
vi	Vietnamese	Vietnam	86	201	4	223	1156	8	7	2.7
zh	Chinese	China	1300	351	16	984	5696	13	8	3.7

*For the languages which are widely spoken in the world, the origin country is not well-defined.

[‡]Esperanto has never been an official language of any country.

[‡]Egypt (the most populated Arab country) time zone.

[†]USA Central standard time zone.

[▲]Central European time zone.

[△]Spain time zone.

[§]Portugal time zone.

Statistics about WPs under investigation. Name of the WP, language, the most populated country, in which the language is spoken, and total number of speakers in the world (millions) are reported in columns 1 to 4, followed by number of articles (thousands) in the WP, number of edits (millions), number of users (thousands), number of active users (users which have edited in the last month), and the percentage of edits by unregistered users (known by their IP-addresses) to the all edits. Two last columns consist of the assigned UTC offset to each WP and the Sleep Depth respectively. The demographic data is taken from Wikipedia and supposed to give an impression to the reader. In the paper, there is not any analysis based on this data.

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inhomogeneities like short time bursty behavior and inter-event interval distributions are reported elsewhere [22].

West et. al. have tried to make use of circadian characteristics of edits to detect vandalism and destructive edits [23]. Their study was again restricted to tracking positive and negative edits from unregistered editors, for which they found that most of the

“offending edits” are committed during the working hours and working days compared to after-darks and weekends. In the admin-ship of Wikipedia it is also becoming fashionable to use the personal temporal fingerprint of editors as a side-tool to detect and prevent sock-puppetry, which is the use of multiple accounts to deceive other editors, disrupt discussions, distort consensus, avoid

sanctions, etc. Although this could only be done with high respect to the privacy policies of Wikimedia Foundation (see http://wikimediafoundation.org/wiki/Privacy_policy).

In this work, we first try to characterize the circadian pattern of edits on Wikipedia, by analyzing massive data of 34 WPs, then we introduce a novel method to locate and find geographical distribution of the editors of large international WPs, e.g., English, simple English, Spanish, etc. Furthermore, we analyze the temporal behavior of editors on longer time scales, i.e. weekly patterns and report on significant differences between various societies.

Methods

This work is carried out on 34 WPs selected from the largest ones in respect to the number of articles, i.e., those ones, which have more than 100,000 articles. However, two Wikipedias of Volapük and Waray-Waray are excluded from the list due to their small number of speakers and Wikipedians and considering that many of articles are robotically generated. The simple English Wikipedia is also included in the list, despite it contains only around 70,000 articles. Among the sample, number of total edits and editors vary between 3 M to 455 M and 46 k to 14 M, respectively. In Table 1 some statistics about the WPs under the investigation are reported.

We considered every single edit performed on each WP and having the timestamps assigned to edits, calculated the overall activity of users for the time of day and day of the week. To see the universality of circadian activity patterns among editors of all different languages, we assumed a local time offset for each language. Clearly there are some languages which are not spoken only in one country or one time zone, e.g., Spanish, Arabic, etc, whereas some others are very localized in a specific time zone, e.g.,

Italian, Hungarian, etc. For the first sort of languages, we initially considered the time offset of the most known origin of the language. For the special cases of the English and simple English Wikipedias, initially we considered an offset corresponding to USA Central Time. In the ninth column of Table 1, the assigned time offset to each language is reported. Note that, due to lack of information such as IP addresses of users, this initial assumptions for the origin of edits and corresponding time offset can not be any improved at this step. It is one of our goals to implement a method, based on the average behavior of WP editors, which is able to determine the percentage of the contributions coming from different geographic units. This method will be described in the next section in sequence with the empirical observations.

Results

Circadian patterns

We calculated the normalized number of edits for each of the 34 WPs with the consecutive time windows of one hour for the 24 hours of the days. The rational activity level of each time window is calculated by dividing the number of edits within the time window by the total number of edits.

This way the circadian activity patterns are created as depicted in Figure 1 (a). Most WPs show a universal pattern; A minimum of activity at around 6 A.M., followed by a rapid increase up to noon. The activity shows a slight increase until around 9 P.M., where it start to decrease during night. Qualitatively similar shapes are observed for other kind of human activities, e.g. cell phone callings and textings [18], and the Internet instant messaging [24].

Deviations. Among all 34 investigated WPs, there are four, which significantly deviate from all the others in respect to the circadian patterns in Figure 1 (c) and (d) circadian activity for these four outliers, Spanish, Portuguese, English and simple English

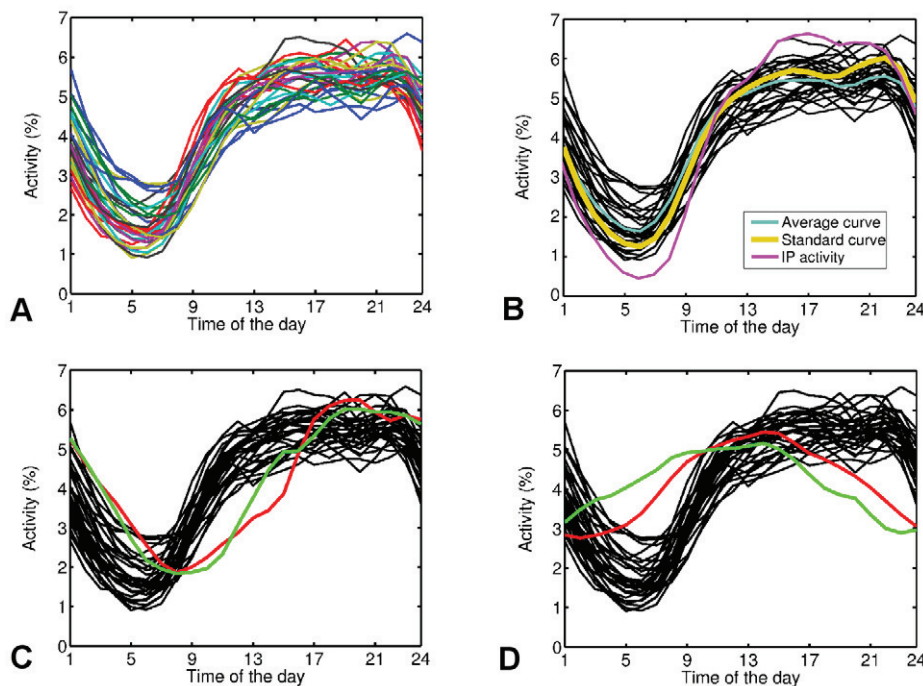


Figure 1. Normalized activity of editors. For (a) all WPs listed in Table 1 excluding English, simple English, Spanish and Portuguese, (b) the average curve extracted from curves in (a) and standard curve extracted from 10 most localized WPs along with the activity curve of unregistered users, whose IP-addresses are known and therefore one is able to locate them and obtain the local time zone precisely (c) activity pattern of Spanish (red) and Portuguese (green) WPs, and (d) activity pattern of English (red) and simple English (green) WPs. doi:10.1371/journal.pone.0030091.g001

WPs are shown. In the case of Spanish and Portuguese, the main difference to the rest WPs, is the slight shift to the right (later times). Having in mind that Spain and Portugal both use local times which have a larger offset compared to the countries with the same longitude, this comes as no surprise. Beside that, the rather large number of speakers from Latin America not only is in favor of this shift, but also flattens the overall amplitude of the circadian pattern (this will be discussed later in more details). And finally the cultural features of those two countries might contribute to this observation.

In the case of the English and simple English WPs, for simplicity, we assumed the reference being UTC-6 (which corresponds to the Central Time Zone of the US). Naturally the deviations from the universal pattern are very strong, indicating the complex origin of the English WP. Later we will come back to this point.

To better illustrate the deviation from an average circadian pattern, we calculated the weighted average of curves in Figure 1 (a). Each WPs pattern is weighted by its total number of edits. The average curve is depicted in Figure 1 (b). Now we can calculate the difference from this average pattern for each WP, $\mathcal{D}(t)$ at different times of the day t . According to the shape of $\mathcal{D}(t)$ and by maximizing the cross-correlation coefficient, almost all WPs could be categorized in 4 categories as in Figure 2. Two of these categories, Figure 2 (a) and (c) consist of WPs which have less activity during nights compared to the average pattern.

These WPs are all in such European languages, which are spoken in single, localized regions and therefore the minimum of activity of their editors is deeper than others. In Figure 2 (b), a category consisting of Asian languages is shown. These WPs are more active during nights and less active during working hours compared to the average. In the last category, shown in Figure 2 (d), a higher activity during night and a lower activity during

working hours is a clear sign of an extended distribution of contributors from different time zones. Arabic, Persian, Chinese are from this category in addition to Spanish, Portuguese, English and Simple English (not shown).

The other way to look at the locality of the languages is to quantify the *sleep depth*. Sleep depth is defined as the difference between the maximum and the minimum of the activity of each language users and might be assumed as a measure of the locality of the global distribution of the editors of the corresponding language. In the last column of Table 1, the calculated depth values are reported. These values vary from 2.3 for simple English to 5.6 for Italian. Among those WPs with small sleep depth are Arabic, Indonesian, Persian and English. The average sleep depth for the category of Fig. 2(d) is 2.8 with standard deviation of 0.4.

Among languages with the large sleep depth are Italian, Hungarian, Polish, Catalan, and Dutch. These are all languages which are mostly spoken in a narrow area of the world and therefore are very localized in time zones. The average sleep depth for the category of Fig. 2(c) is 4.9 with standard deviation of 0.4. It is also to mention, that although Spanish and Portuguese are both widely spoken in different areas and different time zones, but the sleep depth of both lay in the middle range (4.4 and 4.2 respectively). For a more precise interpretation we try to estimate the share of editors from different areas to each WP in the next section.

Geographical distribution of editors. As mentioned above, due to privacy policy issues, there is no access to the locating information of registered editors, such IP addresses. However there are studies only considering contributions by unregistered users which give a very rough image of the real distribution of editors in the globe [16]. We aim at a better method by decomposing the overall activity pattern of each WP to basic elements, which are assumed to be representative for contributions

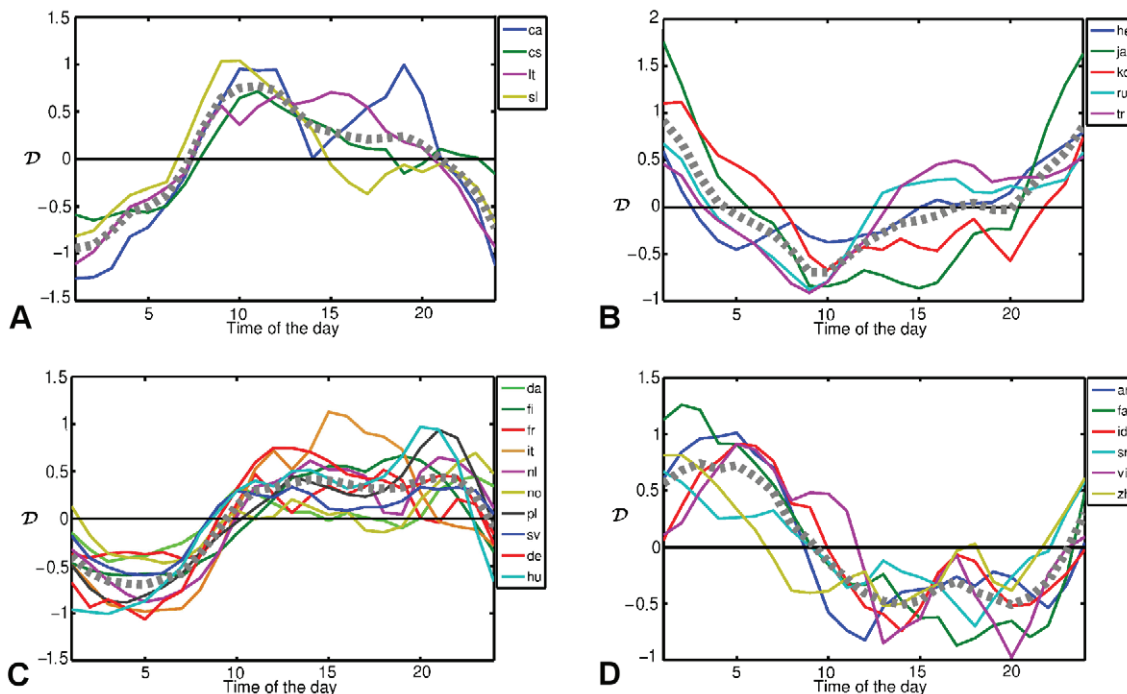


Figure 2. Deviation of activity patterns from the average curve, leading to 4 different categories of WPs. The gray dotted line is the average deviation of each category. The sleep depth (for the definition, see the text) of for categories a–d are 4.5 ± 0.2 , 4.3 ± 0.2 , 4.9 ± 0.1 and 2.8 ± 0.2 respectively.

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purely originated from a certain time zone. For this purpose, we averaged over activity patterns for the 10 WP with the deepest sleep to obtain a smooth curve, which has the features of collective activity of users in synchrony (hereafter called Standard curve $\mathcal{S}(t)$). In the next step, we assume that the activity pattern of a WP, $\mathcal{A}(t)$ with wide spatial distribution of editors can be simulated by superpositions of N standard curves with different time shifts τ_i and different weights w_i for $i=1$ to N ,

$$\mathcal{A}(t) = \sum_{i=1}^N w_i \mathcal{S}(t - \Delta\tau_i) \quad (1)$$

where $\Delta\tau_i$ is the difference between τ_i and the assumed time offset of the language (see Table 1).

In general, one could minimize the error of the simulated activity pattern for each WP for $N=24$ different offsets and find the optimal weighting. Clearly, weights are proportional to the volume of contributions from each time zone. Following this outline we did the optimization, but in a more supervised manner. We restricted N to the number of different time zones, which are relevant candidates for being an origin of contribution, e.g., we excluded time zones of nonliving areas of the earth. Furthermore, to reduce the complexity of calculations and also avoid multiple solutions, we reduced N to the number of areas, which have considerable number of speakers of the language. In many cases, by superposition of N between 3 to 6 standard curves, we could fit the empirical data with a high value of correlation coefficient between the simulated and imperial data sets (see Figure 3), whereas taking larger N s does not decrease the error and it only leads to more zero w_i 's. Finally, by a proper combination of demographic information and optimization techniques, we estimated the share of different regions to 9 different WPs. These estimations are summarized in Figure 4. Though in some cases the

error function is rather flat around its minimum, leading to relative large tolerance in calculated weights, existence of separated multiple minimums is prohibited by applying the demographic restrictions.

Weekly patterns

We also considered the activity of editors during weeks and its dependence on the day of the week. These results are shown in Figure 5. According to the weekly pattern of activity, we could categorize 28 out of 34 WPs into 4 different categories which belong to two main categories of “working days” and “weekend” activity. In the upper-left panel of Figure 5, those WPs are shown, which have highest activity of editors during the working days of the week. Among them, are English, simple English, German, Spanish, Portuguese and Italian. In the rest of WPs, a big part of edits are done during weekends. In the class of Polish, Dutch, Korean and Japanese WPs (upper-right panel of Figure 5) equal activities are shown on Saturdays and Sundays, whereas in the class of Danish, Swedish, Norwegian and Finnish WPs, editors have very low activity on Saturdays. The last class of the “weekend” WPs, consists of Arabic and Persian WPs, in which Fridays are also active days in addition to Saturdays and Sundays. The latter is no surprise, considering that Friday is a public holiday in all of the original countries along with Saturday in most of them.

Discussion

The novel approach to the collective characteristics of community of editors of WPs, described above, enables us, for the first time, to shed light on less studied aspects of Wikipedia. Based on the reported results, many basic questions and concerns about the whole projects of Wikimedia can be investigated. Knowing the spatial distribution of the editors of a certain WP

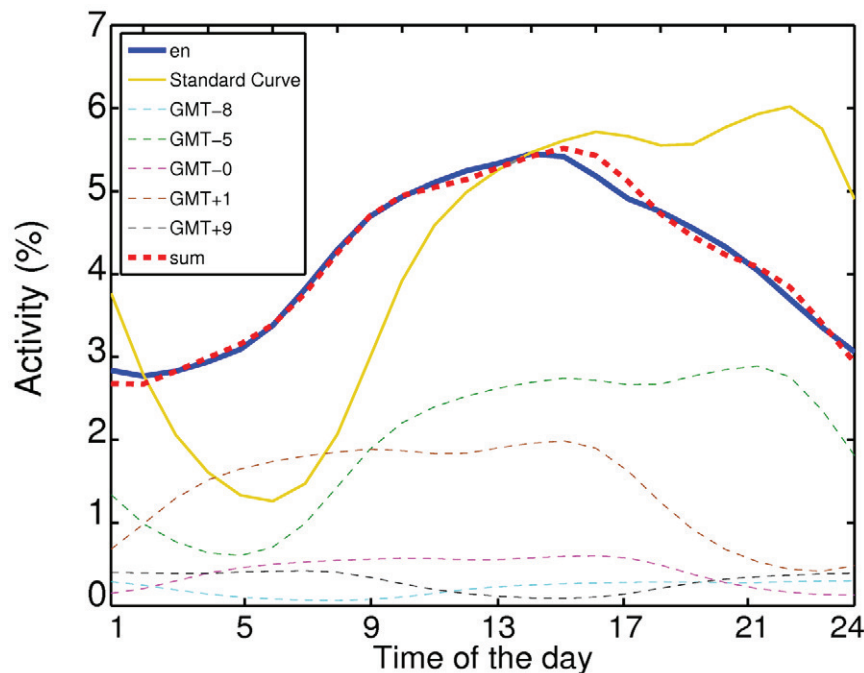


Figure 3. Decomposition of activity pattern of English WP into 5 shifted standard curves with different weights. The blue line is the empirical data, the yellow curve is the *standard curve* (see the text for the definition), the thin dotted lines are shifted and weighted standard curves, and the red dotted line is the linear superposition of them which models the empirical data properly. doi:10.1371/journal.pone.0030091.g003

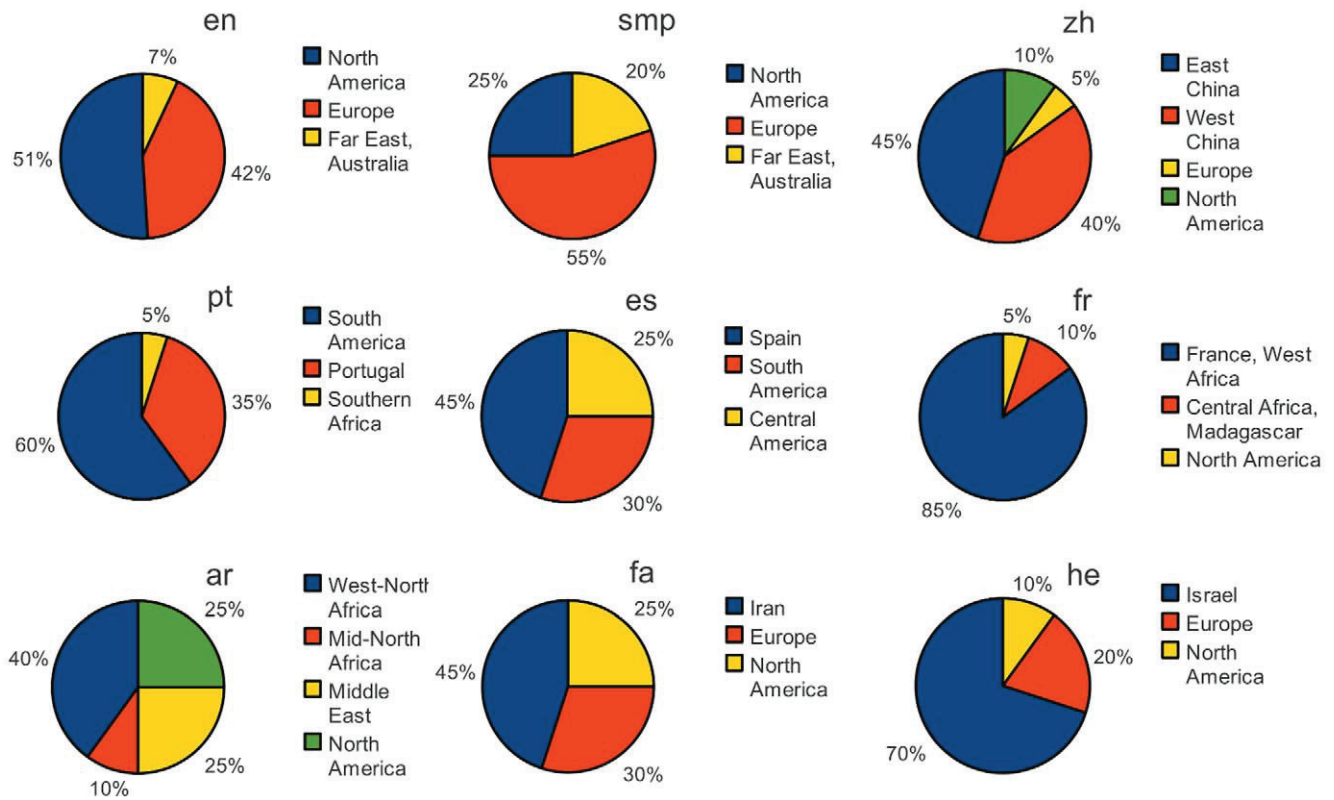


Figure 4. Estimation of users contribution from different regions. By precisely combining the outputs of the optimization process, described in the text, and demographic data of each language, the share of each region to each WP is estimated. For the sake of accuracy in reporting the results, in some cases the contributions of regions closely located, are unified.
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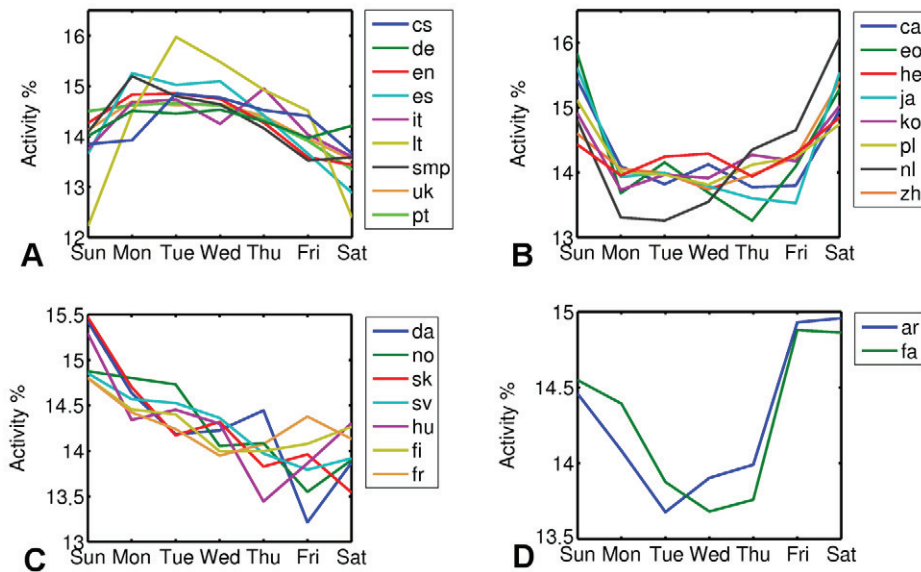


Figure 5. Activity of editors on different days of the week, categorized in 4 subcategories. There are two major categories of weekend, (b)–(d) and weekdays (a) activity. Please note that WPs in (d) are languages spoken mostly in Muslim countries, which have either ThursdayFriday weekend (Saudi Arabia, Oman and Yemen), or FridaySaturday weekend (Algeria, Bahrain, Egypt, Iraq, Jordan, Kuwait, Libya, Qatar, Sudan, Syria, United Arab Emirates), or, SaturdaySunday weekend (Morocco, Tunisia). In Iran and Afghanistan, Persian spoken countries, only Friday is considered as weekend.
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would be reliable basis for explaining specific biases in WP articles, heterogeneous topical coverage and origins of conflicts and editorial wars to some good extent. In addition to that, these results arise new questions and puzzles as well. Considering the large population of English speakers in North America compared to Europe, and the fact that the Internet is most developed in North America, the estimation of around only half share for north America to English WP is a puzzle, which definitely needs further multidisciplinary studies. In the case of Simple English WP, the European share is even larger, which is not surprising, together with the fact that the share of Far East increased, since this WP is meant to be of use by non-native speakers (though, not necessarily written by them). Note that previous results of [16] and [23] are partially supported by the results reported here. For instance, a share of less than 10% for Australian editors in English WP is in both articles reported. Unfortunately, there is no explicit focus on the contributions from European countries in the mentioned works, and it seems the large amount of efforts by European editors was overlooked. However we have repeated the measurements on IP addresses of unregistered users more generally for different WPs by following every single edit from this type to locate the editor. Firstly, we constructed the “precise” activity pattern of unregistered users, as shown in Fig. 1(b). The activity pattern of unregistered users has clearly deeper minimum at night and higher maximum during working hours, compare to most of the other curves. Unregistered users contribute to WP occasionally and mostly only with few edits from the same IP address. To be actively editing even at nights, one must be extremely committed to WP, therefore the deep sleep of the activity curve of unregistered users comes as no surprise. We believe the sample of unregistered users is more representing the activity of WP readers who edit rarely as they notice needs to tiny modifications here and there while reading the articles than committed users who basically write the main body of the articles. The percentage of contributions by unregistered users is measured and reported in Table 1 for all 34 WPs. This value varies between 4 for Slovenian and 37 for Japanese WP. We compared the results for geographical distribution of editors obtained by locating them with the IP addresses to the previous results described above and observed that, both methods mainly give similar results for the WPs with rather larger share of unregistered users, whereas they deviate for WPs with small share of unregistered users. Finally, one should consider the fact that the committed users, sometimes edit without using their registered user name to vandalize or edit specific controversial articles without leaving any trace which may cause troubles for the original user name. In such cases, most of the time an “open proxy” (with an arbitrary IP address) is used to hide the real IP address of the editor. This makes the analysis based on IP addresses even looser.

Another interesting part of the results is on Persian WP. Although more than 70% of native Persian speakers live in Iran and the rest in closely neighboring countries, but the corresponding WP appears in the top list of WPs with small sleep depth. In addition, the estimated share for edits from Iran is only about 45%. This could be due to the following facts. 1) Strong restrictions on the Internet usage have been applied by Iranian government during years as a consequence of socio-political issues, e.g., Wikipedia is one of the few remaining unbanned Web.2.0 web sites currently in Iran., which makes it difficult to contribute to WP using Iranian based ISPs. 2) Iran has a high rate of immigration of students and scholars. That has led to formation of large intellectual communities out of Iran, which might be responsible for considerable amount of edits in Persian WP.

Low level of contribution to the French WP by North American editors and to the Arabic WP by Egyptian editors, could have roots in the differences between the spoken dialects and the standard languages. Though both languages (French and Arabic) are among the official languages in the mentioned regions, it seems that the divergence between dialects play an important role to suppress contributing to WP. It should be mentioned, that there is a separate WP in the local dialect of Egypt, (*Egyptian Arabic Wikipedia*) and there has been an unsuccessful effort to launch the *Canadian French Wikipedia* recently. Therefore we think that the estimations for contributions could be of interest for the WP community too and elaborate the process of decision making for a new WP in a local dialect.

Clearly, the presented method also has its limitations. For instance, accessing to information about the distribution of editors in different longitudes is impossible by only considering the time stamps. Moreover the resolution of the regional estimations are not very high. Because of many factors, e.g. applying summer time in many countries the method can not claim at a resolution higher than a one hour stripe. For example, in the case of English WP, the supervised optimization results in a ratio of 3 for the weight of GMT+1 over GMT+0, corresponding to Central Europe and Western Europe times. But because of the mentioned reasons, distinction between the share of the very close time zones is not justifiable. Moreover, in some cases the error of the simulated activity pattern is not very sensitive to changes in weights of spatially closed offsets. However, all the results presented above are precise up to the last significant digit.

Putting beside the deviations from the average of daily activities and the weekly activity for all WPs, one is able to make very clear conclusions. For example, the daily pattern of Asian languages (e.g., Japanese, Chinese and Korean) show higher activity during evenings and nights along with high level of activity at weekends. This can be related partly to the lengths of working hours in corresponding countries. This general image, which holds partially for Turkey and Russia and Israel too, could be in close relation with the high average working hours per day in those countries (more than 40 hours in all the mentioned cases, according to the dataset of *The Organization for Economic Co-operation and Development*: <http://stats.oecd.org>). Furthermore, among European countries, we also see the same tendency; in the countries with rather larger working times, edits are mostly done in later times in evenings.

It is to mention that same analysis have been done for the seasonal patterns to extract effects of changes in daylight timing, but the large fluctuations in average behavior, makes it very difficult to conclude relevant results. The only significant large scale seasonal pattern is the reduction of activity with approaching to the new year holidays for many WPs.

In conclusion, based on a dataset of time stamped edits on different Wikipedias, we studied the circadian and weekly patterns of activity of editors. We could see a universal circadian pattern for all WPs, which has its minimum at dawn and maximum at late afternoon and early evening. According to this investigation, we also argued that using a weighted mixture of contributions from different time zones and an optimization procedure, we can estimate the different contributions to a WP. In particular, we observe that a considerably large part of edits on English and simple English WPs are originated from Europe and the share of North America was below expectations. The same type of analysis was also performed for other WPs in different languages. In contrast to circadian pattern, which is universal to a great extent, weekly activity patterns of WPs show remarkable differences. We could, however, identify two main categories, namely “weekends” and “working days” active WPs. Further studies are needed to

explain these observations in detail and relate them to cultural and social differences.

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Author Contributions

Conceived and designed the experiments: TY JK. Performed the experiments: TY RS. Analyzed the data: TY RS. Wrote the paper: TY.