Application of Decision-making Support, Nonlinear Dynamics, and Computational Linguistics Methods during Detection of Information Operations

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Abstract

The paper describes application of decision-making support, nonlinear dynamics, and computational linguistics methods to detection of information operations. The term information operation denotes a complex of information measures meant to change public opinion about a certain object or process.

Dynamics of the number of publications about the target object during a given period is represented as a time series. In order to define peculiar features of such series we are using Morlet and "Mexican Hat" wavelets. Besides that, we check the correlation between the time series and the respective information operation template. In addition to the listed approaches, we are also using ΔL-method based on Detrended Fluctuation Analysis.

Linguistic analysis of publications on the target object is another important aspect of information operations detection. Using sentiment analysis, the emotional coloring of these publications texts is determined. For detection of sub-topics related to the basic topic, a collection of publications is used as text corpus, to which TF-IDF and visibility graphs approaches are applied for determination of keywords. The keywords defined in this way are used for clarification of queries in content-monitoring systems.

Decision-making support system tools are used for decomposition of information operation topics and evaluation of efficiency rating of these topics in dynamics. During information operation topics decomposition, knowledge obtained from expert group is used. As a result of decomposition, the goal hierarchy graph of information operation topics is built. Based on this graph, recommendations for decision-makers are produced (using the method of target-oriented dynamic evaluation of alternatives) in the form of dynamic efficiency ratings of information operation topics. The recommendations produced in this way are used to evaluate the damage caused by the information operation, as well as to form the information counteractions.

A concept of the information-analytical system for the detection of information operations is proposed.

Keywords: information operations detection, time series, wavelet-analysis, keywords network, decision support system, expert decomposition.

1 Introduction

Sources of information have a substantial influence on people. The last several years show that mass media sources can be used efficiently for propagating misinformation. Furthermore, social experiments show that people often believe in the unconfirmed news and disseminate them. For example, in [1] the authors present a review of known false beliefs and misinformation in American society. In [2] the author describes his experiments. He examined belief in political rumors surrounding the health care reforms enacted by Congress in 2010. Depending on the details presented, 17-20% of the respondents believed in them, and 24-35% of the recipients did not have a specific opinion, and 45-58% of the respondents rejected the rumors.

Consequently, investigating processes in the information space is a topical issue. The problems of high significance are processing information streams, identifying trends and anomalies, and detecting critical and meaningful events in real-time mode.

Let us define the information operation [3-4]. The information operation (IO) is the complex of informational events (news on the Internet and media, comments on social networks, forums, etc.), aimed to change the public opinion about a particular object (person, organization, institution, country, etc.). Most of IO has the typical structure (Fig. 1). If the presented IO has the following phases: «background publications» – «calm» – «preparatory bombardment» – «calm» – «attack», then by the first three phases it is possible to predict future events with high probability.

To illustrate techniques and approaches presented in the article we use the "Brexit" topic. As you may know, a referendum was held on Thursday 23 June 2016, to decide whether the UK should leave or remain in the European Union. Leave won by 51.9% to 48.1%. Naturally, this event is connected with many informational processes on the Internet. Currently, Brexit is a topical issue that is widely researched by the scientific community [5].

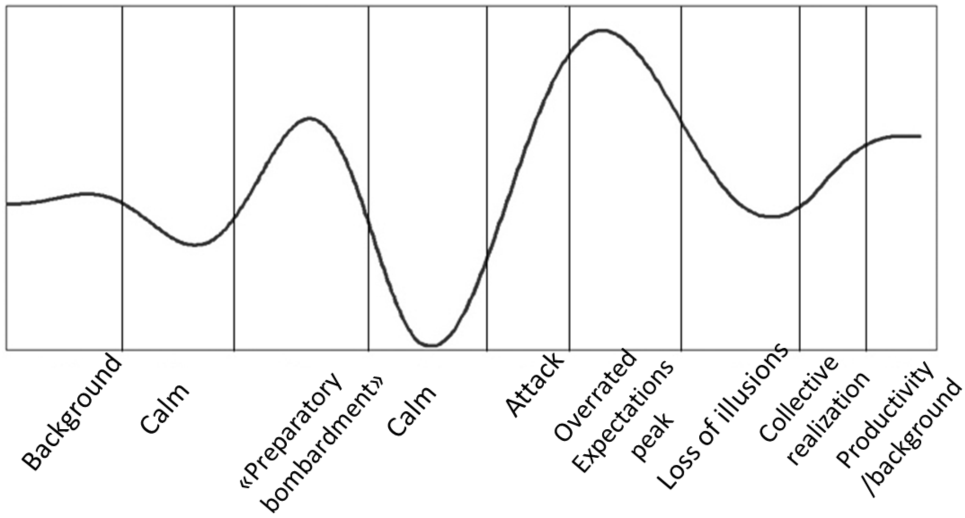

Fig. 1. Information Operation Roadmap.

2 Nonlinear Dynamics Methods for Analyzing Informational Streams

When investigating thematic information streams, we consider how the number of publications changes over time. A content monitoring system provides time series data for a particular topic. In this case, time series is a sequence of the numbers of publications dedicated to the topic per day during a specific time. For example, we gathered the time series for the "Brexit" topic (Fig. 2).

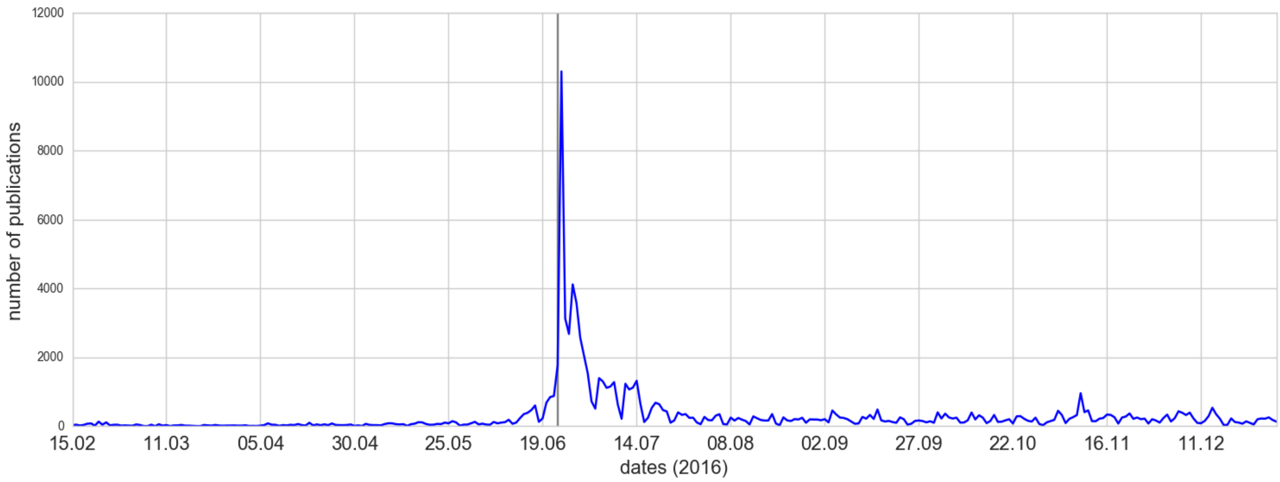

Fig. 2. The Number of Publications on "Brexit" during 2016.

To deal with time series data, we use wavelet-analysis [6]. A wavelet is a function that is well localized in time. In practice, we often use the Mexican Hat wavelet:

$$\psi(t) = C(1-t^2)\exp\left\{-\frac{t^2}{2}\right\},$$

and the Morlet wavelet:

$$\psi(t) = \exp\left\{ikt - \frac{t^2}{2}\right\}.$$

The essence of the wavelet-transform is to identify regions of the time series which are similar to the wavelet. To explore different parts of the original signal with various degrees of detail the wavelet is transformed by stretching/squeezing and moving along the time axis. Therefore, the continuous wavelet-transform has the location` parameter (l) and the scale parameter (s). By definition, the continuous wavelet transform of the function $x \in L^2(R)$ is:

$$W(l,s) = \frac{1}{\sqrt{s}} \int_{-\infty}^{\infty} x(t)\psi^*\left(\frac{t-l}{s}\right)dt,$$

where $l,s \in R$, $s > 0$; ψ^* is complex conjugate of ψ, the values $\{W(s,l)\}$ is called the coefficients of the wavelet transform or the wavelet-coefficients. The wavelet-coefficients are visualized in the plot with a locations axis and a scale axis.

The reason to use the Mexican hat wavelet and the Morlet wavelet is a possibility to detect spikes in time series. The wavelet-coefficients for the “Brexit” time series are shown in Fig. 3 (Mexican hat) and 4 (Morlet). In both cases, the spike in the time series on the second half of June is highlighted strongly. One can also notice smaller spikes in the second part of time series.

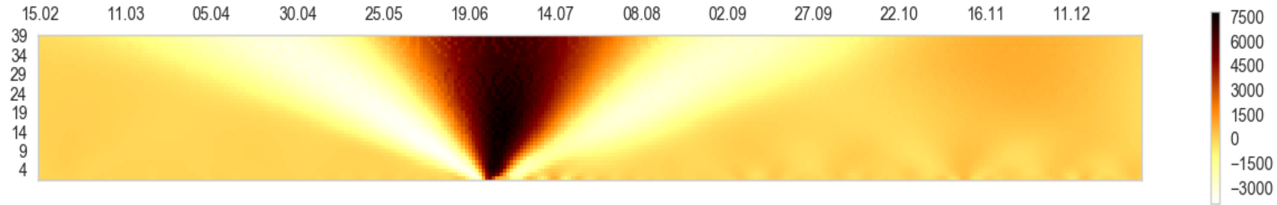

Fig. 3. The Wavelet-coefficients for the “Brexit” Time Series Using the Mexican Hat Wavelet.

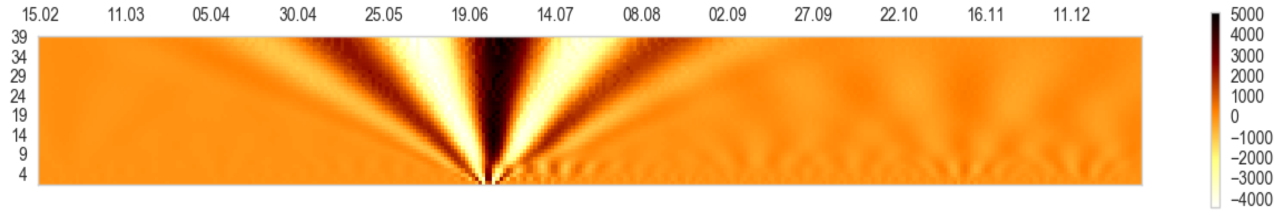

Fig. 4. The Wavelet-coefficients for the “Brexit” Time Series Using the Morlet Wavelet.

A wavelet must meet the mathematical requirements to be used in the continuous wavelet-transform. Generally, we can explore the correlation of the time series with a pattern of our choice. For example, if we aim to detect the IO, we can use the pattern shown in Fig. 5. The shape of the pattern matches stages of the IO. Now we use the number of points in the pattern instead of the scale.

A pattern can be moving along the time axis in the same way as a wavelet. To calculate each wavelet-coefficient we use the entire time series, but in this case, we need k points of the series and a pattern with k points to calculate the correlation coefficient by the formula:

$$C(l,k) = \frac{\sum_{i=1}^{k}\left(x(l+i) - \langle x \rangle\right)\left(s(i) - \langle s \rangle\right)}{\sqrt{\sum_{i=1}^{k}\left(x(l+i) - \langle x \rangle\right)^2 \sum_{i=1}^{k}\left(s(i) - \langle s \rangle\right)^2}}.$$

To visualize the results we make the similar plot as for the wavelet-coefficients (Fig. 6). When applying this method, the small spikes in the second part of the time series are highlighted more noticeably.

Another approach to analyzing time series is the ΔL-method. The ΔL-method is based on the DFA (Detrended Fluctuation Analysis) method [7]. The essence of the approach is to determine and visualize the absolute deviation of the accumulated time series from the corresponding values of linear approximation.

First, let us fix a length of a segment s. We split up the time series into overlapping segments. For the point x_t we choose the segment with the length s and the center at the point t (or at the point t-1 if s is even). For each segment fit the points in it with a linear function. Denote the value of local approximation at the point t for the segment with the center at l by $L_{t,l,s}$. Next, calculate the absolute deviation of x_t from the approximation line as follows:

$$\Delta_{t,l,s} = | x_t - L_{t,l,s} | .$$

According to the method we calculate values $\Delta_{t,l,s}$ for all $l = 1,...,T$ and $s = 1,...,[T/4]$. Finally, we calculate standard deviations:

$$E(l,s) = \sqrt{\frac{1}{s}\sum_{t=1}^{s} | x_t - L_{t,l,s} |^2} = \sqrt{\frac{1}{s}\sum_{t=1}^{s} \Delta_{t,l,s}{}^2} .$$

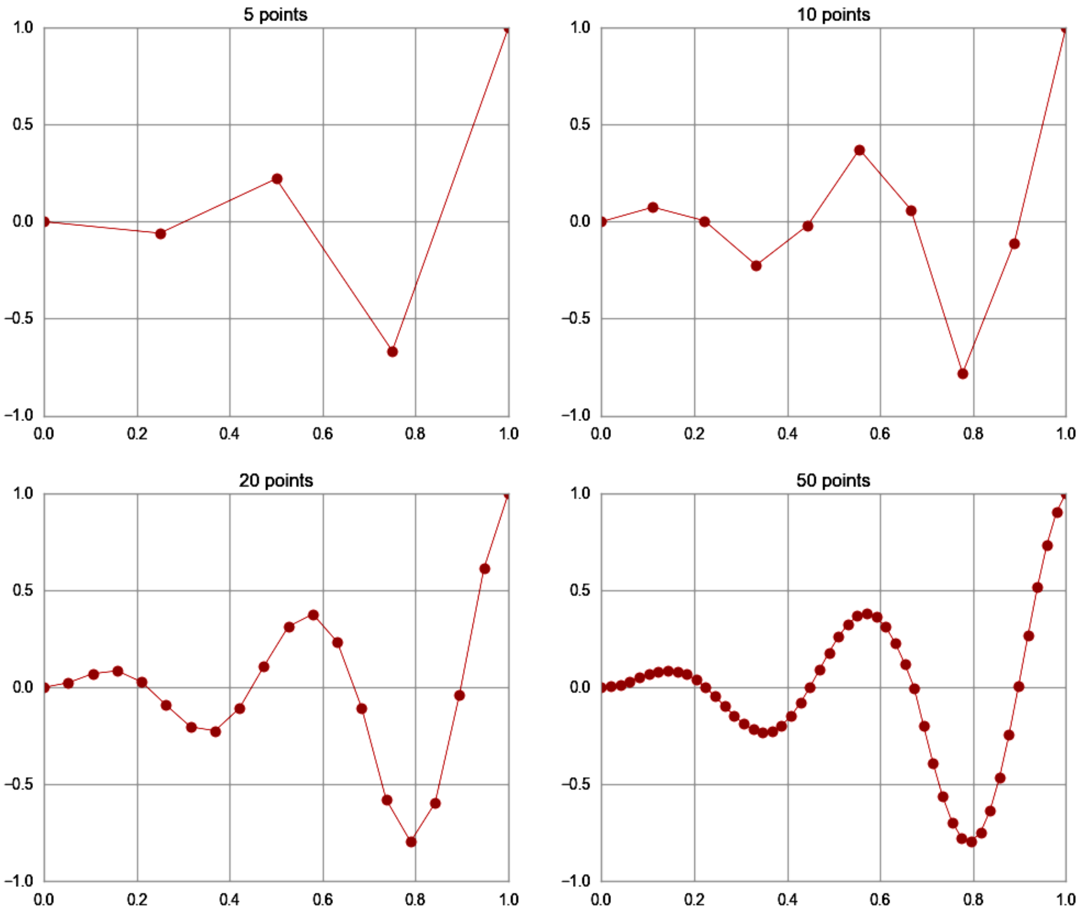

Fig. 5. Pattern with Different Numbers of Points.

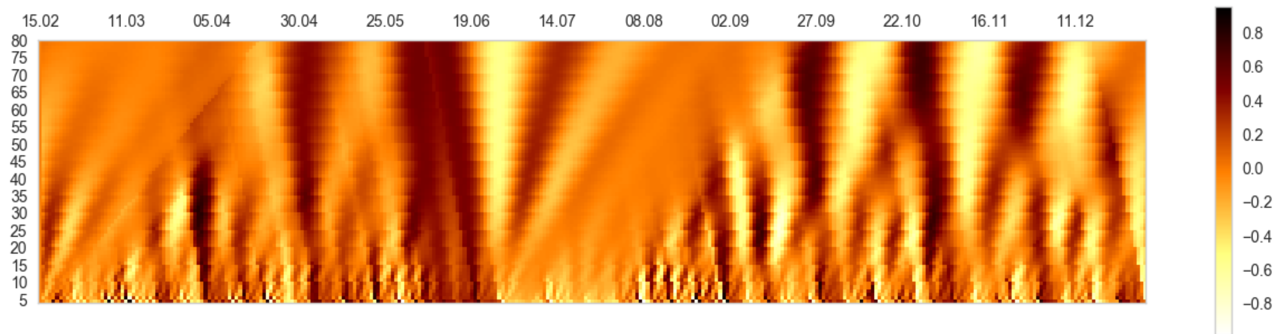

Fig. 6. Correlation Coefficients for the “Brexit” Time Series and the Pattern shown in Fig.4.

Coefficients $E(l,s)$ are plotted in the same way as wavelet-coefficients. We apply the ΔL-method to the Brexit time series and present the results in Fig. 7.

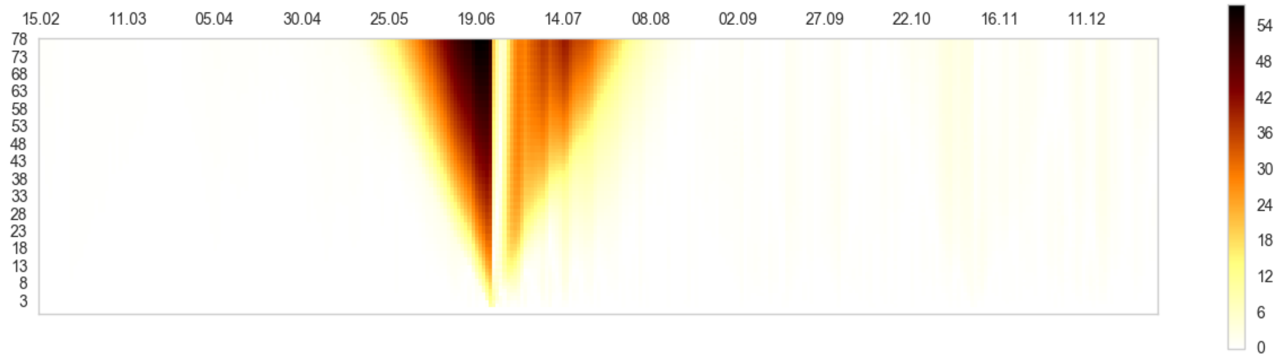

Fig. 7. Coefficients Obtained by the ΔL-method for the "Brexit" Time Series.

The continuous wavelet-transform, the correlation with a pattern, and the ΔL method help to identify spikes, edges, periodicity, and local features of the time series. Plots or scalograms obtained by these methods are used to visualize special features of time series.

3 Computational Linguistics Methods for Analyzing Informational Streams

In the previous section, we discuss the methods from nonlinear dynamics for analyzing the time series associated with the information stream. In that case, we use only numbers of publications dedicated to a particular topic. In this section, we are going to introduce some techniques of computational linguistics to extract useful information from the text of the publications.

Many publications and messages on social networks have strong sentiment. When analyzing the information stream, it is useful to determine the attitude of the text. Therefore, we apply methods of sentiment analysis. In the simple case, we classify whether a publication is positive, negative or neutral, using lists of words commonly associated with having a specific sentiment.

The second useful task is to select significant words from the text. For the task to be done, one can apply widely accepted TFIDF score. To calculate TFIDF scores, a text consisting of N words is divided into equal parts of M words. Then for each *i*-th word in the text TF(*i*) is the frequency of the word in the document, and DF(*i*) is the frequency of parts in which the word occurs. The TFIDF score for each word is calculated as following:

$$\mathrm{TFIDF}(i) = \mathrm{TF}(i)\log\left(\frac{N}{M \cdot \mathrm{DF}(i)}\right).$$

Another estimate of word significance is a standard deviation estimate [8]. Let us numerate all words in the text from 1 to *N*. Denote by $A_k(n)$ layout of a certain word *A*, where *k* is the number of occurrence of this word in the text, and *n* is a position of this word in the text. The distance between occurrences of the word *A* is $\Delta A_k = A_{k+1}(m) - A_k(n) = m - n$, where *m* and *n* are the positions of the *k +1*- th and *k* -th occurrences of the word A in the text, respectively. Denote be ΔA the vector $\Delta A_1, \Delta A_2, \ldots, \Delta A_K$. The standard deviation estimate is:

$$\sigma_A = \frac{\sqrt{\langle \Delta A^2 \rangle - \langle \Delta A \rangle^2}}{\Delta A}.$$

Using the TFIDF score or the standard deviation estimate, one can match each word in the text with a numerical value or weight. The next step might be to transform these pairs into a horizontal visibility graph [9]. The horizontal visibility graph (HVG) allows constructing the keyword network. Such network leads to detecting primary and secondary essential words for understanding the text and significant collocations.

The process of constructing the language network using HVG consists of two stages. At the first step, the traditional HVG is constructed. At the second step, all the nodes corresponding to a single word are combined into a single node and the connections of these nodes are also combined. It was proved that the largest-degree nodes reflect the meaning of the text; thus, these nodes are of informational significance. The keywords can be used to identify subtopics connected with the main topic of interest (Fig. 8).

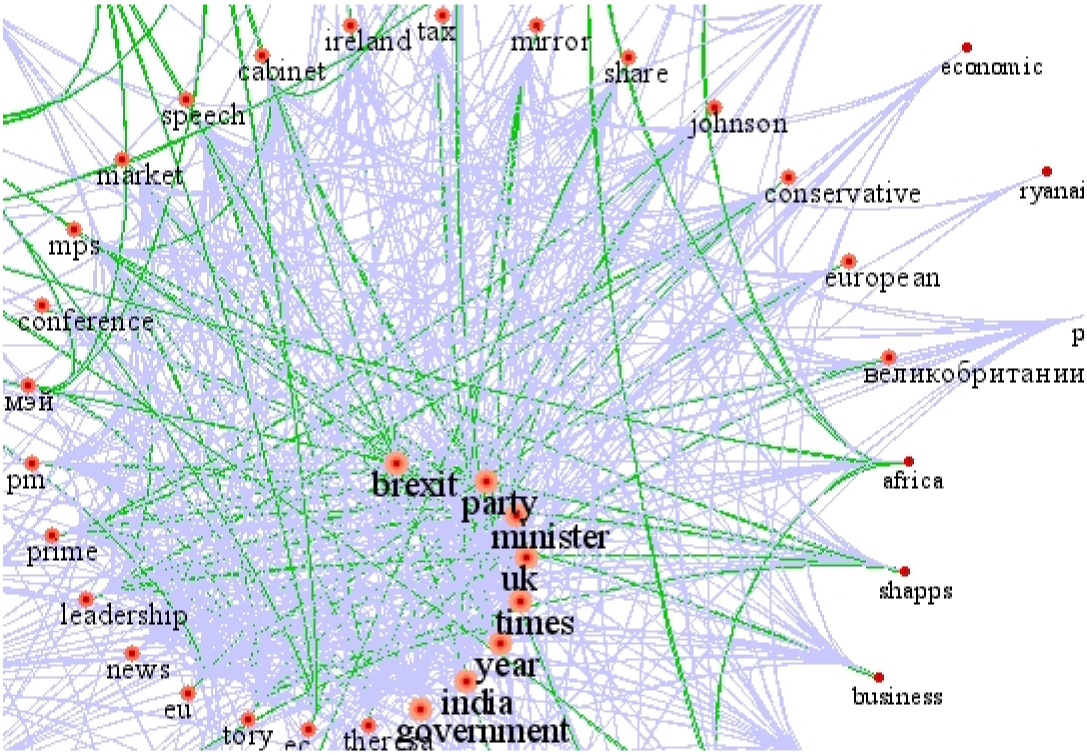

Fig. 8. Keywords for the “Brexit” Topic.

4 Decomposition of Information Operations Topics and Their Rating Calculation

In publications [10-12] it is shown that IO belong to weakly-structured domains. In order to deal with such domains, decision support systems (DSS) are used [13]. DSS produce recommendations for a decision maker. To do this, they are modeling weakly structured subject domains in their knowledge base (KB).

As part of the “goal hierarchy graph” model, a hierarchy of goals, or KB, represented in the form of an oriented network-type graph (an example for the Brexit is shown in Fig. 9), is built by experts. Nodes (vertices) of the graph represent goals or KB objects. Edges reflect the impact of one set of goals on achievement of other goals: they connect sub-goals to their immediate “ancestors” in the graph (super-goals). Goals can be quantitative and qualitative.

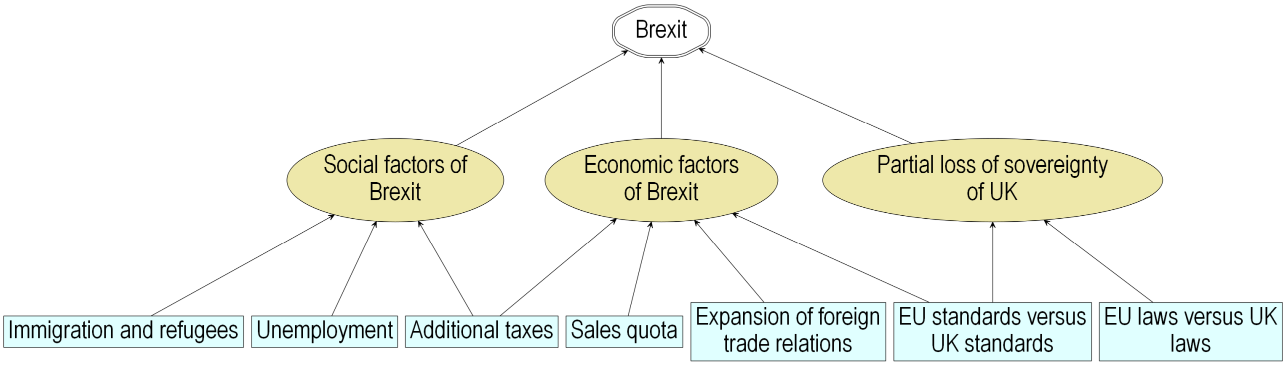

Fig. 9. Structure of Goals Hierarchy of KB for Brexit

For building of the goal hierarchy the method of hierarchic target-oriented evaluation of alternatives is used [13]: a hierarchy of goals is built; then the respective partial impact coefficients are set, and the relative efficiency of projects is calculated. First, the main goal of the problem solution is formulated, as well as potential options of its achievement (projects) that are to be estimated at further steps. After that a two-phase procedure of goal hierarchy graph construction takes place: “top-to-bottom” and “bottom-to-top” [13]. “Top-to-bottom” phase envisions step-by-step decomposition of every goal into sub-goals or projects, that influence the achievement of the given goal. The main goal is to be decomposed into more specific components – sub-goals that influence it. Then these lower-level goals are further decomposed into even more specific sub-components that are, in their turn, also decomposed. When a goal is decomposed, the list of its sub-goals may include (beside just-formulated ones) goals (already present in the hierarchy) that were formulated in the process of decomposition of other goals. Decomposition process stops, when the sets of sub-goals, that influence higher-level goals, include already decomposed goals and decision variants being evaluated. Thus, when decomposition process is finished, there are no goals left unclear. “Bottom-to-top” phase envisions the definition of all upper-level goals (super-goals, “ancestors”) for each sub-goal or project (i.e., the goals this project influences).

As it has been mentioned, the experts build a hierarchy of goals that is represented by an oriented network-type graph (Fig. 8). Its nodes are marked by goal formulations. Presence of an edge, connecting one node (goal) to the other indicates the impact of one goal upon achievement of the other one. As a result of the above-mentioned process of goal hierarchy building, we get a graph that is unilaterally connected, because from each node there is a way to the node, marking the main goal. Each goal is assigned an indicator of achievement level, form 0 to 1. This indicator equals 0 if there is absolutely no progress in achievement of the goal, while if the goal is completely achieved it equals 1. Impact of one goal upon the other can be positive or negative. Its degree is reflected by the respective value – a partial impact coefficient (PIC). In the method of target-oriented dynamic evaluation of alternatives (MTDEA) the delay of impact is also taken into consideration [13]. In case of projects their implementation time is taken into account as well. PIC are defined by experts, and, in order to improve the credibility of expert estimation process, pair-wise comparison-based methods are used.

Application of the approach and the methodology set forth in [10-11], calls for availability of a group of experts. Work of experts is rather costly and requires considerable time. So, reduction of expert information usage during building of DSS knowledge base (KB) in the process of IO detection represents a relevant issue.

The essence of the methodology of DSS KB building during IO detection [14-15] is as follows:

1) Group expert estimation is conducted in order to define and decompose the goals of the informational operation. Thus, the IO is decomposed as a weakly structured system. For this purpose, the means of the system for distributed collection and processing of expert information (SDCPEI) are used.

2) Using the DSS, the respective KB is built, based on the results of the expert examinations conducted by SDCPEI as well as on available objective information.

3) Analysis of dynamics of thematic information flow is performed by means of content-monitoring system (CMS). PIC are enter into the KB of DSS.

4) Recommendations of the decision-maker are calculated by means of the DSS, based on the KB already built.

The methodology is illustrated by the example of Brexit.

The “Consensus-2” system [16], intended for evaluation of alternatives by a group of territorially distributed experts, was used as SDEICP for group decomposition.

Based on interpretation of the data base, formed in SDCPEI “Consensus-2”, the knowledge engineer created the respective KB of “Solon-3” DSS [17]. The structure of goal hierarchy of this KB is provided on Fig. 8.

After that, by means of InfoStream CMS [18] the analysis of dynamics of thematic information flow was conducted. For this purpose, in accordance to each component of the IO, queries were formulated in the specialized language. Based on these queries, dynamics analysis of publications on the target topic was performed. During formulation of queries in accordance to the goal hierarchy structure (Fig. 8), the following rules were used:

1) when moving from top to bottom, respective queries of lower-level components of the IO were supplemented by queries of higher-level components (using “&” symbol), for clarification;

2) in cases of abstract, non-specific character of IO components, movement from bottom to top took place, while the respective queries were supplemented by queries of lower-level components (using "|" symbol);

3) in cases of specific IO components, the query was made unique.

Based on the results of fulfillment of queries to InfoStream system, particularly, on the number of documents retrieved, respective PICs were calculated for each of them. PICs were calculated under assumption that the degree of impact of IO component was proportional to the quantity of the respective documents retrieved. Obtained PIC values were input into the KB. Thus, we managed to refrain from addressing the experts for evaluation of impact degrees of IO components.

A recommendations (in the form of dynamic efficiency ratings of information operation topics) produced in the describe above way are used to evaluate the damage caused by the information operation [12], as well as to form the information counteractions [20].

The structure of goals hierarchy of KB for the Brexit is shown in Fig. 8. Based on the KB, the “Solon-3” DSS provided recommendations. The following rating has been obtained for the information impact of the publications: "Immigration and refugees" (0.364), "EU standards versus UK standards" (0.177), "EU laws versus UK laws" (0.143), "Expansion of foreign trade relations" (0.109), "Additional taxes" (0.084), "Sales quota" (0.08), "Unemployment" (0.043).

5 Use Case Diagram of a Concept of the Information-Analytical System for the Detection of Information Operations

Shown in Fig. 10 is the use case diagram of a concept of the information-analytical system for IO detection. The information-analytical system is an implementation of described above methods via system integration of DSS, CMS, SDCPEI and expert estimation system (EES). Our concept of the information-analytical system has following actors:

- **Expert** is a specialist who is invited or hired to provide a qualified opinion, judgment or estimation on some issues.

- **Knowledge engineer** is a specialist who constructs the knowledge base and provides recommendations with the help of the decision-making support toolkit.
- **DSS** is a system that provides recommendations based on the data from its knowledge base (both objective and expert data).
- **CMS** is a system that collects information from websites automatically in real time. In addition, CMS performs structuring, grouping by semantic features, thematic selecting, providing access to information databases in search mode, and analyzing the dynamics of thematic information streams.
- **SDCPEI** is a system for remote group work of experts in the global network.
- **EES** is a complex of software tools for expert estimation. EES must adapt flexibly to the level of experts and allow getting full and exact knowledge from them. “Level” (“Riven”) system [19] is an example of EES.

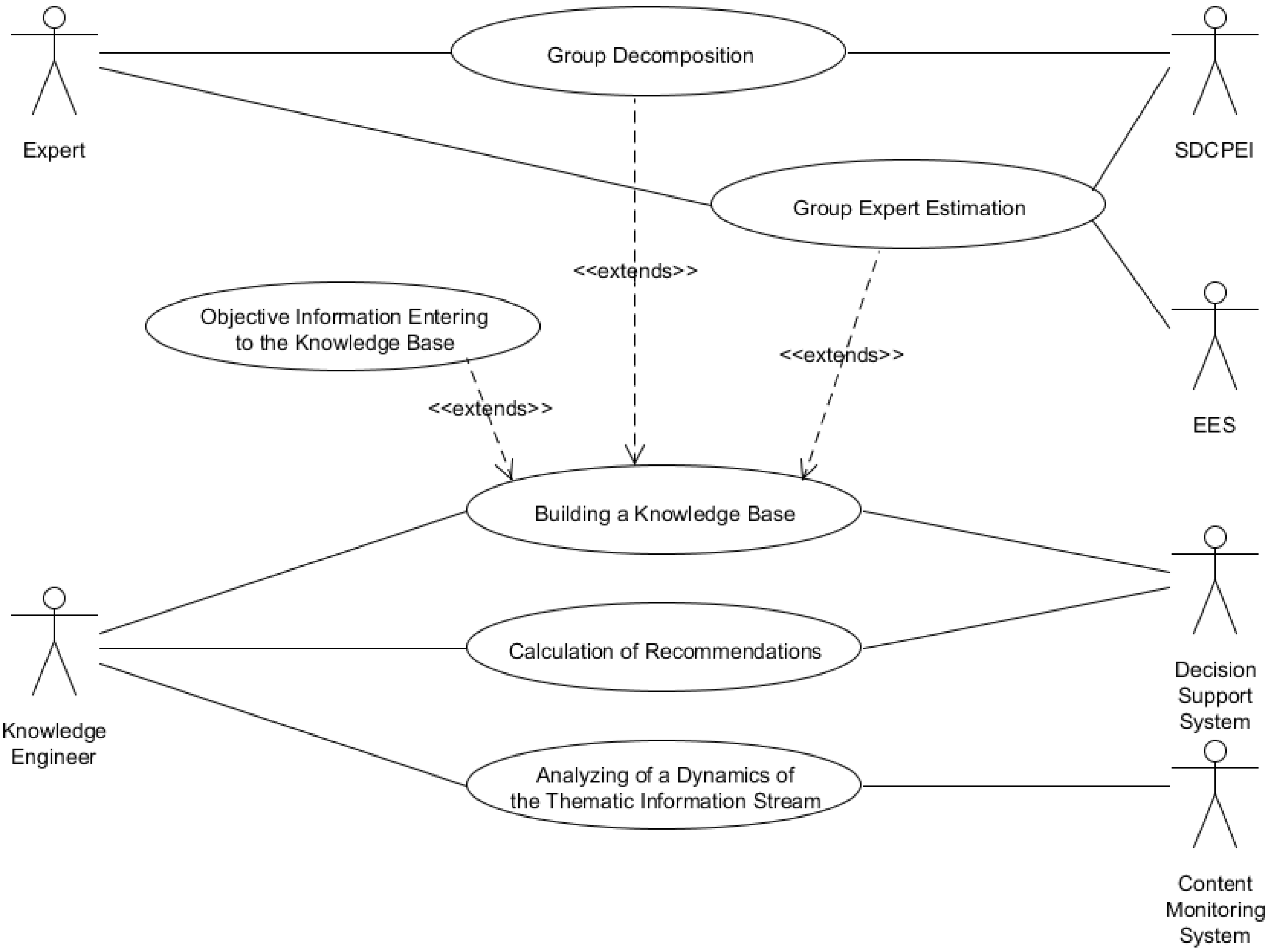

Fig. 10. Use Case Diagram of the Concept of Information-analytical System for Information Operations Detection

Use Cases:

- **Building a knowledge base.** The knowledge engineer builds a knowledge base of DSS for modeling of the weakly structured domain and producing the recommendations. In this process, both objective and expert information can be used.
- **Group decomposition.** Expects take part in the group decomposition. According to the target of the IO, the knowledge engineer forms a group of experts who are specialist in the field. The process of group decomposition is to be carried by dialogue with the experts of the group to decompose (or to divide) the target to the subparts. At each stage of the decomposition, experts are asked to formulate a set of goals (they may choose from the existing ones or formulate their own). These goals must directly affect the target. Further, the decomposition of the next goals is performed similarly. The decomposition process comes up to the end when we obtain the specific components of the IO. These components must have precise formulations that we will use as the queries for the content monitoring system.
- **Group expert estimation.** The process can be initiated by the knowledge engineer after the group decomposition process. During this process, the knowledge engineer identifies the type of the sub-target influences (qualitative or quantitative, positive or negative), as well as their degrees.
- **Objective Information Entering to the Knowledge Base.** The knowledge engineer enters the objective information (content-monitoring results) to the knowledge base.

- **Analyzing of the dynamics of the thematic information stream.** The process is initiated by the knowledge engineer. During this process, CMS performs the search queries. The found publications are used to study the dynamics of number of publications on target topics.
- **Calculation of recommendations.** The process is aimed to calculate the relative efficiency of each component of the IO (information throw-in). The relative efficiency means the contribution of the component to achieving the target. The calculation is based on data from the knowledge base. In addition, we evaluate the aggregated estimation of the effectiveness of the components. Dynamics of the process is taking into account. Based on the past data is possible to change the quantitative values of the target.

The concept integrates all components presented above.

6 Conclusions

In order to detect IO, it is necessary to involve a complex of analytical techniques. The complex includes methods of nonlinear dynamics and computer linguistics.

The wavelet transform and its modifications are applied to detect periodicity, peaks, spikes, and behavioral patterns in the dynamics of the number of thematic publications.

To extract meaningful and significant words from the text of publications we use the TFIDF score, the standard deviation estimate, and horizontal visibility graphs.

Applying decision-making support methods, we provide the decomposition of the topics of the IO and assess rating of the effectiveness of these topics.

It is proposed a concept of a new information-analytical system for detection of IO through integration of a decision support system, a content-monitoring system, a system for distributed expert information collection and processing and an expert estimation system.

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