

# There is No Deadline - Time Evolution of Wikipedia Discussions

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## ABSTRACT

Wikipedia articles are by definition never finished: at any moment their content can be edited, or discussed in the associated talk pages. In this study we analyse the evolution of these discussions to unveil patterns of collective participation along the temporal dimension, and to shed light on the process of content creation on different topics. At a micro-scale, we investigate peaks in the discussion activity and we observe a non-trivial relationship with edit activity. At a larger scale, we introduce a measure to account for how fast discussions grow in complexity, and we find speeds that span three orders of magnitude for different articles. Our analysis should help the community in tasks such as early detection of controversies and assessment of discussion maturity.

## Categories and Subject Descriptors

H.5.3 [Information Interfaces]: Group and Organization Interfaces—*Computer-supported cooperative work, Web-based interaction*

## Keywords

Wikipedia, online discussion, temporal patterns, h-index

## 1. INTRODUCTION

Everyday thousands of people from all over the world edit the articles of Wikipedia, and millions access their content to get information and form opinions about the most various kinds of topics. While one of the weaknesses of traditional encyclopedias is the lack of up-to-date information, due to the time required by the publishing process, Wikipedia tends to cover also very recent events and fresh information, as it can be updated in real time. This is one of its most essential characteristics, as suggested by the very same word *wiki*, which in Hawaiian means *quick*.

Yet, not all articles evolve with the same speed and whether in some cases *quick* may be *too fast* is object of discussion among the editors of Wikipedia. An essay invites users to

consider whether an addition will still appear relevant in ten years<sup>1</sup> to avoid *recentism*, i.e. editing an article without a long-term, historical view. Nevertheless, although another sibling project has been created expressly for in-depth coverage of news<sup>2</sup>, also for recent and current events most editors seem to prefer Wikipedia articles, as unique collective artifacts in constant evolution.

If one would like to study the speed with which an article changes, the first natural choice would be to study the number of edits per time unit. However, the larger an article becomes, more and more of its generative process takes place in talk pages, parallel spaces to every article, where editors are engaged in discussions with the objective of reaching consensus on the article content. These discussions can be seen as a magmatic flow of arguments and counter-arguments, which are progressively transformed into the encyclopedic content. Looking at the associated discussion is often the most effective way to understand the process which brought to the current state of an article, showing traces of the explicit coordination among editors in the form of suggestions, disputes, complains, invocation of community policies, polls and pursuit of consensus [22].

This motivates us to investigate the temporal patterns of these discussions and their relation with edit activity. While previous studies have focused on the amount of activity on talk pages [13, 24], and the shape and complexity of the discussions [15], still little is known about the dynamics of these conversations.

How are the conversations distributed in time? How frequent are spikes of activity? Are they associated to external events or to community dynamics? What is the relationship between discussion and edit activity? How fast do discussions grow, and for how long? Does the topic affect the way a discussion evolves?

Being able to answer these questions could benefit the community in tasks like assessment of discussion maturity and early detection of controversies. Understanding when the biggest controversies associated to an article have been solved (i.e. the discussion is mature) may serve as a proxy for content stability, while detecting disputes which may need the attention of moderators could help avoid their escalation into a too fierce debate, allowing Wikipedians to invest their time into more productive tasks and to reduce their frustration, and ultimately might help to reduce editor drop-out.

To address the above-mentioned research questions, we present here an extensive study of the temporal dynamics

<sup>1</sup><http://en.wikipedia.org/wiki/Wikipedia:Recentism>

<sup>2</sup><http://www.wikinews.org/>

of the English Wikipedia discussions, taking into account all the conversations on article talk pages occurring during its first 9 years of history. We start by summarising our main findings and offering a brief insight into related work in sections 2 and 3. Then, after introducing the dataset in Section 4, we detect and contrast peaks in the edit and discussion activity of articles in Section 5. Afterwards, in Section 6, we introduce a metric based on the h-index [9] to measure the growth speed of discussions. As an example, we illustrate the evolution of the articles about the last three US presidents, and apply our measure to all heavily discussed articles to reveal differences in the discussions about different subjects. Finally, in the last section we draw conclusions and lines for future research.

## 2. OUR CONTRIBUTION

Our main contributions are:

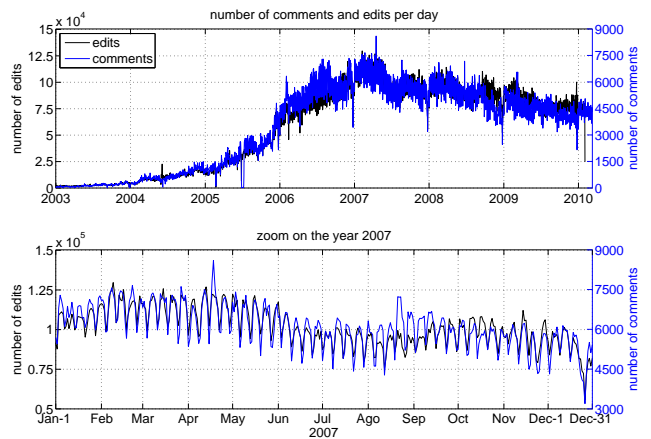
- We detect peaks in the discussions on Wikipedia articles and shed light on some of their statistical properties such as number of peaks per article, peak length and time interval between peaks. A comparison with peaks in the edit history reveals that comment and edit peaks appear mainly independently of each other.
- We offer a qualitative insight into the nature of edit and discussion peaks through the detailed analysis of a case study, which shows that both endogenous (Wikipedia internal) and exogenous (offline world) events can be the cause of such peaks, while the subjects of the disputes are not necessarily related to such events.
- We introduce a measure to account for the speed with which the discussions gain in complexity. The measure reveals speeds that span three orders of magnitude.
- We observe that articles about hot topics in the media receive also considerably more attention, have faster dynamics and longer peak durations in Wikipedia.

## 3. RELATED WORK

Transparency is a pillar of the wiki philosophy, so complete information about the edit history of each page is available. However, it is often difficult to make sense of it, especially for larger pages. To address this limitation, a number of tools have been proposed for the visualisation of the evolution of the activity on a given page [3, 20, 22]. Among the studies focused on mining edit history to extract patterns of interaction, we mention [1] for automatic vandalism detection, [13] and [24] for identifying conflict. The latter also provides a description of the most controversial topics in several language versions of Wikipedia; for the English Wikipedia, positive correlation is found between conflict on an article and length of the associated talk page.

While at the beginning most of the effort in Wikipedia was spent in creating and editing articles, other activities such as coordination and discussion have progressively emerged with the increased complexity [13, 21]. Kittur et al. [12] studied the distribution of work over time, and found a gradual shift from the “elite” users to less active editors, while the authors of [14] described the evolution of Wikipedia’s co-authorship network pointing out its increasing centralisation around the most active users.

The interpretation of Wikipedia as a global memory place led Ferron et al. [6] to observe that articles related to traumatic events are more likely to be characterised by a higher



**Figure 1: Evolution of the number of edits and comments per day between 2003 and 2010 (top) and a zoom on the activity during 2007 (bottom subplot).**

amount of edits in correspondence with anniversaries. In [5] the same authors present a study of activity on different language versions of Wikipedia during the Egyptian revolution, finding evidence of intensive participation on articles and talk pages related to the events. Furthermore, they point out boosts of edits after major events, like Mubarak’s resignation. Another case study [11] analyses edit and collaboration dynamics around articles related to the 2011 Tohoku earthquakes.

Temporal patterns in comment activity have also been investigated in other contexts, e.g. for Slashdot comments by [10] who mainly analysed the reaction time of a community to an initiator event. However, discussions in Slashdot evolve on a much faster timescale than in Wikipedia. They only receive a very short attention span and are subject to time limits, making their dynamics highly influenced by the circadian cycle of its authors. Activity peaks in social media platforms have been studied in other contexts such as small text fragments from blogs and mainstream media [17], Youtube [4] and Twitter [16]. The two latter studies propose models to characterise different classes of activity peaks according to their dynamics, and to associate them to exogenous and endogenous factors.

## 4. DATASET AND DATA PREPARATION

We are interested not only in the evolution of the sizes of the discussions but also in their complexity. To measure the complexity of a discussion we will use its structure, thus we have to go beyond simply analysing the edit history of article talk pages. We use a dataset which identifies every comment and its associated metadata via parsing the wikitext.

This dataset is described in more detail in [15]. It contains all Wikipedia article talk pages, as of March 12th, 2010; each discussion page is represented as a tree, to reflect the thread structure of comments and replies indented under one another<sup>3</sup>. Most comments are signed and dated by the users<sup>4</sup> adopting different conventions and making use of wiki

<sup>3</sup>Note that sometimes users reset indentation; we consider these cases as the start of a new thread in the discussion.

<sup>4</sup>Or, since December 2006, by special bots automatically adding missing signatures and dates

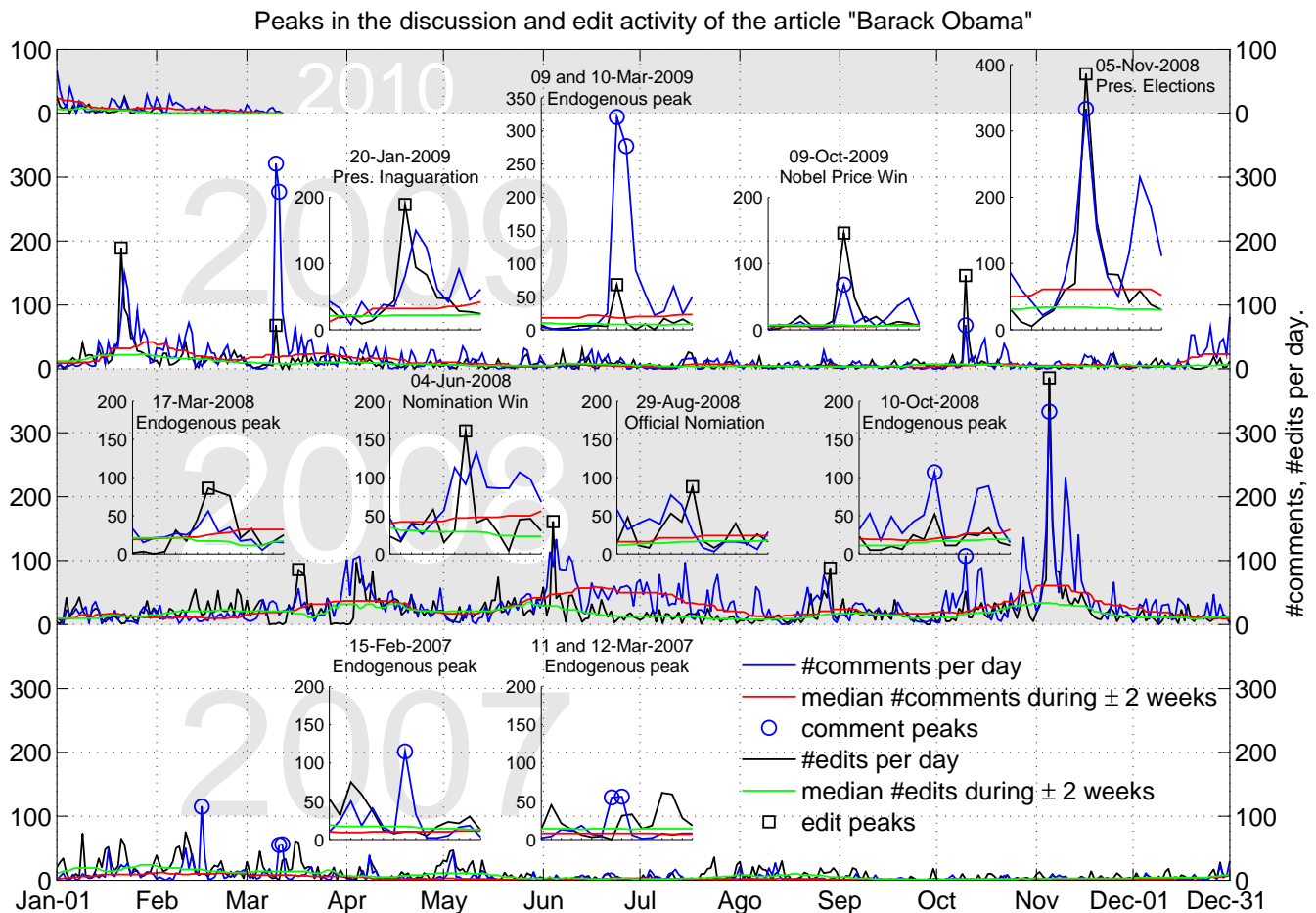


Figure 2: Peaks in the activity of the discussion around the article “Barack Obama”.

shortcuts. We only consider comments for which an author-signature could be identified; of these 9.4 millions comments, about 11% have a malformed date-signature (or none at all). We keep those comments as they still allow to extract the structure of the discussion prior to the first correctly signed comment. This information is then used as starting point for our statistics in the second part of our study.

To extract the edit history of the articles we processed the complete dump of Wikipedia including all revisions of each page, using the WikiXRay parser<sup>5</sup>. We only considered articles having a talk page ( $\approx 871,000$ , corresponding to 27% of all articles in the dump). Figure 1 shows the evolution of the number of edits and comments per day to these articles. We find about 6 comments for every 100 edits and a very similar trend in both curves, which co-evolve nearly in perfect synchrony showing the same weekly activity cycle. The cycles becomes visible in the zoom on the activity during 2007 in the bottom subplot of Figure 1.<sup>6</sup>

The first objective of this study is to investigate whether this co-evolution between edits and comments can also be found at the article level.

<sup>5</sup><http://meta.wikimedia.org/wiki/WikiXRay>

<sup>6</sup>In this Figure the comments of two bots which made on rare occasions comments to several thousands different articles on a specific day were omitted for clarity.

## 5. COMMENT AND EDIT PEAKS

We first analyse the co-occurrence of peaks in the comment and edit activity of the different Wikipedia articles. We start by introducing the method to detect the moments in time with peak activity.

### 5.1 Peak detection algorithm

We extract two time series for every Wikipedia article:

1. The number of edits per day to the article.
2. The number of comments per day on the corresponding article talk page.

To identify peaks in these time-series we adapt the peak detection algorithm of [16]. We compare the number  $n(t)$  of edits (or comments) at day  $t$  to the median activity  $m(t)$  during a sliding window of 4 weeks length<sup>7</sup> centred on day  $t$ . We consider the activity to peak if

$$n(t) > c \cdot \max(m(t), n_{\min}) \quad (1)$$

where  $n_{\min}$  is the minimum activity set to 10 comments or 10 edits respectively<sup>8</sup> and  $c$  is the peak-factor, which we set to 5 if not stated otherwise in the rest of the manuscript. Consequences of other choices of  $c$  are discussed in Section 5.3.

<sup>7</sup>This length accounts for the weekly activity cycles [23] while reflecting seasonal (monthly) trends.

<sup>8</sup>The choice of 10 was taken in analogy to [16].

We consider therefore the activity to peak at day  $t$  if it is larger than  $c$  times the median activity during  $\pm 2$  weeks around  $t$  (or larger than  $c$  times  $n_{\min}$  if the median is lower than the limit  $n_{\min}$ ).

Note that this metric can also be seen as an extension of a method presented in [19] where the logarithmic derivative, i.e. the fraction  $(n(t) - n(t-1))/n(t-1)$ , was used to detect peaks in the number of page views and incoming links of Wikipedia articles. Our metric adds a sliding window and a minimum amount of activity to obtain more stable results which do not depend on low activity fluctuations (which are frequently found in the number of edits or comments). Apart from that, a peak-condition of the logarithmic derivative being larger than one, as used in [19], would be equivalent to the use of  $c = 2$  in our case.

## 5.2 A case study: the article “Barack Obama”

Before analysing the discussion and edit peaks on Wikipedia as a whole we start first with a case study on a specific article to illustrate our peak detection method as well as the co-occurrence of endogenous and exogenous peaks.

Figure 2 gives an example of the activity peaks for the article “Barack Obama” between January 2007 and March 2010. The activity prior to 2007 is considerably lower and has been omitted in the figure for clarity<sup>9</sup>. The blue line corresponds to the number of comments per day and the gray curve to the number of edits. The dashed lines in red and green show the  $\pm 2$  weeks medians of the comments and edits respectively. Peaks in the comment activity are depicted by blue circles, edit peaks by black squares. We count 6 comment peaks, two of them correspond to twin peaks where the activity peaks on two consecutive days. Our method also finds 6 (isolated) edit peaks, of which 3 coincide in time with peaks in the comment activity. The other 3 edit peaks concur as well with elevated activity on the article talk page but the number of comments involved does not surpass the threshold established by Eq. 1.

Some peaks clearly correspond to important events, such as Obama winning the presidential primaries and elections, his inauguration and the Nobel Peace Prize win. However, the subjects treated in the edit peaks and intensive discussions are mostly not directly related to these events, but focused on controversies regarding the figure of Obama and the disputed neutrality of the article. This suggests that these peaks of activity were mainly caused by attention peaks of the public opinion towards the subject of the page.

Other edit and comment peaks seem not to be related to major off-line events, but caused by endogenous factors. For example, the twin discussion peak on March 11th and 12th, 2007 is due to a poll proposed by a user to find consensus about which of the 13 main supposed controversies, previously raised in the talk page, were *notable*<sup>10</sup>, and thus had to be included in the article. On March 9th, 2009, in correspondence with a featured article review<sup>11</sup>, an edit war was raised by users trying to add to the article content about controversial issues, such as Obama’s contact with Rev. Jeremiah Wright. The article was temporarily locked down, allow-

<sup>9</sup>Note that also February 29th, 2008 has been excluded from the figure (but not from the analysis) to allow alignment with the non-leap years. No peaks were found for this day.

<sup>10</sup><http://en.wikipedia.org/wiki/Wikipedia:Notability>

<sup>11</sup>[http://en.wikipedia.org/wiki/Wikipedia:Featured\\_article\\_review](http://en.wikipedia.org/wiki/Wikipedia:Featured_article_review)

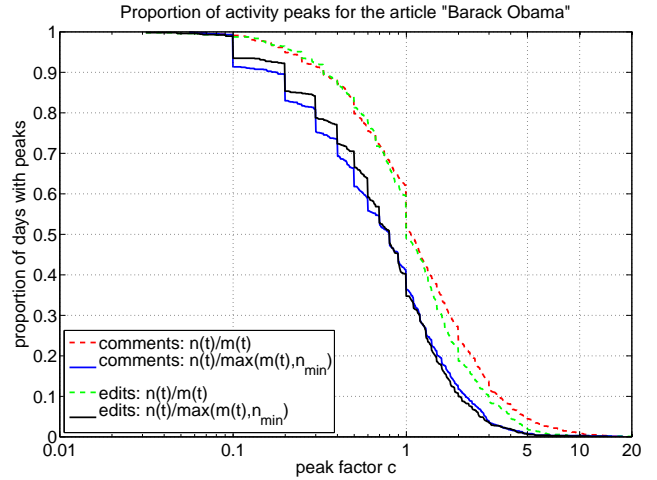


Figure 3: Proportion of days with peak activity for different choices of  $c$  for the article “Barack Obama”.

ing only administrators to edit, and rerouting the dispute to the talk page. This explains the fall of edit activity after the peak on March 9th, accompanied by the burst of discussion in the talk page, resulting in a twin peak (March 9th and 10th). The edit war was reported by some conservative media like Fox News<sup>12</sup>, and media exposure amplified the expansion of the discussion.

Finally, we also observe two endogenous discussion peaks which occur in the vicinity of external events but do not have a direct relation with them. On February 15th, 2007 discussion peaks 5 days after Obama’s candidacy announcement and on October 10th, 2008 in between the two presidential debates on the October 7th and 15th, 2008.

Overall, the example shows that both internal community dynamics and external events can cause spikes of attention towards Wikipedia articles, but the subjects of the disputes are not necessarily directly related to the events which provoked them initially.

## 5.3 Choice of the parameter values

As mentioned earlier we choose  $c = 5$ , this way we ensure that peaks are rare spiky events with a large difference from the usual activity variations. For the article about “Barack Obama” the peaks we find occur with a frequency of about 1%. This can be observed in Figure 3 which shows the complementary cumulative distribution of the ratio between the number of comments or edits  $n(t)$  and the 4 week medians  $m(t)$  for all time-points (days) shown in Figure 2. Continuous lines correct  $m(t)$  with the minimum activity limit ( $n_{\min} = 10$ ) as in Eq. 1 while dashed lines represent the pure ratio between the two quantities<sup>13</sup>. If the ratio surpasses the peak-factor  $c$  our method detects a peak. The curves roughly resemble error functions in log-scale suggesting a log-normal distribution of the variations around the median time series. We observe that a choice of  $c = 2$  would lead to peaks in one of every 4 or 5 days without the use of  $n_{\min}$ , or one in 10 with correction. Choices of  $n_{\min}$  smaller

<sup>12</sup><http://www.foxnews.com/story/0,2933,507244,00.html>

<sup>13</sup>Which is more similar to the logarithmic derivative used in [19].

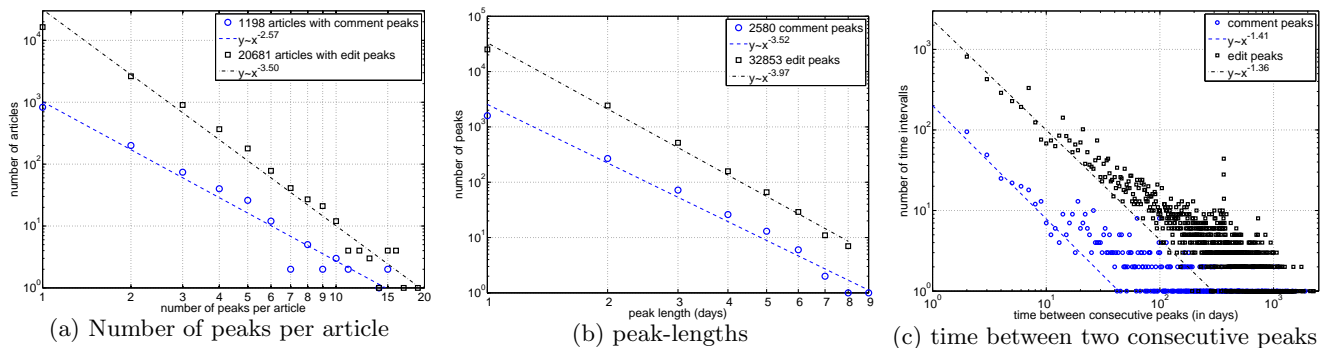


Figure 4: Statistics of the edit (red squares) and comment peaks (blue circles).

Table 1: Numbers of peaks and articles with peaks for different values of parameter  $c$  in Eq. 1.

peak-type	$c$	num. of peaks	num. of articles
comment	5	2,580	1,198
	10	288	195
	20	30	21
edit	5	32,853	20,681
	10	4,944	4,004
	20	706	631
overlap same day	5	307	59
	10	44	8
	20	7	3
overlap $\pm 1$ day	5	703	385
	10	94	52
	20	15	10
overlap $\pm 2$ days	5	871	406
	10	121	54
	20	19	11

than 10 would lead to intermediate values. The choice of 10 was taken in analogy to [16].

Table 1 lists the number of comment and edit-peaks we obtained for our data set. We find 2,580 peaks in the discussions and 32,853 edit peaks with  $c = 5$ . Higher choices for  $c$  significantly reduce the number of peaks we detect: for  $c = 10$  we find roughly one tenth of the comments peaks and 15% of the edit-peaks. If we increase  $c$  further to 20 the numbers decrease in similar proportion. One can draw a similar figure as Figure 3 (not shown) to observe the effect of other choices of  $c$ . The proportions are very similar when not correcting with the minimum activity limit  $n_{min}$ , but are lower when using it. E.g. with  $c = 5$  we obtain, on average, a peak for 0.2% of the days with comment activity and for 0.5% of the days with edit activity. This difference is caused by the fact that the average activity per article is lower than the one for the article “Barack Obama”. Nevertheless, it is the articles with high editing and commenting activity which have to be used to calibrate the peak detection method to avoid an excessive number of peaks.

## 5.4 Peaks in the Wikipedia

In this section we present observations obtained when calculating peaks in comment and edit activity for all English Wikipedia articles.

Table 2: Articles with at least two edit peak anniversaries.

Title	#edit-peak anniv.
Boxing Day	4
Halloween	3
New Year’s Eve	3
Guy Fawkes Night	3
May Day	2
Nowruz	2
Independence Day (United States)	2
Nickelodeon Kids’ Choice Awards	2

Once the peaks are detected the next natural question is whether this edit and comment peaks coincide in time. The bottom nine rows of Table 1 show that for  $c = 5$  only about 12% of all comment peaks coincide with an edit peak at the same day. This number increases to 27% when allowing one day of difference between the edit and comment peaks and to 33.8% when allowing two. These results indicate that not necessarily peaks in the discussion activity have to lead to peaks in the editing activity as well. However, the larger those peaks the more likely is a coincidence. E.g. for  $c = 20$  we find for 63% of the comment peaks a corresponding edit peak within at most 2 days distance.

Furthermore, we can observe that the average number of comment peaks per article (2.15 for  $c = 5$  among the articles with at least one peak) is larger than the corresponding number of edit peaks per article (1.59 for  $c = 5$ ). An article with already one comment peak is thus more likely to obtain a second one than an article with one edit-peak.

This finding is confirmed when taking a deeper look at the distribution of the number of peaks per article depicted in Figure 4(a). We observe the typical shape of a power-law-like distributions, with the majority of articles having at most one peak. Although we find a considerably larger number of edit peaks the shape of the distributions are similar for the comments (blue circles) and edit peaks (black squares) with a steeper exponent for the edit peak distribution. This implies (when normalising the distributions) smaller likelihoods for having multiple edit peaks than having multiple comment peaks.

We observe a similar characteristic for the distribution of the peak-lengths, i.e. the number of consecutive days with peak activity, in Figure 4(b), although in this case the difference in the slopes is less pronounced. The time between

**Table 3: Top 10 articles with most comment peaks.**

Title	#comment-peaks	#edit-peaks
Intelligent design	15	2
September 11 attacks	15	3
Race and intelligence	14	5
British Isles	11	0
Main page	11	0
Anarchism	10	12
Catholic church	10	0
Canada	10	0
Transnistria	9	3
New Anti-Semitism	9	0

**Table 4: Articles with the longest comment peaks.**

Title	max. comment-peak length
2008-2009 Canadian parliamentary dispute	9
Seung-Hui Cho	8
Harry Potter and the Deathly Hallows	7
Fort Hood shooting	7
Capitalism	6
Republic of Macedonia	6
Bronze Soldier of Tallinn	6
2008 South Ossetia war	6
2008 Mumbai attacks	6
July 2009 Ürümqi riots	6

two consecutive peaks also follows a power-law distribution as can be observed in Figure 4(c).<sup>14</sup> A maximum likelihood estimation of the power-law exponents reveals exponents of around  $-1.4$ . Further understanding of the shape of this inter-peak time distributions in the Wikipedia community might be found in models similar to the one of [2] which explain bursts and inter-event time distributions of individual human behaviour.

Taking a closer look at Figure 4(c) we furthermore observe three outliers in the distribution of the edit peaks with significantly more frequent peaks after 364, 365 and 366 days from the previous one. This resonates with the anniversary effect described by [6] as people returning to articles at the anniversary of a traumatic event. However, although we observe one such repeated peak in the article about the September 11 attacks, most of these “anniversary peaks” appear in articles about holidays or other events with a fixed date in the calendar, as can be observed in Table 2. The table lists all articles that repeat an edit peak at least two times. The anniversary effect is not visible in the comment peaks and seems thus restricted to editing behaviour.

We finish the section with three more tables. The first, Table 3, shows a list of the top 10 articles with the largest number of the comment peaks and the second, Table 4, lists the 10 articles with the longest peak-durations (consecutive days with peak-activity). We find that many known controversial topics also have a large amount of comment peaks; the top 7 articles listed in Table 3 can also be found among the ones with the largest number of (prolonged) discussions

<sup>14</sup>Note that we do not count peaks on consecutive days separately in this figure.

**Table 5: Top 10 articles with the most edit peaks.**

Title	#edit-peaks	#com.-peaks
Uxbridge, Massachusetts	19	0
Voodoo (D’Angelo album)	17	0
List of World Wrestling Entertainment employees	16	3
Super Smash Bros. Brawl	16	2
Michael Jackson	16	1
The Biggest Loser: Couples 2	16	0
Roger Federer	15	0
Rafael Nadal	15	0
List of Barney & Friends episodes and videos	15	0
Total Drama Action	15	0

between pairs of users in a listing given in [15]. However, with the exception of the article about Anarchism, it is also interesting to note that there can be found (if any) only a much lower number of edit peaks in these articles. This might be explained by protection or semi-protection of the corresponding articles.

In the list of the longest comment peak durations given in Table 4 we find articles (apart from the one on Capitalism) about one time events, or with a clear relation to an event such as the independence of a country or the publication of a long awaited book. We will discuss some of these articles again at the end of the next section.

Finally, we also list the top 10 articles with the largest number of edit peaks in Table 5. Surprisingly, the majority of the articles listed there seems to be only of limited general interest, indicating that the corresponding edit peaks might be caused by edit wars within a smaller group of users, or a single very, very active user. The latter is for example the case in the article about “Uxbridge, Massachusetts”.

Tables 3 and 5 suggest that the peaks in the discussion activity are more suitable as a measure of a sudden, more widespread interest of the Wikipedians in a specific topic than the edit peaks. The latter seem to be easier to cause by a small group of people. An adaptation of the measure taking into account the number of users involved might be suitable to avoid this effect.

## 5.5 Peak detection in real time

So far we have presented a study of peaks in retrospective, as a first necessary step for the understanding of edit and discussion dynamics. However, the ability to detect peaks in real time could be important for knowing what is going on in the wiki, and detecting quick relative increments of activity around one or more articles. This would be useful for the community, for example to involve mediators early into a controversy and to try to prevent its escalation into a too fierce debate.

To use our peak detection algorithm in real time, one would have to modify the time window used to calculate the median activity, e.g. by using just the activity during 2 weeks before the current date. Another possible modification would be to monitor the fraction of median and current activity instead of fixing a peak-factor. The fraction could then be used to assess the relative size of a peak and depending on the size different actions could be triggered.

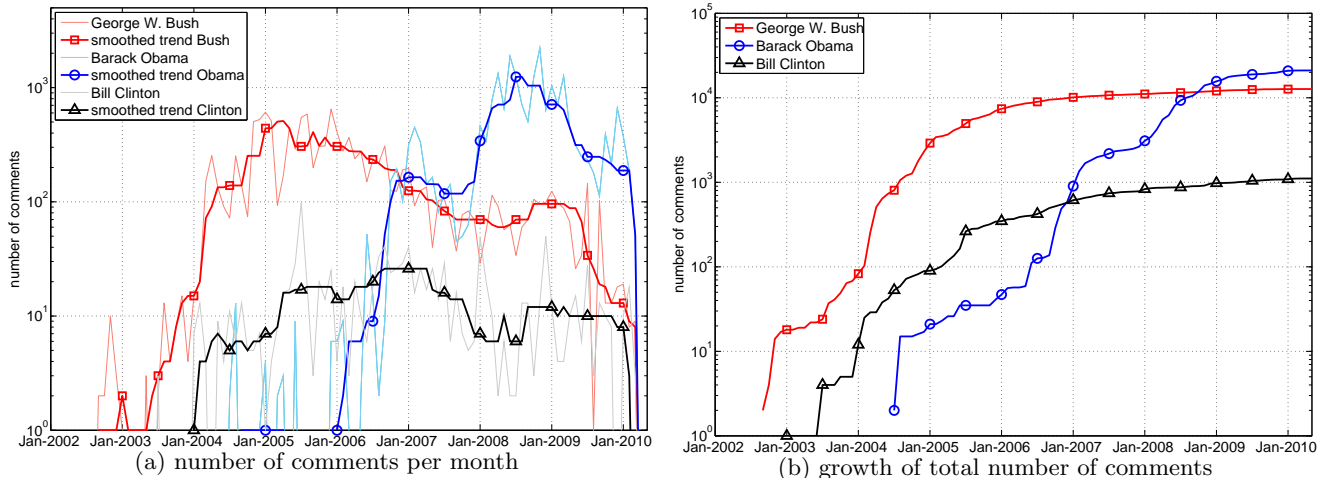


Figure 5: The number of comments per month for the Wikipedia pages of the three most recent US-presidents.

## 6. THE SPEED OF GROWTH OF THE DISCUSSIONS

After having analysed peaks in the discussion activity we are now interested in measuring how fast the discussions grow in complexity.

Figure 5 depicts the number of comments received by the discussion pages of the Wikipedia articles of the three most recent US-presidents. The left plot shows the evolution of the number of comments per month, while the right plot corresponds to the increase in the total number of comments on the pages. One can observe that until the end of 2006 the page of George W. Bush received more comments than those of his predecessor and successor. Between January 2007 and October 2008 the page of G.W. Bush received a similar amount of comments as the one of Barack Obama, who took the lead after the elections of November 2008. The discussion page of the article about Bill Clinton receives considerably less comments than those of his two successors.

How should we assess now the complexity of the discussions on those pages? For that purpose we will use the  $h$ -index of the structure of the discussion introduced in [7].

### 6.1 The $h$ -index of a discussion

The  $h$ -index of a discussion is a balanced depth measure. Figure 6 gives an example of the tree representation of a nested discussion. The root node of the discussion corresponds to its initiating event (i.e. the article in the case of Wikipedia). The comments initiating a sub-thread are placed on the first level, their replies on the second and replies to the replies on the third level and so forth. The level of the comment is also referred to as its depth. The  $h$ -index of a discussion is the maximal number  $\theta$  such that there are at least  $\theta$  comments at level (depth)  $\theta$ , but not  $\theta + 1$  comments at level  $\theta + 1$ . Another possible definition would be that there are  $\theta$  sub-threads of depth at least  $\theta$ . The red line in Figure 6 indicates that for the example thread the condition is fulfilled for  $\theta = 3$ .

This measure is able to filter discussions which are very intense but otherwise restricted to repeated arguments between two or a small group of users. Such threads can reach considerable depths but are normally not representative to

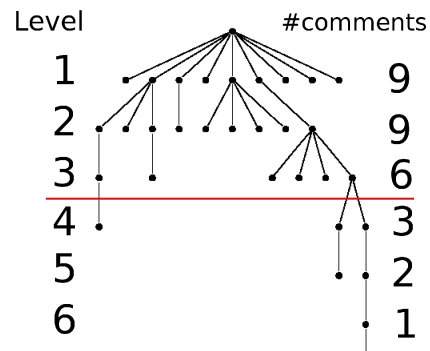


Figure 6: Example for the calculation of the  $h$ -index of a nested discussion with  $h = 3$ , adapted from [7].

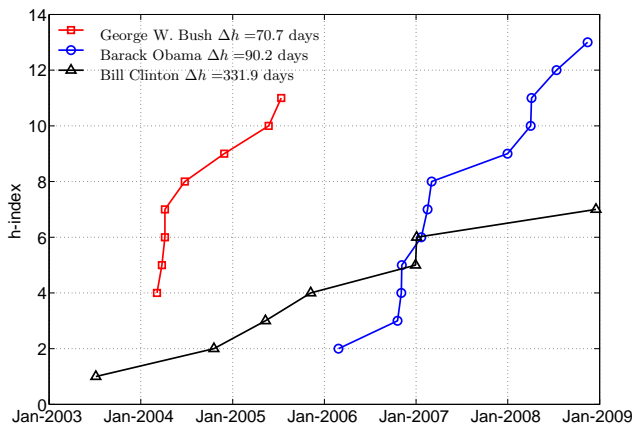
describe the complexity of the discussions. For example, the authors of [15] found discussions with a depth of 42 about the article “Liberal democracy”, while the  $h$ -index of this discussion was just 12. The maximal  $h$ -index they found was 20 for the discussion about “Anarchism”.

### 6.2 The growth measure $\Delta h$

To measure how the  $h$ -index grows over time we define as  $\Delta h$  the average time (measured in days) it takes a discussion to increase its  $h$ -index by one. Mathematically this can be written as: Given the time-series  $h(t)$  of the values of the  $h$ -index of a discussion until day  $t$  we search for the time-points  $t_1, \dots, t_\theta$  such that  $h(t_i) = h(t_{i-1}) + 1$  for all  $i \in [1, \dots, \theta]$  and define then the growth speed of the discussion as

$$\Delta h = \frac{\sum_{i=1}^{\theta-1} (t_{i+1} - t_i)}{\theta - 1} = \frac{t_\theta - t_1}{\theta - 1}. \quad (2)$$

The measure we propose here is very related to the inverse of the  $m$ -index proposed in [9]. The  $m$ -index of a researcher with an  $h$ -index of  $\theta$  and who has first published a paper  $n$  years ago is  $m = \theta/n$ . This definition takes advantage of the fact that the  $h$ -index of a researcher should grow approximately linearly in time. This is also true for the  $h$ -index of the discussions as we will see in the next subsection.



**Figure 7: Evolution of the increase of the  $h$ -index for the three most recent US-presidents.**

### 6.3 Results for three examples

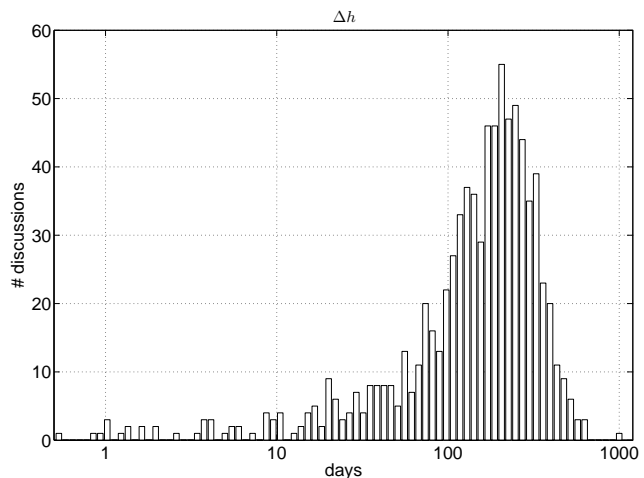
Once introduced we can calculate the growth measure for the discussion pages of the three most recent US-presidents. Figure 7 shows the increase in time of the  $h$ -index of these three pages. We observe a more or less constant growth of the discussions, validating the linearity assumed in the definition of Eq. 2. Note that as explained in the data section the date of the older comments in Wikipedia could not always be determined due to format issues. This explains why the curves in Figure 7 do not start for all articles with  $h = 1$  (in that case Eq. 2 has to be adapted to average over less time-intervals). For example, for the article about George W. Bush we can only determine the time-stamp of the comments when the  $h$ -index of the discussion already reached an  $h$ -index of 4. We observe that the articles about the two presidents in office during the time since Wikipedia has existed experience a considerable faster growth than the page about their predecessor Bill Clinton. For George W. Bush we observe an average  $\Delta h$  of 70.7 days, for Barack Obama<sup>15</sup> this value is 90.2 days, while the article about Bill Clinton takes on average 331.9 days to increase its  $h$ -index by one. This might again be explained by a considerably larger influence of recent events on the discussion dynamics.

### 6.4 General results

How do these growth rates compare with those of other articles? To answer this, in this section we take a look at the distribution of  $\Delta h$  for all 826 articles with more than 1000 comments in our dataset.

Figure 8 depicts this distribution (with logarithmic binning). We observe a certain resemblance to a Gaussian shape, with the mode of the distribution at values of  $\Delta h$  of around 200 days (mean = 183.1 and median = 172.7). The articles about Barack Obama and George W. Bush are in the quartile of the fastest growing discussions, while the one about Bill Clinton can be found in the decile of the slowest discussions. However, none of these discussions falls into the extremes of very slow or very fast growing discussions.

<sup>15</sup>Note here that in difference to [15] we ignore here structural elements such as headlines in the calculation of the  $h$ -index which explains the smaller final  $h$ -index compared to the ones reported by [15].



**Figure 8: Distribution (logarithmic binning) of the  $\Delta h$  of all discussions with more than 1000 comments.**

Tables 6 and 7 list the top discussions according to these criteria together with their  $\Delta h$  values. The start date indicates the earliest dated comment<sup>16</sup>, the end date the day when the final  $h$ -index has been reached for the first time (note that this will be in most cases not the day of the last comment). We observe that many of the fastest evolving discussions appear around articles related to events which received heavy news coverage, such as school shootings (the Virginia Tech massacre and its author which occupy ranks 1 and 5 in Table 6), the 2009 flu pandemic, terrorist attacks, air crashes, etc. Nevertheless we find also topics which reflect ideological or ethical motivated disputes among the Wikipedia editors which lead to discussion gaining complexity very fast. Such topics are the “Bronze Solder of Tallinn” (reflecting a conflict between ethnic Russians and Estonians), “the 2009 Honduran constitutional crisis” as well as discussions about the “Israeli occupied territories” and the “International status of Abkhazia and South Ossetia”. Some of the articles of this list have already appeared in Table 4 suggesting a correlation between  $\Delta h$  and the maximum edit peak-length of the articles. Such a correlation can indeed be found ( $r = -0.25$ , weak although statistically significant,  $p < 10^{-4}$ ) indicating that faster growing discussions are more likely to have longer lasting edit peaks.

We also find the very similar topics “State Terrorism by the United States” and “State terrorism and the United States” appearing in the list. They correspond in fact to the same article, which has been renamed several times (the current title is “United States and state terrorism”) leaving only the archived discussions under the old titles. We have decided to keep these separated discussions, to show the repeated fast growth of the discussion around the slightly renamed (and re-framed) subject.

Finally the list of the slowest evolving discussions in Table 6 is led by the articles about “Christopher Columbus” and “Pi” and contains many more articles about timeless content or content which has been subject of discussion over

<sup>16</sup>As mentioned above this does not have to mean that the discussion started that day, as about 11% of the comments, and especially the oldest comments, do not have a date associated in our dataset.



**Table 6: The 15 fastest discussions,  $\Delta h$  and duration are given in days.**

Title	$\Delta h$	start date	end date	duration	final h-index
Virginia Tech massacre	0.5	15-Apr-2007	20-Apr-2007	5	9
2009 flu pandemic	0.9	25-Apr-2009	30-Apr-2009	5	7
Bronze Soldier of Tallinn	0.9	26-Apr-2007	02-May-2007	6	7
2009 Honduran constitutional crisis	1.0	27-Jun-2009	05-Jul-2009	8	8
Seung-Hui Cho	1.0	16-Apr-2007	24-Apr-2007	8	8
2008 Mumbai attacks	1.0	26-Nov-2008	01-Dec-2008	5	6
Israeli-occupied territories	1.2	22-Sep-2005	03-Oct-2005	11	10
International status of Abkhazia and South Ossetia	1.3	25-Aug-2008	04-Sep-2008	10	8
Air France Flight 447	1.4	01-Jun-2009	08-Jun-2009	7	6
7 July 2005 London bombings	1.7	10-Jul-2005	15-Jul-2005	5	5
State terrorism and the United States	1.7	15-Feb-2008	06-Mar-2008	20	13
July 2009 Ürümqi riots	1.9	06-Jul-2009	21-Jul-2009	15	9
Henry Louis Gates arrest controversy	2.0	24-Jul-2009	09-Aug-2009	16	9
Teach the Controversy	2.6	11-Apr-2005	29-Apr-2005	18	8
State Terrorism by the United States	3.3	31-May-2007	03-Jul-2007	33	11

**Table 7: The 15 slowest discussions,  $\Delta h$  and duration are given in days.**

Title	$\Delta h$	start date	end date	duration	final h-index
Christopher Columbus	1159.0	24-Oct-2003	27-Feb-2010	2318	5
Pi	627.3	07-Dec-2002	20-Oct-2009	2509	6
New York City	617.3	09-Dec-2003	03-Jan-2009	1852	5
Anna Anderson	604.5	17-Mar-2004	09-Jul-2007	1209	3
Harry Potter	589.9	27-Nov-2002	02-Oct-2007	1770	6
France	566.5	13-Nov-2003	26-Jan-2010	2266	6
Scientific method	553.5	15-Jun-2003	08-Jul-2009	2215	6
Instant-runoff voting	546.3	09-Jul-2003	03-Jan-2008	1639	5
Fathers' rights movement	546.0	07-Mar-2004	01-Sep-2008	1639	4
War on Terrorism	533.1	07-Oct-2005	22-Feb-2010	1599	6
World War II casualties	523.0	13-Sep-2004	29-Dec-2008	1568	4
Vampire	517.1	19-Nov-2002	18-Jul-2008	2068	6
Led Zeppelin	511.9	31-Jan-2003	03-Feb-2010	2560	6
Karl Marx	487.6	19-Sep-2004	21-Jan-2010	1950	6
Shakespeare authorship question	485.6	02-Jun-2003	24-Jan-2010	2428	7

prolonged time such as “Harry Potter” or the “War on Terrorism”. Some of these topics may well be topics of century long dispute such as the “Shakespeare authorship question”.

### 6.5 Using $\Delta h$ to measure discussion maturity

Our results show that article discussions can have very different dynamics, with time-spans ranging from days to years. Also, Figure 7 suggests a remarkable difference between discussions which are still growing in complexity, as the one about the article “Barack Obama”, and those whose  $h$ -index has not increased recently, like in the case of the article “George W. Bush”. It seems reasonable to assume that, although both articles are still being edited and discussed, the content of the second one should be more stable as its discussion is mature in the sense that its most conflictive controversies have been fought, i.e. its maximal  $h$ -index has been reached. That does not mean that no new controversy might emerge somewhere in the future to raise it further.

The growth measure  $\Delta h$  introduced in this section can be used to assess this *maturity* of a discussion. One has to assure that a sufficient amount of time has passed since the last time the  $h$ -index of a discussion has increased. Only after some multiples of  $\Delta h$  one can safely assume that the discussion will not grow more in complexity unless something

unexpected will happen. However, more research is need to investigate the correct parametrisation of the proposed technique for this specific application.

## 7. CONCLUSIONS

In this study we have analysed the time-evolution of the discussions about Wikipedia articles on two scales: at a microscopic level detecting peaks in the comment activity and at a macroscopic level introducing a measure for the rate of increase in complexity of the discussions. Although other studies have systematically analysed peaks on Wikipedia before [19], to our knowledge this is the first study which does this for the commenting and editing activity.

We observe that, although on a global scale editing and commenting activity co-evolve nearly in perfect synchrony, at the individual article level discussion and edit peaks seem to occur mostly independently of each other. They can be caused by either endogenous dynamics, such as polls, internal peer reviews and initiatives of some editors, or exogenous factors, such as off-line events or media exposure. However, the subjects of the disputes are not necessarily related directly to the events which provoked a peak of attention.

By introducing a measure for the growth of a discussion based on a balanced depth-measure of its structure we find

several orders of magnitude of different rates of increase in complexity of the discussions. Some discussions need only a few days to evolve, while the slowest go on over years.

Our findings indicate that current events are often edited and discussed on Wikipedia about nearly in real-time either in a new article or in the form of a new peak in an already existing article, while on the other hand, for articles about historical or scientific facts which are not on the people's minds it may take years to reach a similar level of intensity.

Wikipedia is the most up-to-date encyclopedia seen until now and is heavily influenced by recent events as can be observed for example when consulting the Wiki-Zeitgeist<sup>17</sup>, i.e. the list of the most edited topics in a certain time period. Using the metrics presented here one should be able to develop more sophisticated algorithms for such rankings which instead of just counting edits would account also for relative growth dynamics in both edit and discussion activity.

Although there is concern inside the Wikipedia community about the risks of *recentism* and the disproportionate attention received by recent and current events, our results point out that this type of dynamics constitutes a characteristic pattern of activity in the Wikipedia community. Such patterns are probably unavoidable in the context of an open collaborative platform.

According to the interpretation of Wikipedia as a collective memory place [18], where a *living memory* is progressively turned into a fixed text, talk pages are the space where this transformation takes place. Wikipedia discussions can thus be seen as a mirror of a stream of public consciousness, where those elements which are still not part of a shared consolidated heritage are object of a continuous negotiation among different points of view.

**Future Work** Our study presents a first step towards the comprehension of the temporal patterns which rule the collective process of content creation in Wikipedia, and opens up to further research in several directions.

We have sketched applications of our metrics for early detection of controversies and assessment of discussion maturity, which should be implemented for further evaluation.

The extension of existing generative models [8] for the tree structure of the discussions with temporal information could help to explain possible dynamical differences between fast and slow evolving discussions.

A cross-article analysis of peaks would help to unveil hidden relationships between articles and topics, while the classification of peaks according to their shape, as for example proposed in [4]<sup>18</sup>, could allow to automatically distinguish exogenous and endogenous peaks, and to detect the influence of external events. The metrics used in this study could also be applied on specific sub-threads of a discussion, which should allow to detect hot spots within a specific article.

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<sup>17</sup><http://stats.wikimedia.org/EN/TablesWikipediaEN.htm#zeitgeist>

<sup>18</sup>This would make necessary a more fine grained temporal analysis with time rescaling to avoid the influence of daily activity cycles.

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