IoTViz: Visualizing emerging topics in the internet of things

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***Abstract*—The "Internet of Things" is changing the way companies operate and consumers behave. Therefore, it is essential to capture trends in "Internet of Things". This paper proposes *IoTViz*, a visual analytics tool for analyzing "Internet of Things" news on social media. The principal aim of *IoTViz* is to observe the dynamic behavior of topics along with their proximity to other dimensions such as user comments and ratings in multiple coordinated views. *IoTViz* provides an interactive exploration of the IoT topics and supports of a range of interactive features, such as linking and filtering, allowing users to narrow down events of interest quickly. It is interesting to filter and visualize IoT news regarding the individual organization, e.g., user opinions/ratings regarding a company or its products.**

***Index Terms*—Internet of Things, IoT, coordinated multiple views, social media, hacker news, word clouds.**

I. Introduction

The term "Internet of Things" (hereafter, IoT) was first mentioned by Kevin Ashton [1], a co-founder of the Auto-ID Center at the Massachusetts Institute of Technology. Kevin Ashton used the term "Internet of Things" to refer to the existence of identified objects and the connection of the Internet to the physical world via ubiquitous devices. The term IoT is now broadly defined as *"the global infrastructure for the information society, the support for specialized services (computing), through objects (both virtual and real) are interconnected through integrated information and communication technology"* by the IoT-GSI Global Standards Initiative [2]. This new definition indicates the importance of "connecting" between objects that can be identified with one another, or, more generally, the seamless connection between the infrastructures.

In recent years, the IoT has been steadily gaining momentum due to the convergence of a variety of technologies, including dense wireless transmissions, real-time data analysis, machine learning, ubiquitous sensors, and embedded systems. Each of these technologies is the birthplace of many modern devices [3] such as the Apple Home Kit, Amazon Echo [4], Samsung Smarthing Hub [5], and emergency notification systems [6]. It can be seen that the IOT is wading into every corner of our lives, showing their presence everywhere, from every day lives to the discussions on the mass media forum.

It is undeniable that the IoTs are bringing a lot of benefits to society that enhances the quality of ones' lives. On one side, it is a great of beneficial effects, but on the other side, it is a matter of credibility with smart devices as well as the user's information. Google's autonomous car testing [7] is a prime example for crashing, or it is unsure whether smart-home devices [8] will retain all of our private conversations. The cons of smart devices do not mean that they should be discarded from our lives, in fact, they also have many positive aspects. In order to adapt these new technologies appropriately, understanding them is extremely important. By investigating their advantages and disadvantages, we can fully utilize and exploit their pros, while minimizing their cons.

The big IoT concern is *how can we understand them?* There are a lot of articles, discussions and social networking forums out there, but with such a huge amount of information, how do we know which information sources are trustworthy? Even for companies that produce smart devices do not fully give out the full information. Part of the reason is to dominate the competition by cluttering or failing to mention the weaknesses of their products, instead only advertising on the pros is given [9]. What are some of the other channels that specialize in evaluating products on the market? The question is whether they get paid to advertise for a given product. We are sometimes ambiguous about that question if it is not thoroughly investigated.

A lot of researches have been done to look for answers to the mentioned question. By performing a search on Google Scholar with the keyword *"information reliability on the internet"*, we found out an approximately of 2.5 million scientific publications. These results indicate the credibility of information that plays a very important role in research. Further investigating the topic of publications, we found that most of the topics were in the health and education field. This is understandable because these two areas need reliable information. Incorrect information has serious implications for medical treatment such as misdiagnosis, or misinformation in learning knowledge. When we combined the keyword *"information reliability"* with *"internet of things"*, the response results were reduced to 243 publications at the time of writing this manuscript. The vast majority of these scientific publications focus on the field of machinery and transportation. Other areas have not yet been adequately addressed, especially for the field of Cyber-Physical Systems (with only 34 results).

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To mitigate the stated problem, the main objective of this paper is to develop a visualization tool that allows users to investigate and explore all IOT-related issues based on authors and articles ranked by users. Thus the contributions of this paper are:

- We propose a novel approach of exploring and investigating trending terms, authors and their related posts in the IOT area;
- We develop the proposed approach through a visualization prototype, called *IoTViz*. The prototype contains multiple linked visualizations and supports a range of interactive features, such as lensing and filtering, allowing users to quickly narrow down events of interest;
- We evaluate the usefulness and feasibility of *IoTViz* by conducting a user study.

The rest of the paper is organized as follows: We describe related work in the following section. Design considerations and design choices are introduced in Sect III. Then we introduce our *IoTViz* interface and its components in Sec.IV. We illustrate the use of *IoTViz* on social media data and present the results of our user study in Sect. V. Finally, we conclude the paper and discuss future work in Sect.VI .

II. Related Work

Yadav et al. [10] proposed a general trust evaluation method for handling trust on Twitter based on the implicit behavior of users. Their method includes five modules from collecting data, developing implicit trust metrics, verifying trust propagation properties, comparing trust based CF recommender system to evaluating the performance.

Clemons et al. [11] conducted a study of three successful online companies (i.e., 360buy, Taobao, and YiHaoDian) in China for understanding the role of reputation with regard to consumers' willingness to buy a product. Their results showed that vendor reputation is the most influential factor to gain trust from customers. However, this study is limited in China only, we argue that this factor may be influenced by Chinese culture.

Another approach to get reliable information is found on the study of Guy et al. [12] in which they focused on recommendation system. The system is proposed based on the comparison between recommendations. Two metrics are used including "familiarity" - that is the direct relationship between a user and his friends, and "similarity" - that is the overlapping activity between a user and a unknown person. Their study results showed that familiarity plays a critical factor of influencing.

Taking from visualization perspective, Viégas and Donath [13] proposed two visualization applications (i.e, Social Network Fragments, PostHistory) for representing the frequency of network connections over time. Trust can be built based on the strength (or frequency) of the connection. Using graph nodes and links, O'Donovan et al. [14] visualized personalized and feature-based trust based on negative feedback comments extracted from eBay. The trust value and trust strength is calculated according to the number of transactions between two users.

Sherchan et al. [15] conducted a survey of Trust on social network in terms of definition and measurements of trust. Different facets of trust are identified including calculative, relational, emotional, cognitive, institutional/system, and dispositional. The authors also studied some properties of trust.

There are still more similar studies in the literature, however they are mostly focused on a single perspective social media communication without considering the context of IOT. *IoTViz* approach is different from those studies.

III. Design considerations and Design Choices

A. Design considerations

There are many techniques to visualize relationships of topics in social media [16]–[18]. Adjacency matrix [19], force-directed layout [20], circular layout [21], and arc diagrams [22] are prominent examples that have applications in social network, text analysis, among other domains. Figure 1 show examples of three different layouts for the same data: Wikinews articles spanning 10 years from 2005 to 2015. For this figure, named entities are extracted from the news articles.

In Figure 1(a), 100 terms in each category are separated into four tag clouds (one for each category). The arcs link the terms that are mentioned together in the same news. The limitation of using arc diagrams for each tag cloud is that it does not show the relationships of the terms across different categories. The circular layout in Figure 1(b) addresses this limitation by positioning all one hundred term on a circle, where "cross-talk" between categories is depicted using black arcs; mousing-over a term reveals its relationships. Although the circular layout is a useful way to highlight cross-talk between different categories, it causes the visualization to become cluttered when the relationships are dense. This problem can be ameliorated by using brushing and linking, or by filtering to include only strong relationships. The visual clutter also prevents us from visually detecting less obvious clusters. Figure 1(c) shows a force-directed layout which enables us to detect groups of terms that usually "hang-out" together. Clusters are revealed more clearly in this layout.

The above network visualization layouts do not include temporal information, a critical component in many rapidly change domains such as IoTs. To add the time element to these layouts, researchers have used the third dimension [23] or presented multiple snapshots for each time point [24]. The first approach requires user interactions, such as rotating, filtering, and zooming, to get to the point of interest, while the second approach requires more mental efforts, such as memorizing and visual mapping, in order to link multiple snapshots for comparisons.

Below we introduce a new approach to effectively integrate the time element into network visualization, aiming to allow users to quickly identify temporal communities of different categorical entities and to provide an overview of network dynamics over a given period of time.

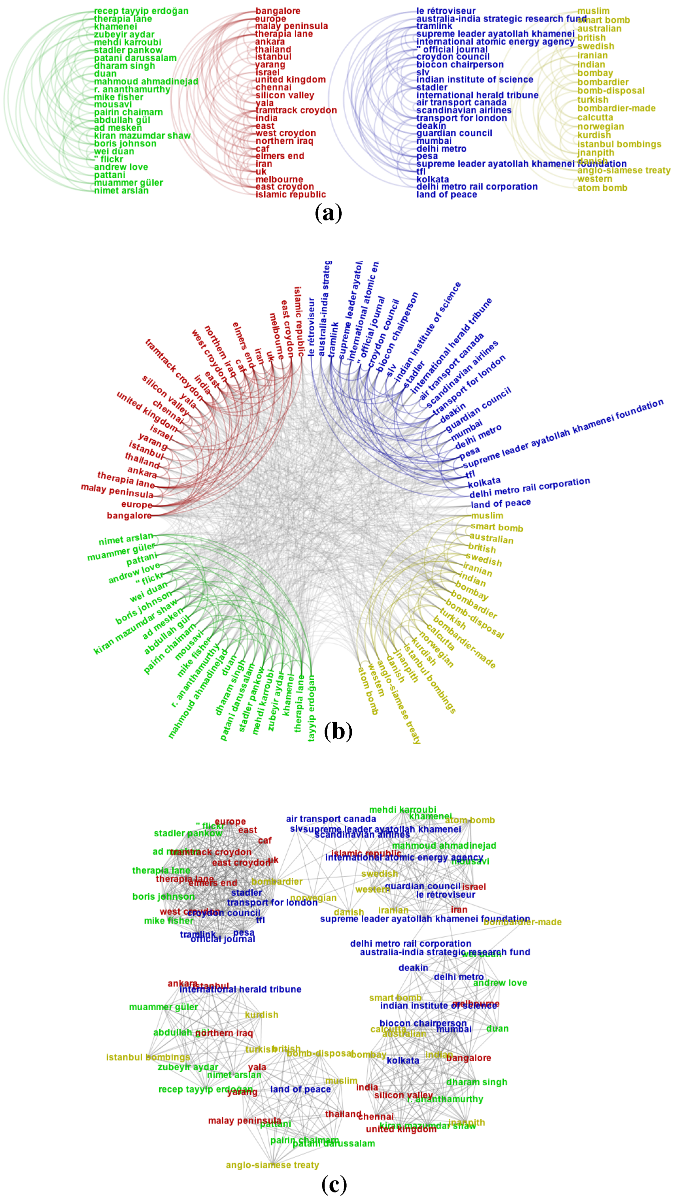

Fig. 1. Visualizing Wikinews articles containing the word "bomb." One hundred popular terms (25 terms in each category) are color-coded by category: green for person, red for location, blue for organization, yellow for miscellaneous category. Each of the three panels shows a different visual representation of the same data: (a) arc diagrams; (b) circular layout; and (c) force-directed layout.

B. Design goals

Data extracted from social media is multidimentional in its nature: author, timestamp, content of the post, comments, and ratings. Visualizing correlations of these dimension is challenging due to data size, complex relationship (many to many), and dynamic nature of the data. For the given a set of dimensions and their dynamic relationships over time, the following design criteria are desirable and widely adopted timeline visualizations:

G1. Display the evolution of entities as they change over time [18], [25]–[27].

G2. Pull related entities close to each other [18], [28], [29]. Links are used to explicitly present the relationships [16].

G3. Reduce edge crossings that lead visual clutter [28], [29].

C. Design choices

To satisfy the design criteria introduced in Section III-B, we choose the following visual designs:

D1. Time axis is aligned horizontally from left to right. This design is widely used when visualizing time series data [30], [31] to highlight the evolution of entities. This meets the design goal **G1**.

D2. Each dimension in *IoTViz* occupies a separated vertical spacing. We adopted this design from Parallel Coordinates [32]. The force-directed layout is applied on each dimension to bring entities to their associated timestamp and to avoid overlapping (which meets the design rationale **G2**).

D3. We use polylines to connect related entities. We use edge bundling [33], [34] to provide smooth curves that are easy to follow with the eyes [35]. Additionally, by bringing connected entities together using force-directed layout, we reduce crossing between consecutive dimensions (which meets the design rationale **G3**).

Overall, we regard *TimeArcs* as a hybrid visualization which contains multiple force-directed layout to organize entities in each dimension. Edge bundling [36] is used to aesthetically connect related entities across dimensions in a Parallel Coordinates metaphor [37].

IV. THE *IoTViz* ARCHITECTURE

A. The IoTViz approach

IoTViz[1] is developed using JavaScript in accordance with the D3.js library [38]. *IoTViz* provide an intuitive visual interface that summarize trending topics in IoT domain along with their corresponding ranked authors, posts, and reviews related to a set of similar keywords {*internet of things, internet 0f things, iot, i0t, cyber physical systems* }. It is noted that in our predefined keywords, the letter 'O' and the digit '0' are both included due to our experienced search, people tend to use these symbols interchangeably. The tool enables users to investigate and explore the IOT - cyber physical systems related issues over a period of time such as 1) the emerging topics [13], [31], 2) the most influential authors or commenter [12], [31] , and 3) the most reliable posts/comments [15] and their correlations [14]. To meet this end, this paper proposes several interactive features that are implemented in *IoTViz*:

- **Overview Display (F1)**. Display overview of terms, authors, posts and comments' distribution.
- **Details-On-Demand (F2)**. Present details on demand, including author's ranking, posts and comments information.
- **Relationship on views (F3)**. Show the relationship among trending terms, authors, posts and comments.
- **Filter (F4)**. Search and filter out desired information

[1] App demo link of *IoTViz*, visit https://goo.gl/NVBQc3

– **Anomaly Detection (F5)**. Detect anomalies of events from visualization.

Figure 2 shows a schematic overview of *IoTViz*.

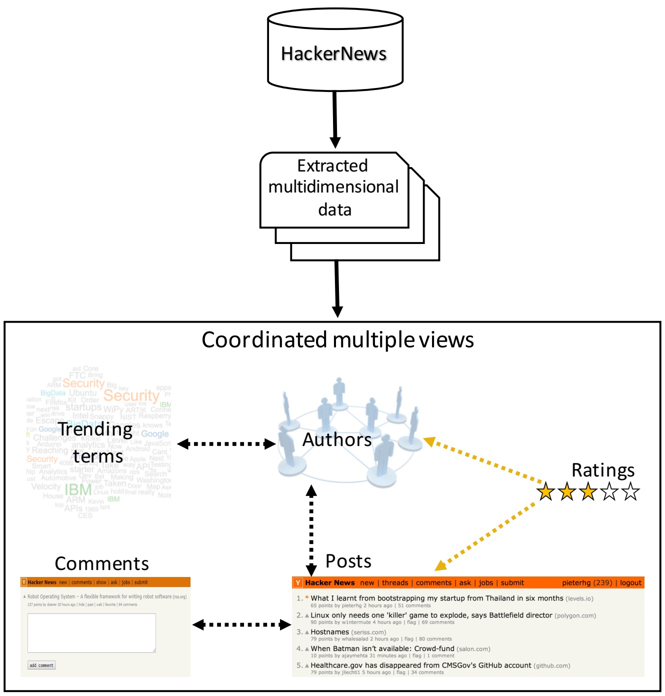

Fig. 2. The *IoTViz* architecture

B. Data collection and pre-processing

The dataset for this study was retrieved from Hacker News [39], a social news website developed by Paul Graham, based on some filtering keywords such as "internet of things", "internet 0f things", "iot", "i0t", "cyber physical systems". The purpose of these keywords is to extract information related to IOT and cyber physical systems. The dataset contains approximately 4000 posts. Each post has 18 attributes including: *by, commentLevel, date, dead, deleted, descendants, id, parent, postCount, ranking, score, text, time, timestamp, title, type, url, and year*. The retrieved data is cleaned, extracted topics and frequencies, and then fed into *IoTViz* as depicted in Figure 2. We decided up with this source due to the following main factors: first, it contains adequate amount of information regarding IoT issues. Second, it has a mechanism for generating trust for voting a post, as well as comments. Trusted metric for each user (author) can be inferred by averaging the ratings of his/her posts.

C. The IoTViz visualization components

IoTViz consists of four main components as depicted in Fig. 3 where 1) Box A contains the *trending terms* over time distributed yearly, 2) Box B presents a collection of authors distributed by month, 3) Box C includes posts spreading by month and ranked by their points, and 4) Box D shows the comments that contain our pre-defined keywords.

The trending terms component (Box A): This component extracts the most popular keywords that are mentioned in the *HackerNews* posts. The top 10 keywords are color-coded while others are gray. This allows users to quickly focus on important topics. These trending keywords are grouped quarterly and fit into the overall frequency stream using the Word Cloud algorithm [40], summarization technique allowing readers to get a glimpse of the emerging topics in the internet of things at a glance (the visualization feature **F1**). The arrangement of terms over time reinforce the frequency stream graph which allows to commute global trends. Instead of shuffling orientations as in the original Word Cloud algorithm [41], terms are arrange horizontally to increase the readability. Fig. 4 shows the enlarged version of (Box A) in three consecutive years.

The author scatter plot (Box B): This view allows users to investigate and evaluate the credibility of a given author. Basically, each post is evaluated by a point given by other users. The author's score is calculated by taking the average of all author's points on his posts. The vertical axis represents authors' score using log scale (the visualization feature **F5**) due to the skewness of data. The horizontal axis shows the distribution of author's posts that are most frequent of a given month. Each author is represented by a small circle, the size of circles indicate the number of posts that authors had made.

The posts component (Box C): We also represent each post by a black circle. Each post is distributed horizontally by month and vertically by its voting points. Size of each circle shows the number of comments contained filtering keywords for its post.

The comments component (Box D): It can be seen that the number of comments is relatively low compared to the number of posts because they are extracted by the contained *keywords*. One comment may be positioned in a post that is not related to IOT - Cyber Physical System issues. The representation of comments and their distribution are similar to that of posts.

D. User interactions

The *IoTViz* supports four types of interactions on components as follows:

Mouse over:

a) Box A. When users mouse over a trending term, a tooltip will be popped up to show the connection between the given term with its corresponding authors, posts along with related comments (as depicted in Fig. 5).

b) Box B: When user mouses over an author (Fig. 6), *IoTViz* shows author's details (i.e., username, number of posts, average score) (the visualization feature **F2**), author's posts, related comments along with his contribution to trending terms. This information is highlighted and connected by a line (the visualization feature **F3**)

b) Box C: Information (Fig. 7) shown in this component when a user mouses over a post includes post's detail such as post type (story or comment), title, date posted, number of comments, and URL to the original post (if applicable). Other relations the visualization feature **F3**) are also revealed such

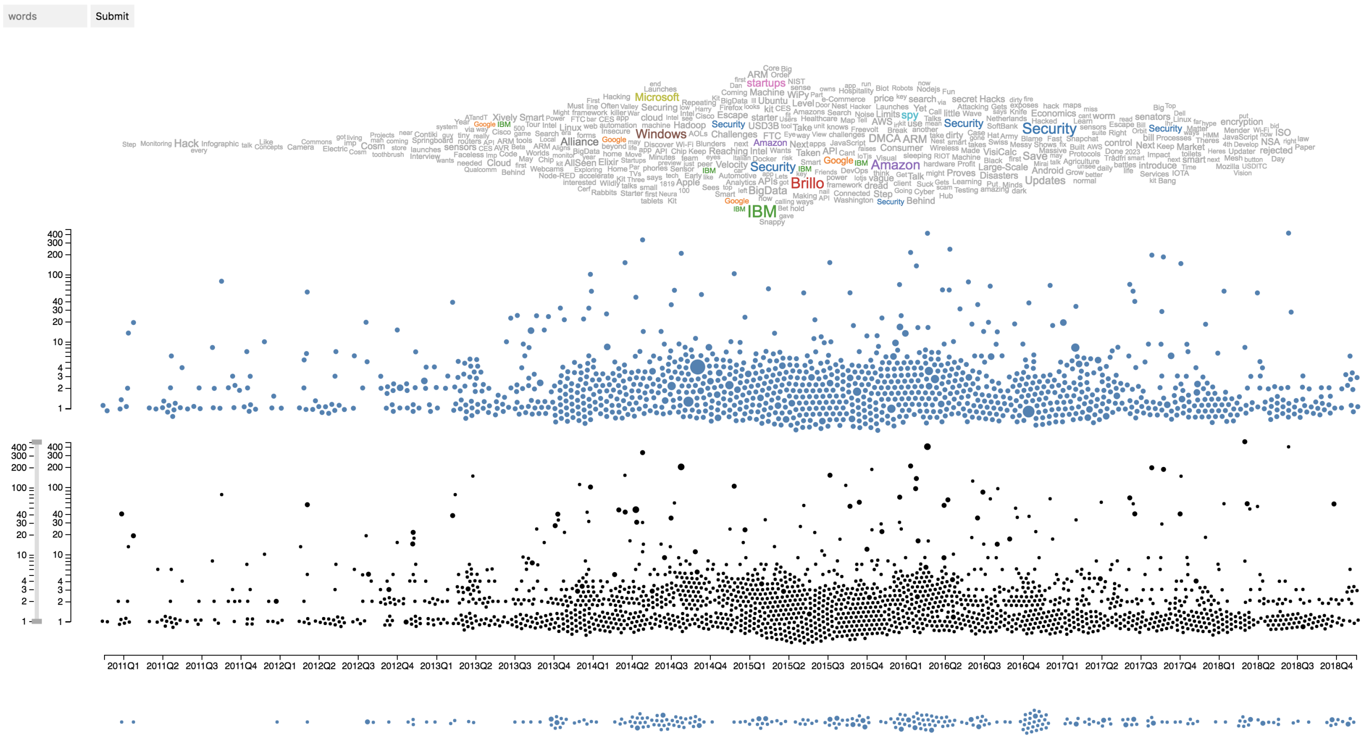

Fig. 3. Visual interface of *IoTViz*: A) Trending topics, B) Authors' distribution by time (x axis) and average rating (y axis), C) User posts, and D) User comments.

Fig. 4. Emerging topics in IoTs in 2014, 2015, and 2016.

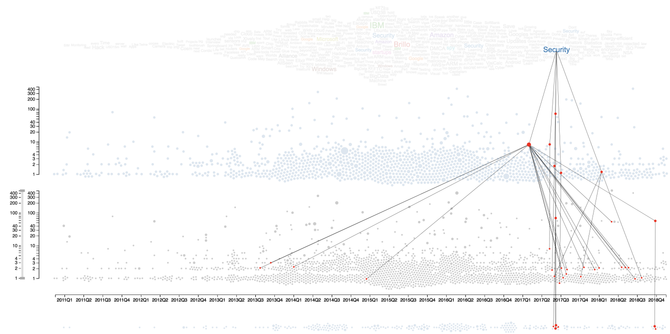

Fig. 5. Mouse over a trending terms highlights its relations with authors, posts and comments

as related comments, the author of current post and trending terms contributed by this author.

b) Box D: Details (Fig. 8) of the moused over comment include comment's author, posted date, number of sub-comment and the content of comment. The *IoTViz* also shows the relations of current comment with posts (if any), author of the post, and author's related trending terms.

Mouse click: This interaction is supported to help users look into detail of a given term, author, post or comment without loosing the schema when the mouse is moving.

Search box: To narrow down the results shown on the overview, or to explore contents of interest, *IoTViz* provides a search box (the visualization feature **F4**), on the top left of the screen, that allows user to input desired information. The four components update the results according to the search word interactively as shown in Fig. 9.

Filtering on axis: Users are also able to filtered posts based on their voting points by sliding the range buttons on the vertical axis.

V. Results

To evaluate the usefulness and effectiveness of the *IoTViz*, we conducted a use case with three volunteer users who have experience on utilizing social media as a means to update information. The purpose of this study is to gather users' feedback which can be used as an indicator to improve *IoTViz*. Each user study is carried out in approximately 15 minutes. An

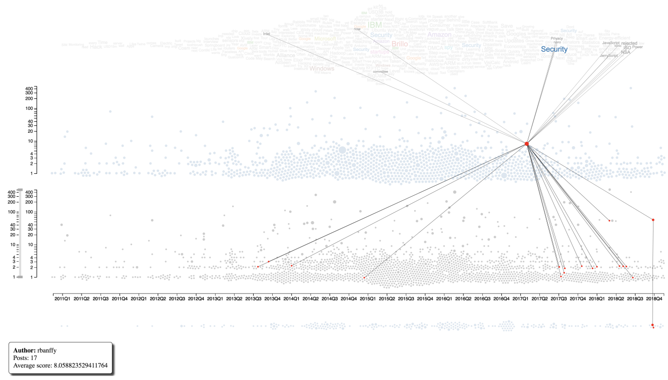

Fig. 6. Mouse over an author shows author's details, posts, related comments and trending terms.

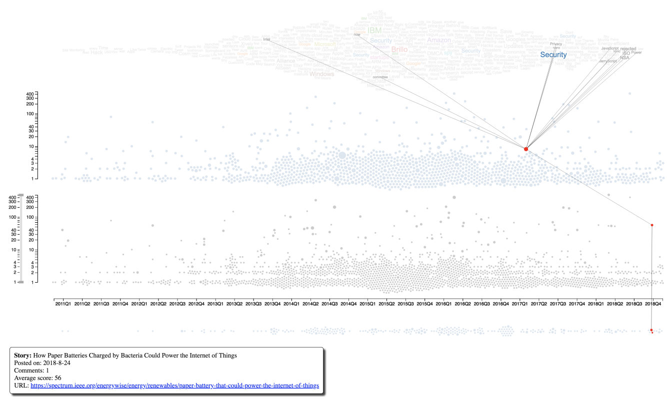

Fig. 7. Mouse over a post shows post's details, author, related comments and trending terms.

introduction about the purpose of *IoTViz*, the source of data, the structure of the visualization representation is presented to individual before moving on to the actual experiment. After playing with the application, users are asked by a set of proposed questions to measure the level of understanding on the tool.

The questions are as follows:

- (R1) Who are the authors that get the most credibility? Which posts are most reliable?
- (R2) Which features, score or the number of posts, do you consider as trust?
- (R3) What are the most interesting patterns observed from *IoTViz*?

Findings:

For the first question (R1), users are able to find the most influential authors or posts based on the relative position to the horizontal base line. However, users are prone to get the wrong answer for a few first times due to the unfamiliarity with the visual tool.

For the reliable information (R2), users tend to put more trust on high scored posts and average score of a given author. Most of them are not interested in an author who owns a huge number of posts but gains relatively low scores, especially all

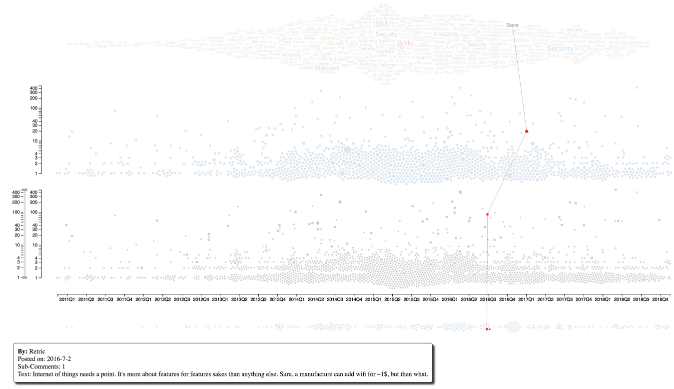

Fig. 8. Mouse over a comments shows details of comments, relation to post (if any), author of the post and trending terms.

of the posts have no comment as depicted in Fig. 10.

For question (R3), users pay more attention to the authors/posts that may not have the highest score but lots of comments compared to ones which have higher score but no comments.

When looking at the trending terms component, users recognized that *Security* is the most catchy word that spans over a long period of time, especially a boom throughout the year of 2015. One interesting finding for this term is that in spite of its popularity, its reliability may vary due to contributed posts as shown in Fig. 10.

One issue of the *IoTViz* is that the short distance between the authors' component and posts' component may lead to mislook between the lower points of the former and the upper points of the latter. This issue will be fixed after the experiment.

VI. Conclusion and Future work

In this paper, we present a novel approach that unites coordinated multiple views to highlight various attributes of the *HackerNews*. We introduce an interactive data analytic prototype to help viewers to summarize the emerging IoT topics along with the user opinions and ratings on those topics. *IoTViz* supports of a range of interactive features, such as linking and filtering, allowing users to quickly narrow down events of interest. We demonstrate the usefulness of our tool through different use cases. An important aspects of the paper is the human-centric IoT. The paper aims to address the tool gap in human interacting with the system, a well known gap and a known research challenge.

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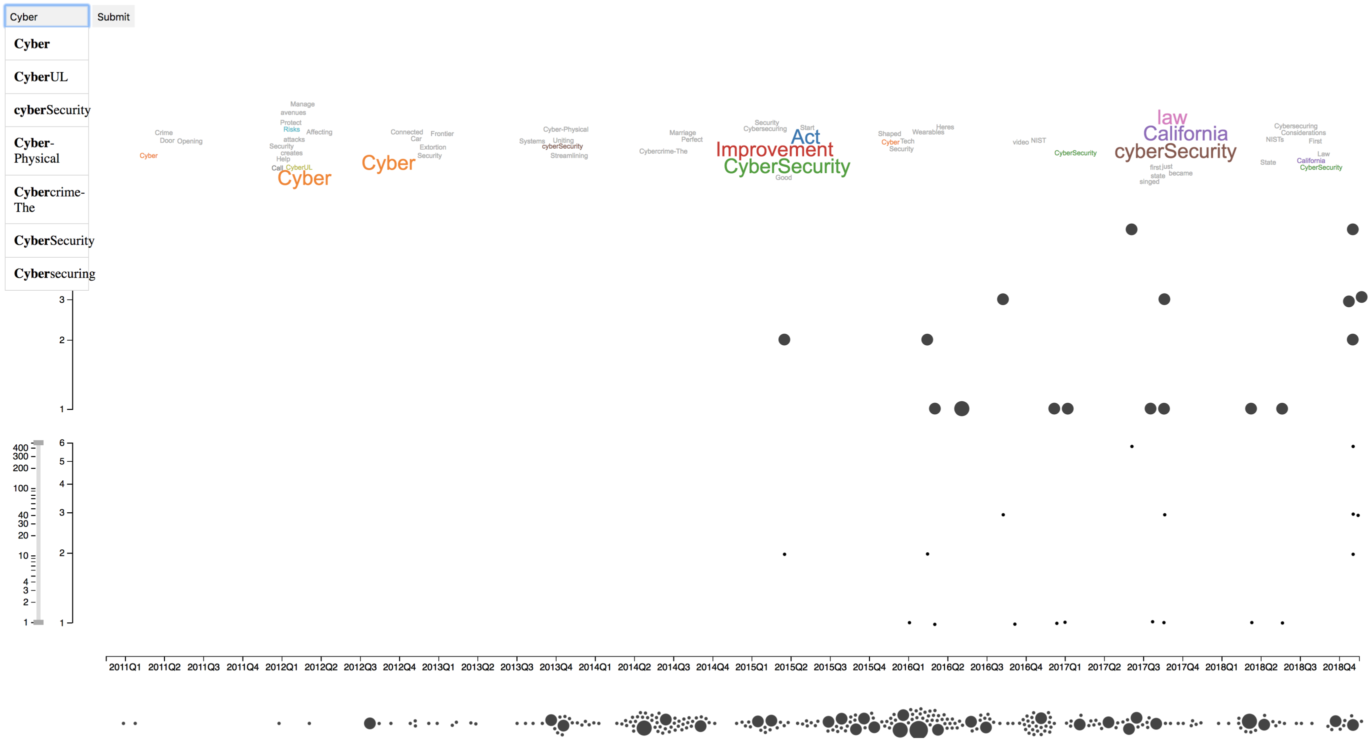

Fig. 9. Search box integrated with "autocomplete widgets" provides suggestions while typing.

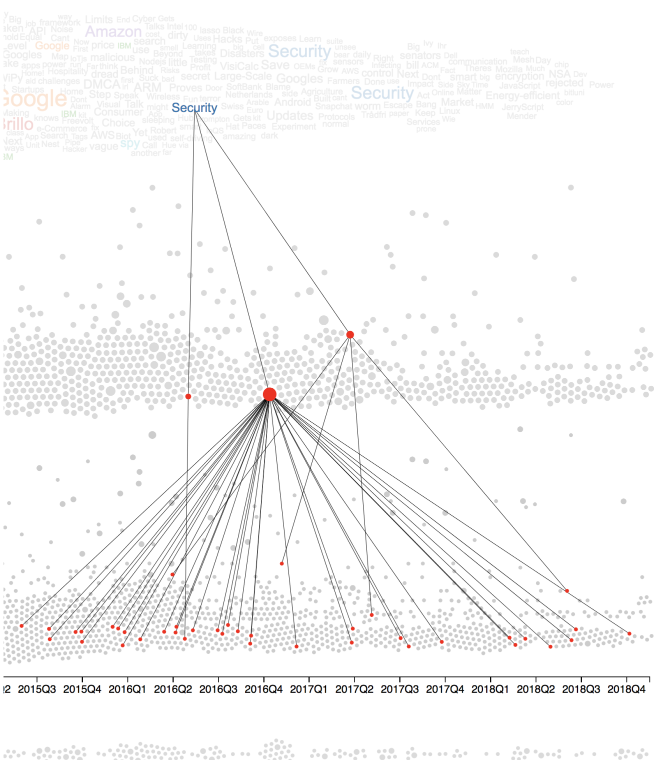

Fig. 10. An author with lots of posts but low score. Security gains popularity but low credibility.

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