

TrackMeNot-so-good-after-all

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Abstract. TrackMeNot is a Firefox plugin with laudable intentions - protecting your privacy. By issuing a customizable stream of random search queries on its users' behalf, TrackMeNot surmises that enough "search noise" will prevent its users' true query profiles from being discerned. However, we find that clustering queries by semantic relatedness allows us to disentangle a nontrivial subset of true user queries from TrackMeNot issued noise.

1 Background

The decreasing cost of persistent media for storage, coupled with the steady rise in E-commerce, social networking, and various other online services, has led to a dramatic increase in the volume of readily available, personally identifiable information. One often overlooked source of such information is the logging of user queries by search engines.

There have been several high-profile examples of search query data being used in inappropriate ways, most notably an incident involving AOL in 2006 [4]. The company disclosed a data set comprised of information from 658,000 subscribers' search histories; it was released as a flat file into the public domain. Upon admitting their error, they removed the link, but the data was already mirrored elsewhere. This incident highlights just how personally revealing search engine queries can be, as at least one user was identified using only the content of her searches [1].

The average Internet user may browse under the false impression that deleting cookies or diverting traffic through a proxy will protect their anonymity on the web. Neither of these measures provide complete protection. If a user wishes to utilize certain services such as Google Mail, they must log in to their personal profile. Once logged in, their queries are then tied to their account.

TrackMeNot is a Firefox plugin that aims to protect the privacy of its users by issuing random queries on their behalf. These random queries are pulled from a variety of sources, with the intuition that providing enough "noise" around a user's true search patterns will make it impossible to disentangle the queries made by TrackMeNot from those actually made by human searchers.

2 TrackMeNot details

TrackMeNot operates completely on the client side as a Firefox plugin. Upon start-up, an initial *seed list* is popu-

lated from RSS feeds and known public "popular search" lists. During execution, queries are selected from this list and issued to designated search engines on the user's behalf.

The user is offered many parameters, which can be tuned to customize TrackMeNot behavior. For instance, the user can select which, if any, popular search engines he wishes TrackMeNot to query on his behalf. If the user only performs searches at <http://www.Google.com>, he can specify that TrackMeNot query only that site as well. The user can also specify the frequency of TrackMeNot queries (the default average query rate is 10 queries per hour), as well as whether or not to enable *query bursts*. Query bursts are triggered by actual user queries; when TrackMeNot detects a genuine query, it responds by issuing a batch of simulated searches. In a subset of query bursts, a longer query is selected and permuted to form a set of potentially similar searches.

The basis of the TrackMeNot model is its *dynamic query list*. Starting from the initial seed list, queries are randomly marked for replacement over time. When a marked query is sent by TrackMeNot as a search engine request, the HTTP responses are parsed to identify any suitable "query-like" terms for replacement. If an acceptable term is found, it is then substituted into the dynamic list in exchange for the marked query. In this way, the list of searches will evolve over time.

TrackMeNot also attempts to simulate user browsing patterns with "selective click-through"; upon issuing a random query, it will parse the results page, using regular expression matching to identify and remove revenue generating ads. It then selects one or more of the remaining links on the page and simulates a user click.

Although TrackMeNot simulates temporal search patterns with techniques like query bursts and selective click-through, it may not simulate contextual search patterns - sequential TrackMeNot queries are most likely semantically unrelated. Individual queries are selected at ran-

dom from a 100-200 term dynamic query list. So while it is likely that the dynamic query list contains related searches, as long as searches are selected individually at random, there is no guarantee that related terms will be issued in temporal proximity. This is the aspect of the TrackMeNot design we wish to exploit.

3 Design overview

Our overall design can be logically divided into three parts. The first part deals with logging all user Google Search queries as well as those fired from TrackMeNot. The second part comprises the computation of a similarity matrix on this set of queries using a suitable semantic distance measure. The last part consists of clustering this data using a suitable technique to get a visual representation of the data from which conclusions can be deduced.

4 Data Gathering

To gather the data we ran TrackMeNot with the default behaviors of 10 queries per hour with burst queries enabled; we also enabled the logging feature and disabled the other search engines, focusing on Google only. Moreover, we disabled the instant search feature as it produces incomplete queries. However, this does not give Google a chance to distinguish TrackMeNot queries as they appear as inserted by the keyboard. On the Google side, we made a new Google account, **cse509tmn**, and enabled the web history for verification.

To collect and label queries, we implemented a proxy server to log all HTTP requests made by the browser. By collating the proxy log with the TrackMeNot log, we were able to differentiate between the user queries and those generated by TrackMeNot.

The plugin was running for at least 3 days on three machines with three different users. Data was compiled over different periods for each user.

5 Semantic Distance Measure

The basic idea here was to find how *similar* each search query was to every other query, making no distinction based on its origin (user or TrackMeNot). To do this, we needed a *semantic* distance measure. We did not implement our own measure, but instead explored the available choices from other research groups. After examining the feasibility of using different available measures, we settled on two of them. One of them is DISCO¹, which is a Java package, and the other is Google Normalized Distance. For details, see sections 5.1 and 5.2 respectively. In

each of these cases, we disabled the auto-complete feature of Google so that our search queries were always the exact phrases that the user or TrackMeNot requested from the Google Search Engine and never prefixes of the actual queries.

5.1 DISCO

The DISCO (extracting DIStributionally related words using CO-occurrences) API allows to compute the semantic similarity between any two words by looking up those words in a pre-defined repository. For our analysis, we downloaded the Wikipedia repository available on the DISCO website to compute the distances. By looking up this local repository, the DISCO API returns a value between 0 and 1 for any pair of words that it looks up in the repository, such that the higher the value returned, the more similar the words are. In this sense, the API works like a similarity measure. We were however faced with one issue: Google search queries are typically phrases, and not single words. To overcome this, given two queries $Q1$ and $Q2$, we compared each word in $Q1$ with every word in $Q2$ and in each case chose the highest returned value. We aggregated this score over all words in $Q1$ and normalized the addition by dividing the aggregate score by the number of words in $Q1$.

5.2 Google Normalized Distance

Google Normalized Distance (GND) is a measure of semantic similarity based on statistics. GND utilizes an extremely large vocabulary set. The similarity can be calculated according to the following equation:

$$GND(Q1, Q2) = \frac{Max(\log f(Q1), \log f(Q2)) - \log f(Q1, Q2)}{\log N - Min(\log f(Q1), \log f(Q2))} \quad (1)$$

where $f(Q)$ is the number of results found by Google for query Q , and $f(Q1, Q2)$ denotes the number of results found by Google for the combined query of $Q1$ and $Q2$. The more often two queries appear together, the smaller the distance between them. GND is not an accurate function to measure the distance[2]. Moreover, GND is not a metric nor does it satisfy the triangle inequality, and $GND(x, y)$ is not larger than 0 for every $x \neq y$.

6 Disentangling user queries

Once we create a matrix of semantic similarities, we are tasked with deciding which queries were actually made by the user. We first perform cluster analysis to identify groups of related queries. We then use the size and distribution of the cluster assignments to classify a set of user queries.

¹ http://www.linguatools.de/disco/disco_en.html

6.1 Clustering

For clustering we use the Partitioning Around Medoids algorithm (PAM). It is conceptually similar to the well known k -means algorithm; however, rather than minimize squared Euclidean distances, it aims to minimize dissimilarity [3].

An ideal assignment of n objects into clusters would be an assignment that minimizes cluster widths while maximizing cluster separations. In other words, each element i belonging to a cluster A should be closely related to the other members of cluster A . At the same time, each element i in cluster A should be unrelated to the members of all other clusters C such that $C \neq A$; individual clusters should be well separated from other clusters.

Formally, for an element i in a cluster A , let $a(i)$ denote the average dissimilarity between i and all elements $j \in A$ where $j \neq i$. Let $d(i, C)$ denote the average similarity between an element i and all elements in a cluster C to which i does not belong: $C \neq A$. If we let $b(i)$ be the minimum $d(i, C)$ such that $C \neq A$, then

$$s(i) = \frac{b(i) - a(i)}{\max(a(i), b(i))}$$

is a good indicator to the quality of element i 's cluster assignment. If $s(i)$ is close to one, then i is well assigned. If $s(i)$ is close to negative one, then i is poorly assigned. $s(i)$ is known as the Silhouette width. Choosing the number of clusters, k , that maximizes the average Silhouette width is the heuristic used to determine the cluster assignments [3].

For our implementation of the PAM algorithm, we use the cluster package from the R statistical programming language[5].

6.2 Classification

Our classification strategy is a simple one. It is not our goal to show that every user query can be discerned from those queries issued by TrackMeNot. What we want to show is that some nonempty subset of user queries can be identified as "real" with high probability. For this task, we simply choose the single largest cluster (or set of clusters in the case of a tie), and label all constituent members as user-generated queries.

6.3 Validation

We have compiled and performed testing on four data sets, containing both user and TrackMeNot generated searches. The data sets are summarized in the following table.

Data Set	# Queries	Similarity Measure
test.m	79	Disco BNC
bill.m	131	Disco Wikipedia
rami.m	305	Disco Wikipedia
nikhil.m	600	Disco Wikipedia

As you can see, our data sets, intentionally, vary greatly in size (number of queries). This allows us to test the effectiveness of our classification strategy in both small and large window sizes. Data in the larger sets span multiple sessions over multiple days. The `test.m` and `bill.m` data sets are taken from a user's search engine use over a single day.

To validate our classifier, we first compute a similarity matrix using the Disco Wikipedia distance measure. From this matrix, we performed clustering using PAM, as described in Section 6.1. Our classifier then identified the largest cluster or set of clusters, assigning the label 'U' to these queries. We finally compare the assigned label against the real value to calculate the precision and recall over our validation data set.

7 Results

Our results are very promising. We are able to successfully identify a subset of the user generated queries with a high precision for small window sizes. It is important to note that we make no attempt to classify all user queries. Thus, our recall is very low, even for small window sizes.

Data Set	Precision	Recall
test.m	1.0	0.147
bill.m	1.0	0.25
rami.m	0.867	0.188
nikhil.m	0.125	0.067

In addition to classification, our tool outputs what we term a cluster map. It is a way of organizing and visualizing the similarity matrix by cluster assignment. Clusters are organized by size, starting with the largest at the top left corner, to the smallest in the bottom right corner. Any position, (i, j) , represents the similarity between query i and query j . The darker the map is at that index, the farther apart the two queries are. Additionally, the true class label is displayed along the diagonal, replacing the trivial similarity of 0 between a query, i , and itself.

We also performed cluster analysis of the data using Google Normalized Distance as our measure of semantic similarity. The `rami.m` analysis is shown in Figure 5. We find that this measure is not appropriate for calculating similarity at the scale of entire queries. Like Disco, GND is capable of computing distances between keyword pairs only. When inputting entire queries, the similarity matrix is homogeneous; most queries are comparably close/far from most other queries, and no clusters are found.

8 Conclusions

For small windows, our classifier performs well. We achieve perfect precision in the `test.m` and `bill.m` data sets. But as our window size grows, we observe declining precision.

Intuitively this decline makes sense. TrackMeNot does seed its dynamic query list with multiple entries from an individual source, so we expect to find multiple groups of related searches within its query list at any given time. The reason our classifier performs well for small windows is that TrackMeNot chooses its queries at random. As the window size increases, so does the coverage of TrackMeNot's query list. We do not see poor performance for large windows as a cause for concern. Rather, it confirms the reasoning behind our strategy.

We also find that the Google Normalized Distance did not serve as a good distance measure when applied to full queries. If we instead used it per word in each query, and aggregated the distance for each word in each query like in DISCO, we could get a better measure.

9 Future work

As seen in our results, TrackMeNot does succeed in protecting the user's privacy over a long period of time by forming clusters even in the set of TrackMeNot queries. However, TrackMeNot does not protect against search engines tracking time of use. For example, as also shown in our results, if a clustering of Google Search queries is performed over smaller time-frames, it is effective in filtering the TrackMeNot queries from those of the user because in smaller time-frames, TrackMeNot queries do not form

big enough clusters. Hence, we feel that by incorporating more semantic relatedness in consecutive TrackMeNot queries, then even in smaller time-frames, the queries generated by TrackMeNot will form clusters that will make it difficult to filter them out using a clustering analysis such as ours.

Also, by operating as a Firefox plugin, TrackMeNot operates only when the user has Firefox running. This prevents TrackMeNot from firing off queries when the user is not actively browsing the Internet. We are convinced that if TrackMeNot can run as a standalone application running continuously in the background, this would not only provide the same semantic search noise as the current TrackMeNot implementation, but also serve to protect the temporal search habits of users.

References

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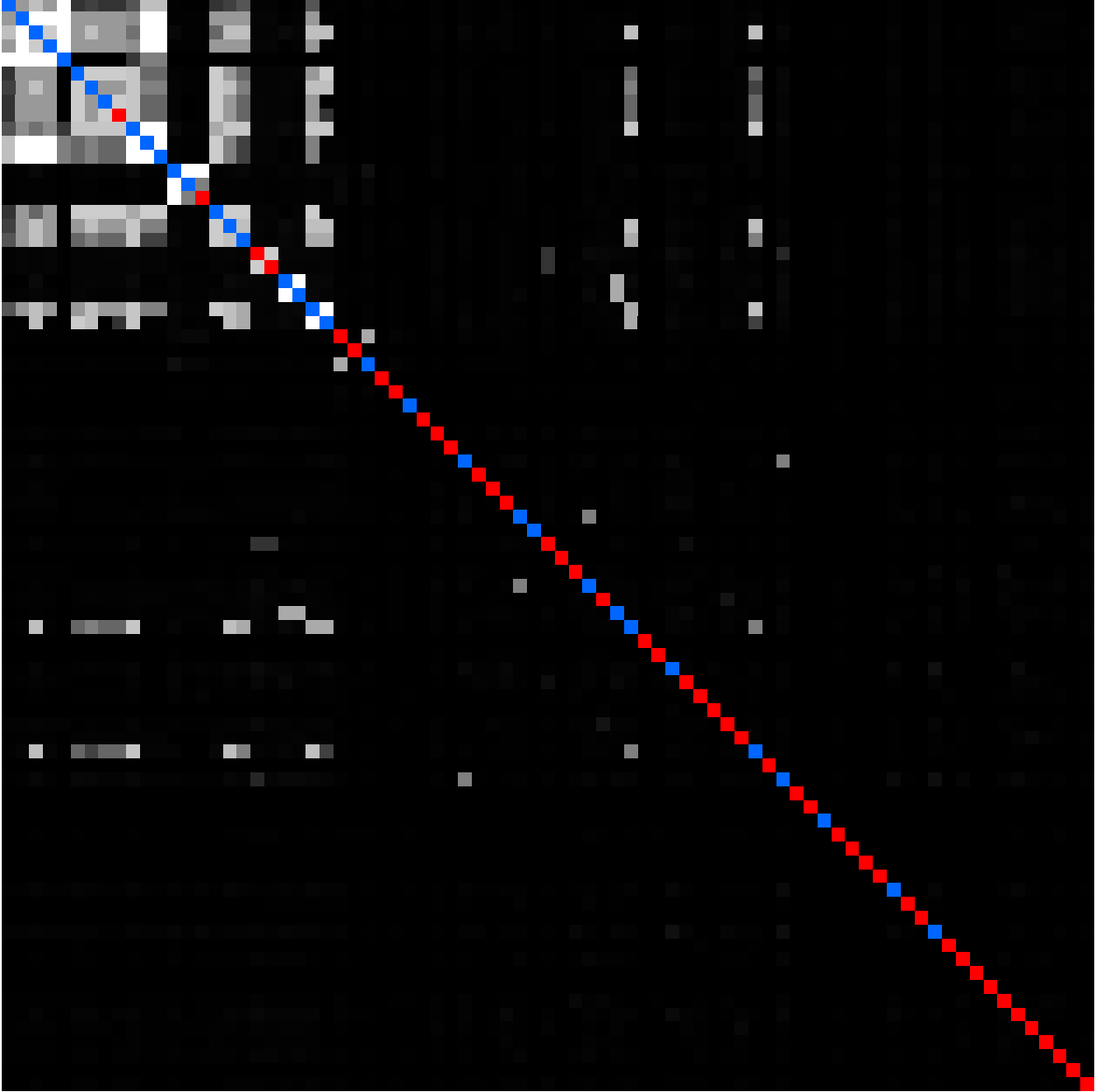


Fig. 1: A pictorial representation of the `test.m` clustering. Position (i, j) represents the similarity between query i and query j - the lighter the shade, the more similar the queries are. Each query's class is displayed along the diagonal. If (i, i) is red, then query i was generated by TrackMeNot. If (i, i) is blue, then the query is genuine. We see that many queries are semantically unrelated. The largest cluster, seen in the top left of the graph, has 5 user queries and 0 TrackMeNot queries.

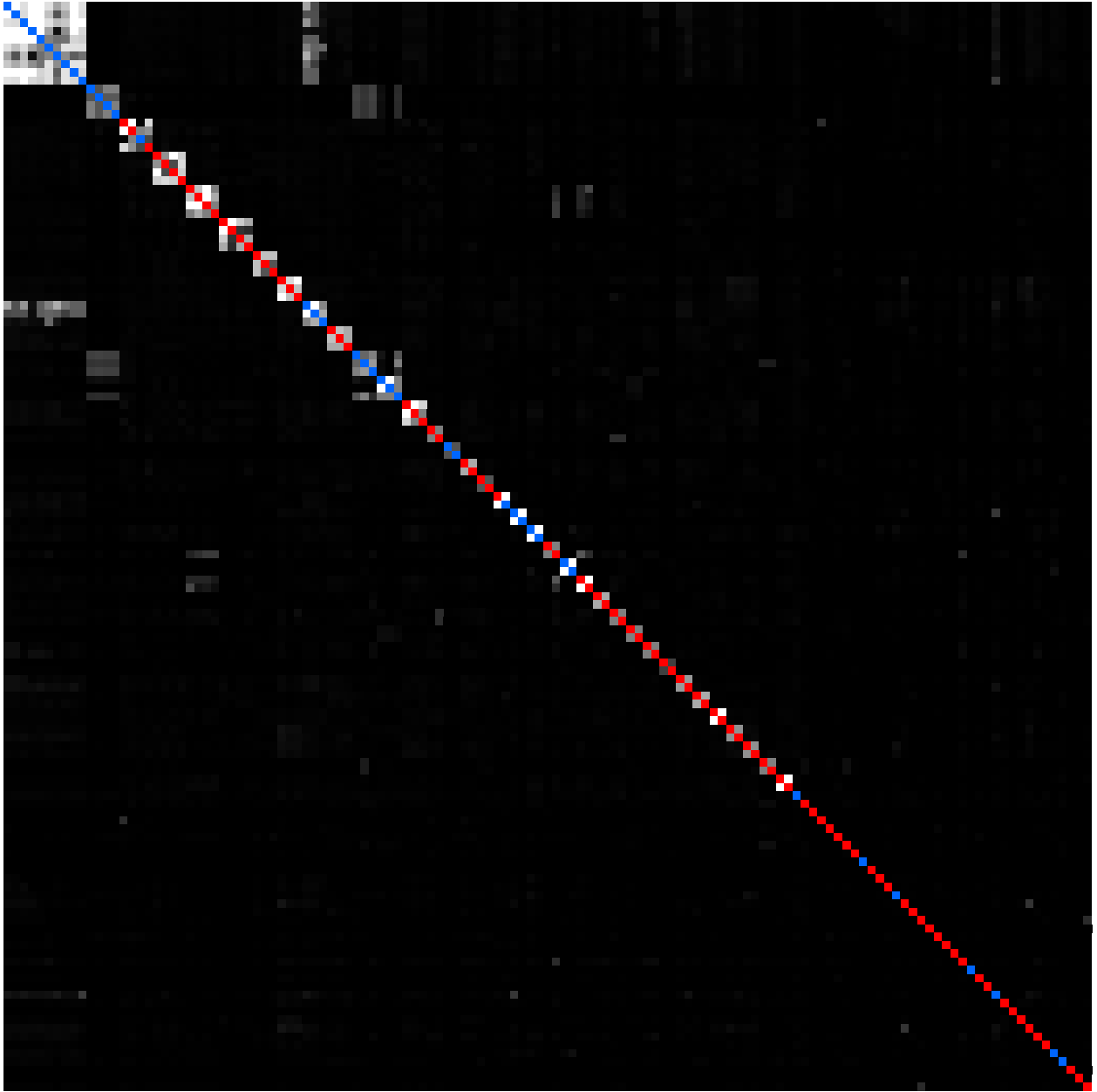


Fig. 2: A pictorial representation of the `bill.m` clustering. Position (i, j) represents the similarity between query i and query j - the lighter the shade, the more similar the queries are. Each query's class is displayed along the diagonal. If (i, i) is red, then query i was generated by TrackMeNot. If (i, i) is blue, then the query is genuine. We see that many queries are semantically unrelated. The largest cluster, seen in the top left of the graph, has 10 user queries and 0 TrackMeNot queries.

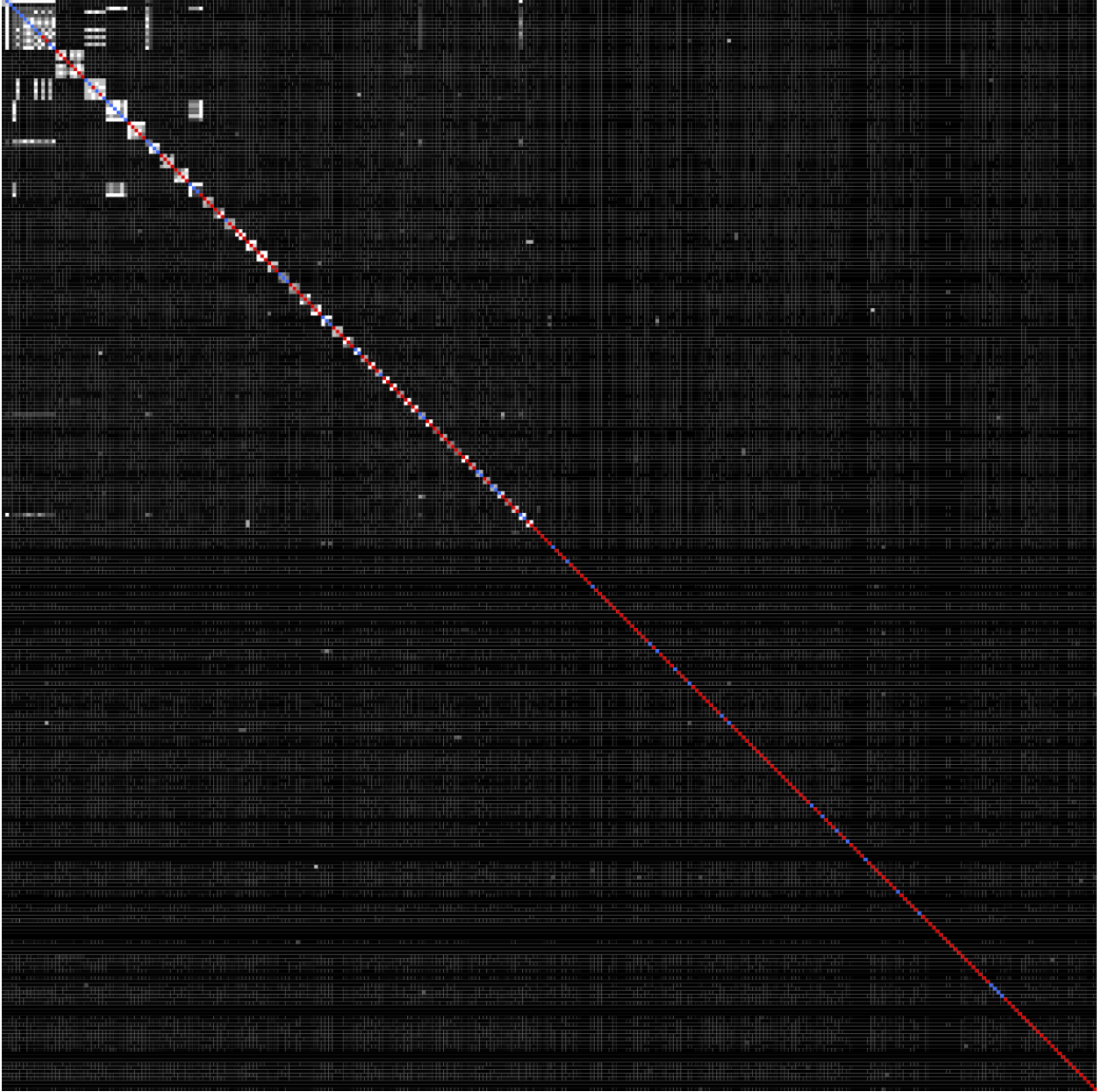


Fig. 3: A pictorial representation of the `rami.m` clustering. Position (i, j) represents the similarity between query i and query j - the lighter the shade, the more similar the queries are. Each query's class is displayed along the diagonal. If (i, i) is red, then query i was generated by TrackMeNot. If (i, i) is blue, then the query is genuine. We see that many queries are semantically unrelated. The largest cluster, seen in the top left of the graph, has 13 user queries and 2 TrackMeNot queries.

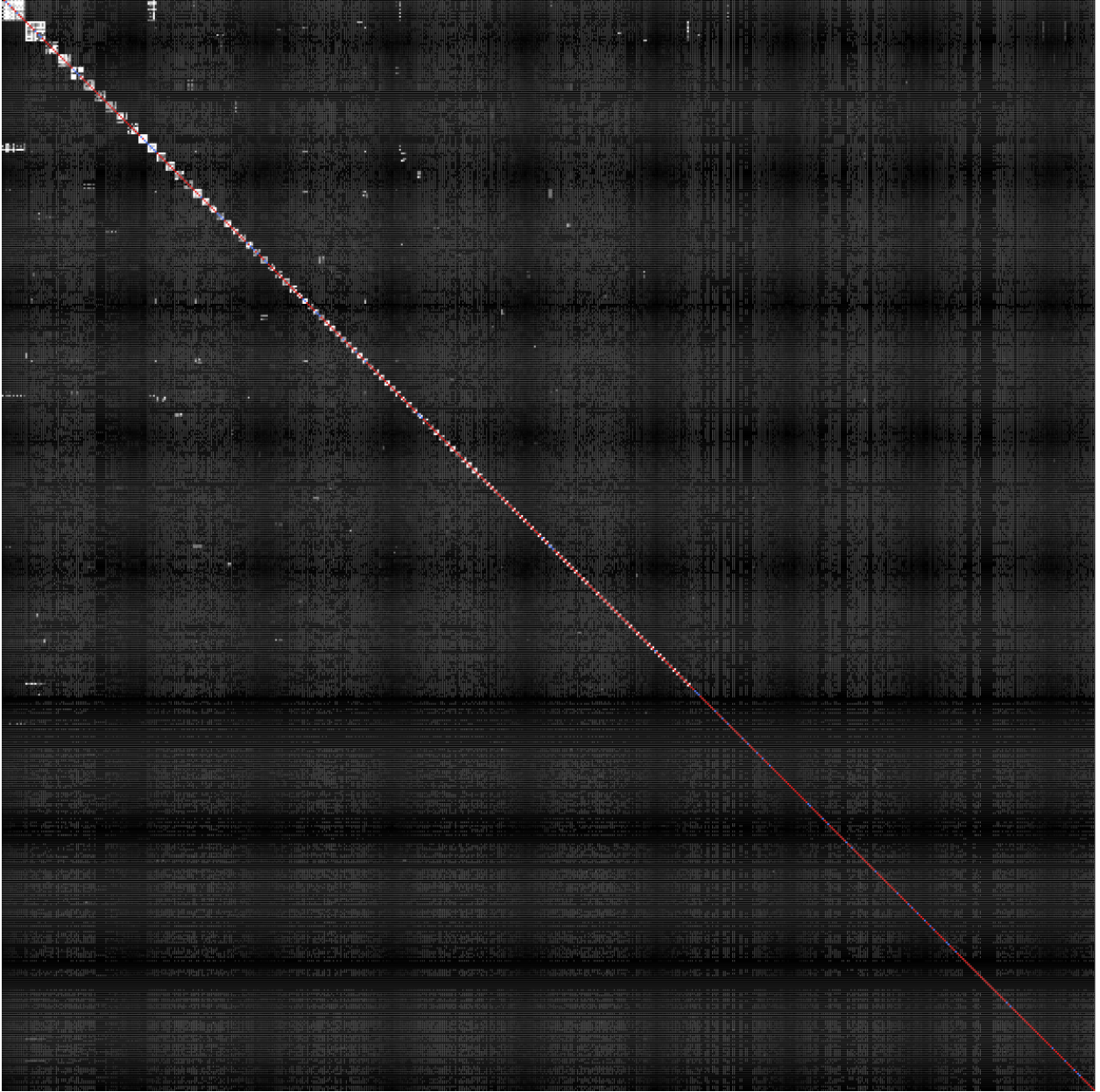


Fig. 4: A pictorial representation of the `nikhil.m` clustering. Position (i, j) represents the similarity between query i and query j - the lighter the shade, the more similar the queries are. Each query's class is displayed along the diagonal. If (i, i) is red, then query i was generated by TrackMeNot. If (i, i) is blue, then the query is genuine. We see that many queries are semantically unrelated. The largest cluster, seen in the top left of the graph, has 4 user queries and 9 TrackMeNot queries.



Fig. 5: A pictorial representation of the `rami.mat` clustering using GND. Position (i, j) represents the similarity between query i and query j - the lighter the shade, the more similar the queries are. Each query's class is displayed along the diagonal. If (i, i) is red, then query i was generated by TrackMeNot. If (i, i) is blue, then the query is genuine. We see that the similarity matrix itself is homogeneous; most queries are equally semantically unrelated. Only one cluster was found, spanning the entire data set. We conclude that GND is not an appropriate similarity measure when applied to entire query strings.