Visual Analysis of Controversy in User-generated Encyclopedias*

Ulrik Brandes†   Jürgen Lerner‡

Department of Computer & Information Science
University of Konstanz

ABSTRACT

Wikipedia is a large and rapidly growing Web-based collaborative authoring environment, where anyone on the Internet can create, modify, and delete pages about encyclopedic topics. A remarkable property of some Wikipedia pages is that they are written by up to thousands of authors who may have contradicting opinions. In this paper we show that a visual analysis of the "who revises whom"-network gives deep insight into controversies. We propose a set of analysis and visualization techniques that reveal the dominant authors of a page, the roles they play, and the alters they confront. Thereby we provide tools to understand how Wikipedia authors collaborate in the presence of controversy.

Keywords: Wikipedia, social network analysis, controversy.

1 INTRODUCTION

Recently the World Wide Web has witnessed a shift from Websites supplied by traditional information providers like universities or companies to sites where every user can not only read but also modify content. A remarkable example of such sites is the user-generated online encyclopedia *Wikipedia* (http://www.wikipedia.org/) which allows every user (even anonymously) to create, modify, and delete pages about encyclopedic topics. This approach—which is so entirely different from traditional encyclopedia-writing by domain experts and supervised by editors—seemed to be destined to fail from the beginning. Not only could users (ignorantly or maliciously) introduce inaccurate information, they also could delete previously written good articles, thereby making every progress impossible. Despite these concerns, Wikipedia turned out to produce much better articles than expected. A study carried out by *Nature* in 2005 suggests that the accuracy of Wikipedia articles about scientific topics comes close to the accuracy of their counterparts in the *Encyclopædia Britannica* [6]. Viégas *et al.* [21, 22] observed that antisocial behavior like vandalism (e. g., deletion of whole pages, or insertion of vulgarities) is often repaired within minutes. Another indicator of Wikipedia's success is simply its ever increasing popularity: at the end of 2006, Wikipedia has more than five million articles—about 1.5 million alone in the English Wikipedia—and grows by several thousand articles per day (http://stats.wikimedia.org/). Furthermore, Wikipedia ranges among the top 20 in Alexa's most visited sites (http://www.alexa.com/).

In this paper we are interested in how do Wikipedia authors collaborate when writing about controversial topics (such as abortion, gun rights vs. gun control), delicate historic events, or persons that are highly important in politics. Such pages have often been revised up to tens of thousands of times by several thousand authors who, arguably, not all share the same opinion on the particular topic. Al-

Figure 1: Small part of the revision history of the page `Gun politics`. This page has $1,101$ revisions in the November 2006 database dump.

though Wikipedia policies[1] urge authors to take a neutral point of view (NPOV) and to provide only facts rather than opinions, controversies are nevertheless reflected in some pages. Since some facts appear to support more a certain opinion and reject or discredit the other, it is fiercely fought over whether such facts should be mentioned and how could balance be established.

We do not see it as a fundamental drawback of Wikipedia that controversies are reflected in the development of (some of) its pages. Different opinions simply exist in society and, since Wikipedia is "the free encyclopedia that anyone can edit," it is a good mirror of such controversies. However, this gives rise to several important questions: First of all, to assess the neutrality of a given controversial page, it is crucial (and very informative) to know about ongoing and past disputes and about beliefs and opinions of the various authors. Even more important is to understand in general the social process of content-generation in Wikipedia. Concrete questions include whether controversial pages converge at all or whether they are destined to perpetual editing and, if they converge, is their content balanced or determined by opinion groups. Furthermore, what are the roles that Wikipedia authors typically play when arguing for or against specific statements in the page.

Support to answer these questions comes from Wikipedia itself which makes available not only the current content of a page but also its complete history. The analyst is thereby enabled to see all past versions and time, content, comment, and author of the various edits (see e. g., Fig. 1). Needless to say that the typical size of the revision history of a disputed page calls for automated visual and analytic support to get insight into the page's development and author community.

In this paper we show that a visual analysis of the "who revises whom"-network gives deep insight into the author-community behind a controversial page. We provide a set of analysis and visualization techniques that reveal the dominant authors, the roles they play, and the alters they confront.

---

[1] http://en.wikipedia.org/wiki/Wikipedia:List_of_policies

The rest of this paper is organized as follows. Our contributions in relation to previous work are explained in Sect. 2. In Sect. 3 we define the revision network. Section 4 introduces several meaningful author properties and how they are visually represented and Sect. 5 presents some illustrating findings on particular pages.

2 RELATED WORK AND CONTRIBUTIONS

Web 2.0 is a common term for denoting those sites of the WWW where Internet users are not just readers but can actively participate. Specific forms include blogs, wikis, podcasting, file sharing, and social networking sites (see, e. g., [13] for an overview). In this paper we analyze the author community of wikis, i. e., Web-based collaborative authoring environments where anyone on the Internet can create, edit, and delete pages. The term *wiki* was coined by Ward Cunningham, who launched the first wiki in 1995 [14]. *Wikipedia*, which is currently the largest wiki, has been established in 2001 to collectively create an encyclopedia. Maybe due to its size, popularity, and relevance for understanding new forms of collective knowledge creation, Wikipedia receives increasing interest in research. For instance, Wikipedia's growth rate, information quality, or edit histories have been analyzed [9, 20, 21, 22, 23]. Other papers (e. g., [4, 19]) use the collection of Wikipedia articles to improve machine learning techniques for text categorization and detection of semantic relatedness of terms.

It has been widely recognized that user-generated content is also a rich source for user *opinions*. Some papers (e. g., [3, 7, 15, 17]) apply natural language processing (NLP) to determine users' sentiments about positive or negative aspects of commercial products. Agrawal *et al.* [1] argued that "links carry less noisy information than text" and applied a network analysis approach to divide newsgroup authors into two opposite camps: those that have a positive opinion on a certain topic and those that have a negative opinion. They completely ignored the content of postings and used only the "responded-to" relationship between authors. It is argued (and validated) that people respond more frequently to a message when they disagree than when they agree. Thus, partitioning the network into two groups such that most links are between the groups will reveal the opposing camps. Note that previous work on user opinions [1, 3, 7, 15, 17] assumes the existence of only two poles of opinion (positive and negative), which is certainly a restriction to generality. However, research about *multipolar* conflicts (i. e., situations where there are more than two camps that are mutually in opposition) can be found in political science, e. g., [18].

Our work here is based on the idea from Agrawal *et al.* [1] that controversy is reflected in the reply behavior (revision behavior in our case) of authors but achieves several improvements. Instead of the strict partition of authors into opinion groups, we propose a visual analytics approach that can deal with more complex and more realistic controversy structures and in addition reveals authors' involvement and roles.

Independently, Kittur *et al.* [12] applied a similar idea by building the *RevertGraph* to analyze disagreement among authors. Our proposal of the revision network can encode conflicts in more general situations, since using only reverts "cannot detect conflicts between users who were not involved in reverts [12, p.460]." Furthermore, in addition to different opinion groups, our method reveals several author characteristics. Last but not least, the spectral layout method outlined in Sect. 4.1 seems to be preferable to the force-directed method from [12], since it optimizes a well-defined criterion function, cannot be stuck in local minima, and is quite robust to noise (compare [2]). Note that Kittur *et al.* provide additional results in different directions by analyzing the global cost of coordination and learning models to predict whether an article is controversial.

Viégas *et al.* [21, 22] proposed a *history flow* approach for the visual analysis of the page history. The *history flow* diagrams show the development of the content of a page over time and are therefore orthogonal to our work since we analyze the page's author community.

The determination of the authors' positions developed in Sect. 4.1 is a generalization of the method that we proposed for the analysis of political conflicts [2]. The method from the current paper can deal with more general conflict structures (e. g., multipolar conflicts). Furthermore, we make several visual and analytical enhancements that have been necessary to represent well the complex interaction structure between Wikipedia authors.

Concrete contributions of our paper include the following. First, the definition of the revision network is a simple, efficient, and language-independent way to represent controversies among Wikipedia authors. Note that this approach can be applied to Wikipedia articles in any language without the need for adapting NLP algorithms. This is a significant advantage since for most languages, text processing algorithms are not so highly developed as for English. Second, we define a set of author characteristics or properties that give deep insight into the overall structure of the community as well as into individual authors' roles. Third, we develop visualization techniques to show the author characteristics simultaneously in a simple and easy to understand picture. Last but not least, several case studies of controversial pages have a value on their own in revealing some typical author roles and patterns of confrontation.

It is important to note that our analysis cannot and does not attempt to determine which opinion is more acceptable.

3 REVISION NETWORK

The definition of the "who-revises-whom"-network (in short *revision network*) is a crucial step to develop an efficient and robust method for analyzing interaction among Wikipedia authors. In contrast, approaches based on NLP would not only have to solve the difficult task of automatically understand natural language (compare [1]) but would also have to deal with much larger file sizes (see Sect. 3.1). We describe the input data in Sect. 3.1 before defining the revision network in Sect. 3.2.

3.1 Input Data

Wikipedia makes its complete database (containing all versions of every article since its initial creation) available in XML-format.[2] The files containing the complete history of all pages can be extremely large. For instance, the complete dump for the English Wikipedia unpacks to more than 600 gigabytes (GB).[3] Wikipedia makes also available so-called stub-files. These files contain meta-data about every revision but not the text (see Fig. 2 for a small portion) and are still quite large. For the present study we used the stub-file for the English Wikipedia (which is the largest one) from the 20061130 dump with a size of 23 GB. (Note that this dump includes some revisions from December 2006, since it takes several days to create it.) The number of revisions (edits) of a page and the number of authors that made at least one revisions can also be quite large. The most-revised page in the English Wikipedia is `George W. Bush` having $33,086$ revisions and $10,167$ different authors (registered or anonymous). Parsing the XML-document has been done using a Java implementation of the event-based SAX interfaces[4] which proved to be very efficient for parsing such huge files. Constructing the whole document tree, as this is normally done by DOM parsers[5], would simply be impossible (at least very inefficient and/or requiring uncommonly huge memory), given the file sizes.

---

[2] `http://download.wikimedia.org/`
[3] `http://meta.wikimedia.org/wiki/Data_dumps`
[4] `http://www.saxproject.org/`
[5] `http://www.w3.org/DOM/`

```
...
<page><title>Gun politics</title>
   ...
   <revision><timestamp>2006-03-18T22:31:41Z</timestamp>
      <contributor><ip>24.12.208.181</ip></contributor>
      <comment>/* Self-defense */</comment>
   </revision>
   <revision><timestamp>2006-03-18T23:18:38Z</timestamp>
      <contributor><username>Yaf</username></contributor>
      <comment>rv POV edit (discussion belongs on discussion page,
            not in article)</comment>
   </revision>
   <revision><timestamp>2006-03-19T02:39:25Z</timestamp>
      <contributor><ip>24.12.208.181</ip></contributor>
      <comment>/* General discussion of arguments */ Fact with cite.
            DO NOT DELETE WITHOUT VERY GOOD REASON!!!!!!!
            Different placement on page acceptable.</comment>
   </revision>
   <revision><timestamp>2006-03-19T02:52:41Z</timestamp>
      <contributor><username>Mmx1</username></contributor>
      <comment>wikipedia is not a collection of facts. This page
      is a summary of the arguments, not a place to make them</comment>
   </revision>
   <revision><timestamp>2006-03-19T05:24:30Z</timestamp>
      <contributor><ip>24.12.208.181</ip></contributor>
      <comment>HUH??  Facts don't belong in this article.
            Can that be true?</comment>
   </revision>
   <revision><timestamp>2006-03-19T05:30:16Z</timestamp>
      <contributor><username>Mmx1</username></contributor>
      <comment>are you making an argument? rv random insertion of
            statistics as weasley POV</comment>
   </revision>
   ...
```

Figure 2: Six consecutive revisions of the page `Gun politics` in XML format. (The corresponding HTML-view is part of Fig. 1.)

To abstract from the particular format we define a *revision* or *edit* to be a tuple of the form

$$r = (page, time, author, comment, revert) \; ,$$

where *page* is a text-string denoting the page-title, *time* contains the exact timestamp of the revision (given by the second), *author* is a real user name if the contributor of the revision has been logged in or an IP-address if the revision has been done anonymously, *comment* is free text explaining what has been done or why this revision has been necessary (often authors have kind of a discussion in consecutive comments, compare Fig. 2), and *revert* is a Boolean flag labeling the revision. (A revert is a specific edit where the author sets back the page content to an earlier version.[6])

3.2   Network Construction

Given a sequence $R = (r_1, \ldots, r_N)$ of revisions on the same page, which is ordered by increasing timestamps, the associated *revision network* is a directed, weighted graph $G = (V, E, \omega)$ defined as follows (also compare Fig. 3).

- V is the set of authors that performed a revision in R.

- $E \subseteq V \times V$ is the set of *revision edges*. For two different authors $u, v \in V$ the edge $(u, v) \in E$ is introduced if there are two consecutive revisions $r_i, r_{i+1} \in R$ such that u is the author of r_{i+1} and v is the author of r_i. An edge (u, v) can be read as "u revises changes made by v".

- The function $\omega : R \to \mathbb{R}$ assigns *weights* to edges. For an edge (u, v) the weight $\omega(u, v)$ indicates how "urgent" u considers it to revise the changes made by v (see more detailed explanation below).

Before explaining how the edge weights are defined we will briefly discuss the meaningfulness of the revision network. Edges with high weight are interpreted later as *disagreements* between the connected authors. To see how the edge weights have to be defined to achieve this goal, assume that there are two (fictitious) authors `Alice` and `Bob` connected by an edge. If `Alice` makes only once
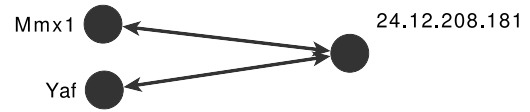
---

[6]http://en.wikipedia.org/wiki/Help:Revert

Figure 3: Revision network arising from the six revisions shown in Fig. 2. Both edges go in both directions but edges from the left to the right have higher weights since the corresponding revisions are performed faster, compare (1).

a revision immediately after `Bob`, then this may or may not indicate that she disagrees with his edits. If, on the other hand, it is the case that `Alice` revises dozens of times `Bob`'s revisions (and especially if these revisions happen very fast, e. g., within an hour or even within minutes), then it becomes very likely that she does not at all agree with his edits. It turns out later that there are indeed such pairs of authors on some highly controversial pages. To summarize these considerations, we assume that dominant revision patterns are meaningful but that not too much confidence should be put on single revisions. This simply means that the revision network has a typical characteristic of social network data, namely that of being noisy, and that it should only be analyzed/visualized with robust methods. In a sense, the same considerations would apply to the construction of "quotation links" for the analysis of newsgroups [1]. There it has been claimed that "it is more likely that the quotation is made by a person challenging or rebutting it rather than by someone supporting it" [1, p.529]. Of course not every single quotation is necessarily antagonistic, but a huge number is likely to indicate disagreement.

Thus, to define edge weights such that they are likely to indicate the magnitude of disagreement, fast revisions are assigned higher weights and weights of several revisions between the same authors are added up. So, let r_i, r_{i+1} be two consecutive revisions on the same page where u is the author of r_{i+1} and v the author of r_i. Let t_i and t_{i+1} denote the timestamps of r_i and r_{i+1} respectively, $\Delta = t_{i+1} - t_i$ the time difference between the two revisions, and Δ_{max} a maximum time limit when a revision is still considered as a disagreement. Then, the weight of the edge (u, v) is defined to be

$$\omega(u, v) = \begin{cases} -\Delta/\Delta_{max} + 1 & \text{if } \Delta \leq \Delta_{max} \\ 0 & \text{else.} \end{cases} \tag{1}$$

If there are more pairs of consecutive revisions where u revises v, then the edge weights of (u, v) are summed up.

In the examples we defined the time limit Δ_{max} to be equal to the average revision time. If a revision occurs at about the average time, it becomes more unlikely that it is meant as a disagreement. On the other hand if the revision occurs much faster than the average time, the probability increases that it is indeed a correction of the previous edit. It is reasonable to count revisions more heavily if they are reverts since this indicates that the reverting author considers the previous edit as obsolete or even harmful. An even more sophisticated construction of revision edges could be achieved by taking into account the comments made by authors. Since comments are free text and not standardized this would involve NLP and will not be considered in this paper.

Sometimes several Wikipedia pages have strongly related topics (see, e. g., Sect. 5.1) and then often largely overlapping sets of authors. In these situations it is appropriate to combine the associated revision networks by taking the union of their author sets and adding up edge weights.

4   VISUAL ANALYSIS OF THE REVISION NETWORK

In this section we define a series of characteristics of the revision network and its actors (the Wikipedia authors) and how they are

visually represented. These characteristics include for all authors their *position* (i. e., which other authors do they confront), their involvement in controversy, an indicator telling whether they are mostly revisors or mostly being revised, and an indicator telling whether their edit behavior is rather constant over time (so that they showed sustained interest in the page) or highly concentrated on small time periods. See Fig. 6 for an image showing these and a few other properties. Technically most involved is the determination of the authors' positions. We will treat this issue in Sect. 4.1. Graphical representation of this and other indicators is explained and illustrated in Sect. 4.2. In Sect. 4.3, two possibilities to prune the revision network and to detect relevant substructures are examined.

4.1 What Position Do They Take?

The *position* of a particular author should express which other authors she confronts. Confrontation is reflected in the revision edges: if two authors take different positions they disagree with the edits of the other and therefore will frequently revise each other. (Asymmetry of edges is ignored here but will be used later to determine the authors' roles.) Thus, if two authors u and v are connected by a revision edge of large weight, then we want to draw u and v on opposite sides of the image. The difficulty lies in the fact that we have to draw not only two authors but the whole network such that all confronting pairs are simultaneously as far from each other as possible (compare Fig. 4). This objective (which contrasts to most objective functions for graph drawing that traditionally want to keep edge lengths as short as possible [11]) is of course due to the negative interpretation of the revision edges. The good news is that this problem is efficiently solvable, as will be derived next.
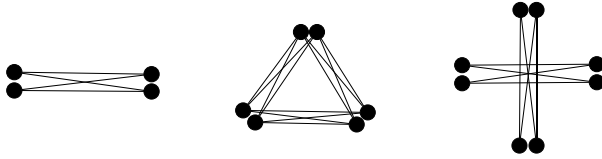

Figure 4: Sample of pure conflict patterns. Bipolar conflict (*left*), 3-polar conflict (*middle*), and two independent bipolar conflicts (*right*). Actors that are in conflict are drawn as far from each other as possible. Conflicts in real data are often a mixture of these types.

Let $G = (V, E, \omega)$ be a revision network with author set V of cardinality $n = |V|$. We associate with G its *symmetric adjacency matrix* $A = (a_{uv})$ with rows and columns indexed by V and entries $a_{uv} = \omega(u,v) + \omega(v,u)$ corresponding to the sum of the weights of the two directed edges between the two endpoints (if an edge is not present, the weight is simply equal to zero). We want to draw the conflict network in two-dimensional space. Thus, the positions of all n authors are represented by two vectors $x, y \in \mathbb{R}^n$. If for two authors u and v the entry a_{uv} in the adjacency matrix is large (i. e., if they frequently revise each other), then they are well-represented by the coordinate vector x if the entry x_u is (say) strongly negative and the entry x_v strongly positive. Then, the value $x_u a_{uv} x_v$ is negative and has quite large absolute value. Summing this up over all pairs of authors, x is determined to minimize the objective function

$$\Phi_A(x) = \sum_{u,v \in V} x_u a_{uv} x_v = x^\mathrm{T} A x \ ,$$

under the condition that x must have unit length (to keep the drawing to the screen size). It follows from an alternative description of the eigenvalues of a matrix that this term is minimized if and only if x is equal to the eigenvector of A associated to the smallest eigenvalue $\lambda_{\min}$ (see, e. g., [8]). The second coordinate vector y is

chosen to minimize $\Phi_A(y)$ under the condition that y is normalized and orthogonal to x. This is solved by taking for y the eigenvector of A associated to the second smallest eigenvalue $\lambda'_{\min}$.

The coordinate vectors derived so far would already represent well some pure conflict patterns as in Fig. 4(*middle*) and (*right*). However, real data is normally not so balanced. For instance, it might be the case that in Fig. 4(*middle*) one side of the triangle consists only of very weak edges so that it approaches a bipolar conflict (compare Fig. 5). To achieve a smooth transformation between different conflict patterns we scale y with the ratio between the two minimal eigenvalues $\lambda'_{\min}/\lambda_{\min}$. The derivation why this rescaling interpolates between different conflict patterns is quite lengthy and will be omitted here. However, a justification is provided by the examples shown in this article.
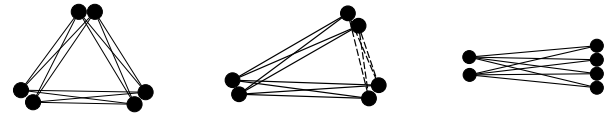

Figure 5: Smooth transformation from pure 3-polar conflict (*left*) to bipolar conflict (*right*). The dashed edges of the intermediate graph (*middle*) are assumed to have lower weight.

The absolute values of the two coordinates of an author v are a measure of how much v is *involved* in controversy, since they indicate how strongly v is connected to others via revision edges.

Putting this together, we get the following algorithm for determining the authors' positions and involvement, which takes as input the symmetric adjacency matrix A of the revision network.

1. Compute the smallest and second smallest eigenvalue $\lambda_{\min}$ and $\lambda'_{\min}$ of A and the associated (normalized and orthogonal) eigenvectors x and y.

2. Set $s = \lambda'_{\min}/\lambda_{\min}$ as the network's *skewness* and define for an author v its *position* $p(v) = (p_1(v), p_2(v)) = (x_v, s \cdot y_v) \in \mathbb{R}^2$ and its *involvement* $i(v) = \sqrt{p_1(v)^2 + p_2(v)^2}$.

Efficient computation of the extremal eigenvalues and -vectors is possible, e. g., with the so-called *orthogonal iteration*, which can also exploit sparsity of the network (see [8]).

Note that, although our layout method seems to be similar to multidimensional scaling (MDS) on a distance matrix, it enjoys a further desirable property: MDS would try to achieve distance zero for all authors that are not connected, whereas our method requires in addition that authors must confront (approximately) the same others to be placed at the same position. Thereby, independent conflicts (as in Fig. 4(*right*)) can be recognized as such in the final drawing.

4.2 Visual Representation of Author Properties

Next we define several additional characteristics of the authors and explain how these (and the previously defined position and involvement) are graphically represented.

4.2.1 Position and Involvement

Let $(p_1(v), p_2(v))$ be the position of an author v and $i(v)$ her involvement as defined in Sect. 4.1. The position coordinates $(p_1(v), p_2(v))$ could be directly used for drawing authors in two-dimensional space. However, when doing so, many of the not-so-important authors would be placed near the center of the drawing, making it hard to recognize their positions. To overcome this we normalize the positions to draw authors on an ellipse: Let r_1 be
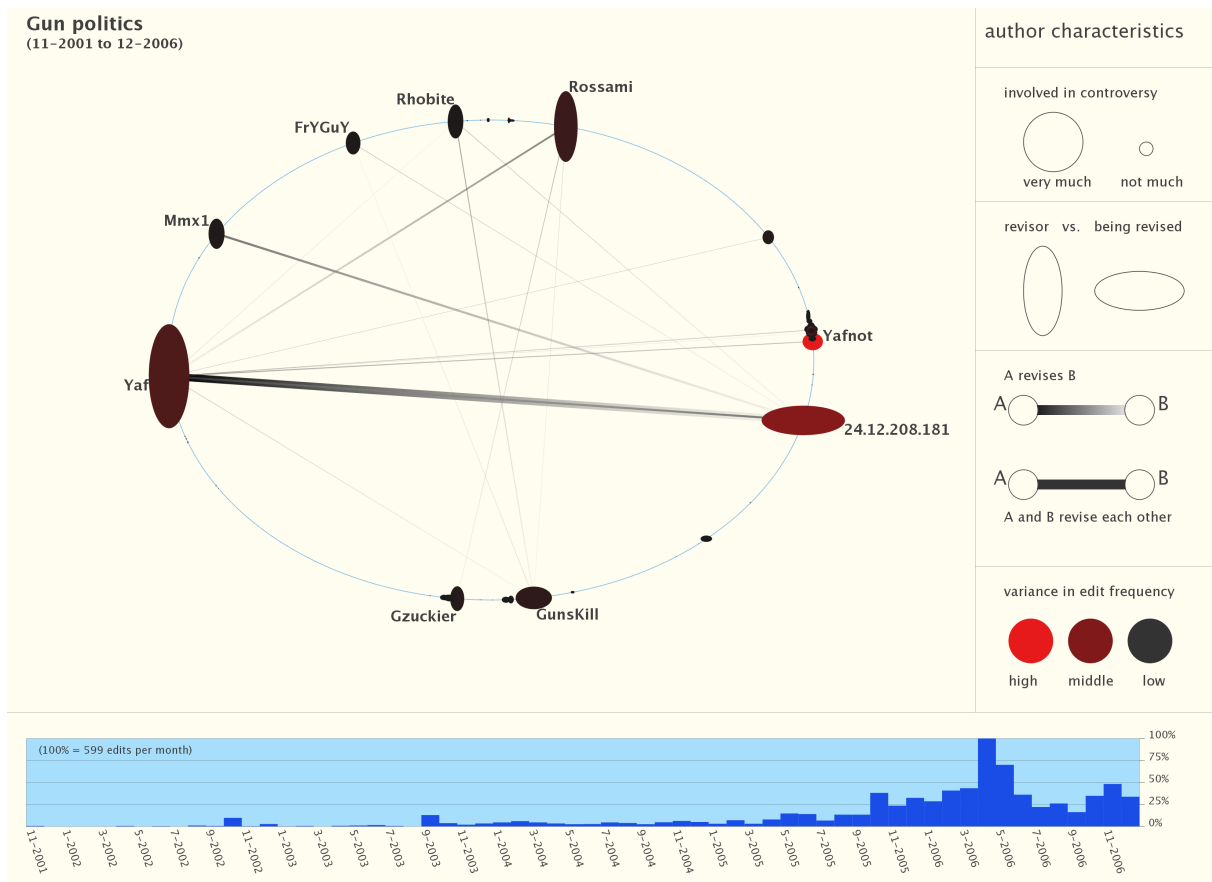
Figure 6: Example visualization of a revision network (determined from `Gun politics` and related pages). Nodes represent the different authors. If two authors are on opposite sides they strongly revise each other. Other characteristics are represented as described in the legend on the righthand side (also see Sect. 4.2). The diagram at the bottom shows the total number of edits per month. For more on this particular network see Sect. 5.1.

the horizontal half axis (value determined by the size of the image) and $r_2 = s \cdot r_1$ the vertical half axis. We draw author v at the coordinates $(r_1 \cdot p_1(v)/i(v), r_2 \cdot p_2(v)/i(v))$. Normalizing author positions to an ellipse rather than a circle has the advantage that we can still distinguish between the dominant conflict (shown horizontally) and secondary conflict (shown vertically) if their magnitude is different (compare, e. g., Figs. 7 and 9).

The area size of the node representing v is proportional to the involvement $i(v)$ (shape will be explained in Sect. 4.2.2). Thus, even after the normalization of positions it is still possible to distinguish between different involvement of authors.

We draw the usernames (or IP-addresses in case of anonymous contributors) of the most involved authors as node labels. Printing all usernames would produce clutter, considering that the revision networks can have several thousand authors.

4.2.2 Revisor vs. Being Revised

The out-degree $d^+(v) = \sum_{(v,u) \in E} \omega(v,u)$ of an author v indicates how strongly she revises others and is called her *degree as a revisor*, the indegree $d^-(v) = \sum_{(u,v) \in E} \omega(u,v)$ indicates how strongly she is revised by others and is called her *degree of being revised*. We draw v as an ellipse with height/width-ratio proportional to $d^+(v)/d^-(v)$, while keeping the area size proportional to the involvement $i(v)$. (However, to avoid very thin ellipses we bound the aspect ratio.)

The distinction between revisors (high and narrow) and those that are revised (wide and flat) is a very interesting one: Those who

are mostly revisors seem to be quite satisfied with a page and react only to revise changes made by others. On the other hand, those that are mostly revised attempt to initialize changes to a page that are not approved by the revisors and therefore corrected very fast. To use terms that are easy to remember, the revised authors play the role of *revolutionaries*, the revisors the role of *reactionaries*. Note that these roles are to be understood relative to the content of a page: writing the page as desired by the revised would probably interchange the roles.

As an example consider Fig. 6, where the anonymous author `24.12.208.181` is frequently revised—mostly by the revisors `Yaf` and `Mmx1` (see Sect. 5.1). It is likely that authors keeping a page on their *watch-list*[7], as well as authors fighting vandalism also play the role of revisors (see Sect. 5.2).

4.2.3 Direction of Revision Edges

The edges show a dark-grey to light-grey gradient from the revising author to the revised author (compare the edge from `Yaf` to `24.12.208.181` in Fig. 6). If an edge is almost symmetric it shows uniformly dark-grey. The information encoded by asymmetric edges is finer grained than that of the nodes' aspect ratio (as defined in Sect. 4.2.2): An author who is both, revisor and revised, appears as a circle, nevertheless, she may have asymmetric edges to some specific alters. The line thickness of an edge is chosen proportional to its weight and we show only the edges with the highest

---

[7] http://en.wikipedia.org/wiki/Help:Watching_pages

weights.

4.2.4 Steady vs. Unsteady Participation

One further indicator provides an important distinction between different author roles: there are authors that show sustained interest in editing a certain page and there are authors that perform a huge number of edits in a small time interval and loose their interest afterwards (or sometimes get blocked from editing Wikipedia). To assess this distinction we define a measure of how much does the weekly participation of an author vary. The decision "one week" is in a certain sense arbitrary and exchangeable by longer or shorter intervals of time. However, we have chosen a week as this marks how people normally organize their work (an author being very active on week-ends and inactive during the week will not be considered as unsteady).

Let a particular author and page be fixed and let $(e_i)_{i=1,\dots,K}$ denote this author's number of edits on that page performed in week i. The sum $\mu = \sum_{i=1}^{K} e_i / K$ is the *mean value* (edits per week) and $\sigma^2 = \sum_{i=1}^{K} (e_i - \mu)^2 / K$ is the *variance* of the author's edit volume. However, variance is not yet an appropriate measure for the unsteadiness of a author, since authors with higher mean will normally have higher variance. This drawback can be overcome by considering the *relative standard deviation* σ/μ. This makes sense since the edit volume is always positive (authors with no edits are not in the network). However, the normalization gives un-proportional weight to authors that have very small mean, e. g., those that perform only one edit to the page. Since we are not interested in such peripheral authors, we will simply ignore them and apply the normalization only for those that exceed a certain minimum number of edits.

The relative standard deviation σ/μ is still not an appropriate measure for the unsteadiness, due to an observed characteristic of the input data: the variance of the aggregated number of edits (i. e., edits performed by all authors) can reach extremely high values (see, e. g., Fig. 10), so that on those pages all (busy) authors will appear as highly unsteady. Since we are interested in differences between the authors (rather than absolute values), we subtract the minimum value of σ/μ, so that the minimum becomes zero, and normalize so that the maximal value becomes one.

The node color of an author is black if this unsteadiness indicator is zero, i. e., if the author showed sustained interest in the page. It becomes red if this indicator is one, i. e., if the participation frequency is the most volatile. For instance, the anonymous user `24.12.208.181` in Fig. 6 is slightly unsteady and `Yafnot` very unsteady (compare Sect. 5.1).

4.2.5 Total Number of Edits Per Month

The aggregated edit volume performed by all authors of the analyzed page (or set of pages) is visualized in a bar chart at the bottom of the image. This diagram provides the information about time periods when this page was a "hot topic" (compare Sect. 5.3) and can also provide clues to restrict the revision network to interesting time intervals, see Sect. 4.3.1.

4.3 Filtering

Visualizing the complete revision network over the whole lifetime of the page gives an overview revealing the most important authors, the roles they play, and the other authors they confront. Next we describe how relevant sub-structures of the revision network can be determined.

4.3.1 Restriction to Time Intervals

The edit volume diagram shown at the bottom of the images reveals time points when the page receives much interest. It is straightforward to restrict the revision network by including only revisions
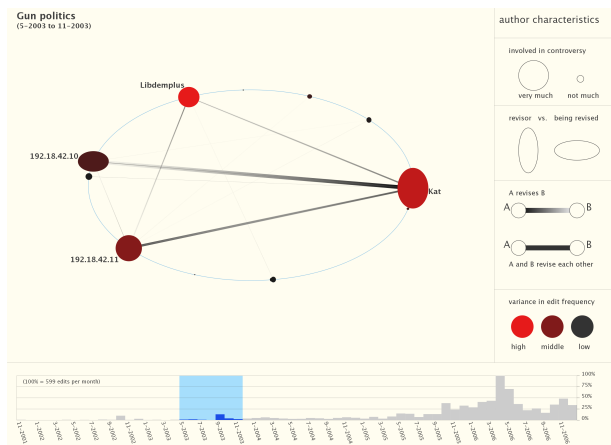

Figure 7: Filtering in time: a peak in the revision plot of `Gun politics` during 2003 has been caused by authors that vanish in the global image shown in Fig. 6.

within a certain time interval. For instance, Fig. 7 shows the revision network of `Gun politics` during a rise of interest in the earlier stages of the page. The dominant authors during that time are different from the dominant authors over the whole lifetime (shown in Fig. 6). Restricting the network to specific time intervals also enables the analyst to examine the most recent development.

4.3.2 Restriction to Relevant Sub-networks

A revision network often contains several ongoing controversies that are almost independent, i. e., involving disjoint sets of authors. For instance, one controversy can be due to different opinions of the authors (see, e. g., Fig. 6 and Sect. 5.1) and another conflict can arise between vandals and vandalism repair (see, e. g., Fig. 8). Since such controversies might overlap in time, it is in general not possible to separate them by restriction to time intervals as described in Sect. 4.3.1. Instead, an approach based on network clustering, which is described in the following, performs quite well in doing this task.

The goal of the network clustering is to put authors that strongly revise each other into the same cluster and authors that have only little interaction into different clusters. The sub-networks induced by the various clusters are then analyzed separately. In general, density-based graph clustering is a hard task (compare [5]). We used a variant of spectral graph clustering heuristics proposed, e. g., in [10, 16]. These spectral heuristics are efficient, received much empirical and theoretical support (see [10, 16] and references therein), and also performed quite well in the examples that we considered. Figure 8 shows a meaningful sub-network determined by network clustering.

5 EXAMPLES OF PAGES AND PATTERNS

In this section we describe a sample of illustrating findings on specific pages and some patterns that could repeatedly be observed.

5.1 Gun politics

The issue gun rights vs. gun control is a typical pro/con topic. Several Wikipedia pages, like `Gun politics`, `Gun politics in the United States`, etc. are related to this topic and have largely overlapping author communities. We took the union of the associated revision networks which are built together from 4,609 revisions by 781 different authors. This network, which is shown in Fig. 6, contains several interesting subnetworks that are extracted
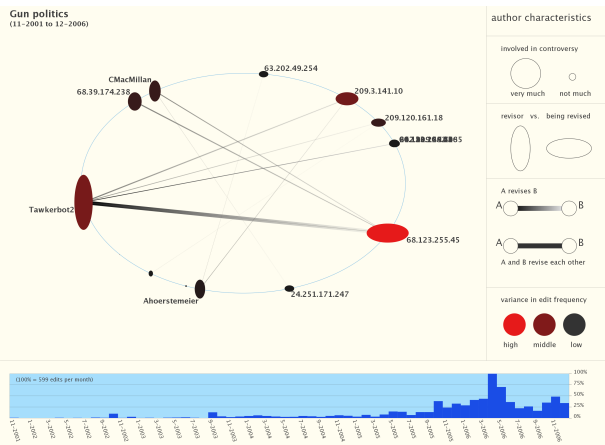
Figure 8: Network clustering reveals a relevant sub-network of the revision network of `Gun politics`. Another controversy cluster of larger aggregated edge weight is similar to Fig. 6 and not shown separately. User `Tawkerbot2` is not a real author but a script for vandalism repair; its dominant opponents are anonymous users. It seems that this image shows revisions caused by vandalism, overlapping in time with the dispute over different opinions shown in Fig. 6.
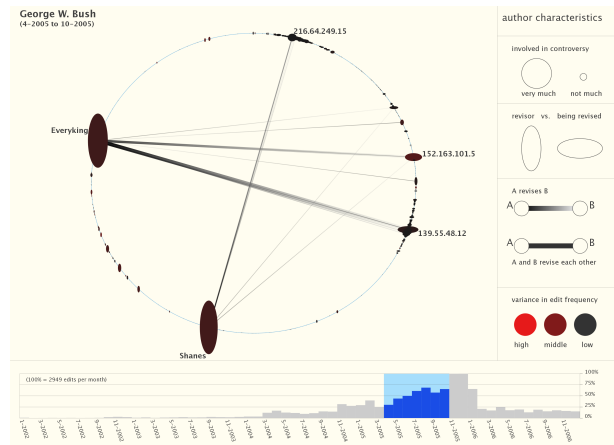
Figure 9: Revision network of the page `George W. Bush` in 2005. Two very busy revisors (`Everyking` and `Shanes`) opposed to numerous anonymous users—all of them much less involved than the former two. It is likely that `Everyking` and `Shanes` play the role of "watchdogs", defending the page against vandalism.

either by filtering in time (compare Sect. 4.3.1) or by network clustering (compare Sect. 4.3.2). For space limitations we will describe only the global view in Fig. 6.

The dominant confrontation in this network is clearly between `Yaf` and the anonymous user `24.12.208.181` (which we abbreviate in the following with `181`). (Strictly spoken it is not clear whether the same IP implies the same person—however, looking at the sustained interest of `181` in gun politics makes us believe that this is the case.) Looking at `Yaf`'s user-page[8] makes it rather simple to guess that he/she advocates the freedom to carry guns. In contrast, looking at the contributions of `181`,[9] makes it almost evident that he/she takes the opposite point of view. The author `181` shows a slightly unsteady edit behavior and is therefore drawn in dark-red in Fig. 6. Indeed, `181` performed almost a hundred edits in Wikipedia (see Footnote 9)—all of them between November 2005 and April 2006 and almost all to pages related to gun politics. Besides differences in opinion, another distinction between these two users is that `Yaf` is more a revisor and `181` more revised (see Sect. 4.2.2). The asymmetry of the edge between these two users is mostly due to a couple of very quick revisions (within less than five minutes) where `Yaf` reverts[10] edits made by `181`.

Interestingly, some Wikipedia authors chose a username that itself expresses a certain orientation. For instance, the name `GunsKill` (also shown in Fig. 6) already gives a indication that this author may advocate more gun control (looking at his/her contributions[11] further supports this). It is remarkable that this user is—similarly as `181`—more revised (mostly from `Rhobite`) than revisor.

While names like `GunsKill` indicate a certain opinion with respect to a specific topic, names like `Yafnot` indicate a negative feeling towards another Wikipedia user (`Yaf` in this case). Not surprisingly, `Yafnot` and `Yaf` are on opposite sides in Fig. 6. `Yafnot` shows a very high variance in his/her edit behavior and is therefore drawn in red. Indeed, this author made only seven con-

tributions[12] to Wikipedia—all on April 2'nd 2006 in a period of less than two hours and all to the page `Gun politics in the United States`. Author `Yafnot` is an example of a user that did not contribute much (only seven edits) but is quite a lot involved in controversy (among the nine most involved users in Fig. 6).

Looking in detail at the sequence of edits of `Gun politics in the United States` on April 2'nd 2006, taking into account the positions of `Yaf`, `Yafnot`, and `181` in Fig. 6, and considering the purposeful name of `Yafnot`, on could come to the hypothesis that `Yafnot` and `181` are the same person. Indeed, `Yaf` had the same idea, as the following quote (taken from the user talk page of `Rhobite`, archive nine[13]) indicates:

> User 24.12.208.181 has apparently taken the user name Yafnot after your 2nd Level warning. He has continued to delete content of Gun politics in the United States. Thanks. Yaf 06:14, 2 April 2006 (UTC)

It is difficult to prove this hypothesis conclusively, without access to the log-files of the Wikipedia server. In any case, user `Yafnot` was blocked[14] on April 2'nd 2006 (still less than two hours after his/her first edit) by `Rhobite` for *impersonation*[15].

5.2 Vandalism Defense

A typical pattern emerges when analyzing the page `George W. Bush`. This page is the most edited in the English Wikipedia (more than 30,000 revisions by more than 10,000 authors), is a frequent target of vandalism, and was the first Wikipedia page that become protected[16] (compare [22]).

The network visualization (see Fig. 9) reveals two dominant users playing the role of revisors, which are opposed to a huge number of much less involved anonymous alters. User `Shanes` is a Wikipedia administrator [17] and user `Everyking` a former administrator who had this status in 2005. A significant difference between the pages `Gun politics` (see Fig. 6) and `George W.`

---

[8] http://en.wikipedia.org/wiki/User:Yaf
[9] http://en.wikipedia.org/wiki/Special:Contributions/24.12.208.181
[10] http://en.wikipedia.org/wiki/Help:Revert
[11] http://en.wikipedia.org/wiki/Special:Contributions/GunsKill

[12] http://en.wikipedia.org/wiki/Special:Contributions/Yafnot
[13] http://en.wikipedia.org/wiki/User_talk:Rhobite/Archive_9
[14] en.wikipedia.org/w/index.php?title=Special:Log&type=block&page=User:Yafnot
[15] http://en.wikipedia.org/wiki/Wikipedia:Doppelganger_account
[16] http://en.wikipedia.org/wiki/Wikipedia:Protected_page
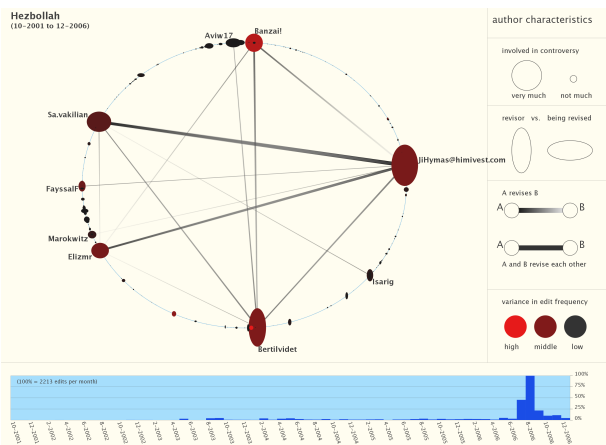[17] http://en.wikipedia.org/wiki/Wikipedia:List_of_administrators

Figure 10: Page on `Hezbollah` has a very high variance in its edit volume. The strong peak in 2006 ($2,213$ edits in August 2006 alone) is probably triggered by the 2006 Israel-Lebanon conflict.

`Bush` is that in the former the dominant authors confront dominant alters. It is likely that the users confronting `Everyking` and `Shanes` in Fig. 9 are not really interested in writing a good article but rather want to vandalize the page. On the other hand, the dominant authors of `Gun politics` seem to care about its content, since they contributed a lot (although they have quite different ideas of what is a good `Gun politics` page).

5.3 News-triggered Pages

The edit history of some Wikipedia pages is strongly influenced by political events. An extremal example is the page on `Hezbollah` (see Fig. 10). Although this page exists in Wikipedia since October 2001, it only became a hot topic during the 2006 Israel-Lebanon conflict and calmed down afterwards.

An issue for future work is to find out which pages are especially influenced by news events and whether these pages are more likely to be controversial than pages with more constant edit volume.

6 CONCLUSION

Wikipedia makes it possible to assess the author community behind an article by providing the complete edit history of a page. However, the sheer number of edits and authors makes it hard to understand this data without automatic support.

The main contribution of our work lies in the proposed techniques for visual analysis of the revision network. Our drawings easily reveal the authors that are the most involved in controversy (taking the number of edits as a measure for user involvement would be insufficient as the example of `Yafnot` in Sect. 5.1 shows). Furthermore, our network visualizations show who confronts whom and who plays which role.

Another contribution is that we identified some recurrent patterns of confrontation in the examples we considered: both Fig. 6 and Fig. 9 show a high asymmetry in the sense that users on one side of the conflict play the role of revisors and users on the other side are revised. However, the interpretation of the revisor vs. revised pattern can be quite different. In Fig. 6 it seems to be caused by differences in opinion and in Fig. 9 by vandalism.

One issue for future work is to determine more conclusively the difference between opinion-triggered and vandalism-triggered confrontation. Possibilities include to make use of log data about user blocking, statements on talk pages or user-talk pages, or contributions of an author to other pages. Another issue is to improve the construction of the revision network by taking into account whose text has been changed during a revision.

REFERENCES

[1] R. Agrawal, S. Rajagopalan, R. Srikant, and Y. Xu. Mining newsgroups using networks arising from social behavior. In *Proc. 12th Intl. Conf. WWW*, pages 529–535, 2003.

[2] U. Brandes, D. Fleischer, and J. Lerner. Summarizing dynamic bipolar conflict structures. *IEEE Transactions on Visualization and Computer Graphics*, 12(6):1486–1499, 2006.

[3] C. Chen, F. Ibekwe-SanJuan, E. Sanjuan, and C. Weaver. Visual analysis of conflicting opinions. In *IEEE Symp. Visual Analytics*, pages 59–66, 2006.

[4] E. Gabrilovich and S. Markovitch. Overcoming the brittleness bottleneck using Wikipedia: Enhancing text categorization with encyclopedic knowledge. In *Proc. 21'st Natl. Conf. Artificial Intelligence*, 2006.

[5] M. Gaertler. Clustering. In U. Brandes and T. Erlebach, editors, *Network Analysis*, pages 187–215. Springer Verlag, 2005.

[6] J. Giles. Internet encyclopaedias go head to head. *Nature*, 438:900–901, 2005.

[7] N. Glance, M. Hurst, K. Nigam, M. Siegler, R. Stockton, and T. Tomokiyo. Deriving marketing intelligence from online discussion. In *Proc. 11'th ACM SIGKDD*, pages 419–428, 2005.

[8] G. H. Golub and C. F. van Loan. *Matrix Computations*. John Hopkins University Press, 1996.

[9] T. Holloway, M. Božičević, and K. Börner. Analyzing and visualizing the semantic coverage of Wikipedia and its authors. arXiv:cs/0512085.

[10] R. Kannan, S. Vempala, and A. Vetta. On clusterings: Good, bad and spectral. *Journal of the ACM*, 51(3):497–515, 2004.

[11] M. Kaufmann and D. Wagner, editors. *Drawing Graphs*. Springer Verlag, 2001.

[12] A. Kittur, B. Suh, B. A. Pendleton, and E. H. Chi. He says, she says: conflict and coordination in wikipedia. In *Proc. SIGCHI Conf. Human factors in computing systems*, pages 453–462, 2007.

[13] J. Kolbitsch and H. Maurer. The transformation of the Web: How emerging communities shape the information we consume. *Journal of Universal Computer Science*, 12(2):187–213, 2006.

[14] B. Leuf and W. Cunningham. *The Wiki Way*. Addison-Wesley, 2001.

[15] B. Liu, M. Hu, and J. Cheng. Opinion observer: analyzing and comparing opinions on the Web. In *Proc. 14th Intl. Conf. WWW*, pages 342–351, 2005.

[16] F. McSherry. Spectral partitioning of random graphs. In *Proc. 42nd IEEE Symp. Foundations of Computer Science*, pages 529–537, 2001.

[17] K. Nigam and M. Hurst. Towards a robust metric of opinion. In *Proc. AAAI Symp. Exploring Attitude and Affect in Text*, 2004.

[18] R. N. Rosecrance. Bipolarity, multipolarity, and the future. *Journal of Conflict Resolution*, 10(3):314–327, 1966.

[19] M. Strube and S. P. Ponzetto. WikiRelate! computing semantic relatedness using wikipedia. In *Proceedings of AAAI'06*, 2006.

[20] B. Stvilia, M. B. Twindale, L. C. Smith, and L. Gasser. Assessing information quality of a community-based encyclopedia. In *Proc. Intl. Conf. Information Quality*, 2005.

[21] F. B. Viégas, M. Wattenberg, and K. Dave. Studying cooperation and conflict between authors with history flow visualizations. In *Proc. SIGCHI Conf. Human factors in computing systems*, pages 575–582, 2004.

[22] F. B. Viégas, M. Wattenberg, J. Kriss, and F. van Ham. Talk before you type: Coordination in Wikipedia. In *Proc. HICSS'07*, 2007.

[23] J. Voss. Measuring Wikipedia. In *Proc. Conf. International Society for Scientometrics and Informetrics*, 2005.