Data Mining Corporate Emails to Model Employee Behaviors and Analyze Organizational Structure

Abstract

Email correspondence has become the predominant method of communication for businesses. If not for the inherent privacy concerns, this electronically searchable data could be used to better understand how employees interact. For example, after the Enron dataset was made available, researchers were able to provide great insight into employee behaviors based on the available data despite the many challenges with that dataset. The work in this paper demonstrates the application of a suite of methods to an appropriately anonymized email dataset created from volunteers' email metadata. This new dataset, from an internal email server, is first used to validate machine learning and feature extraction algorithms and then to generate insight into the interactions within the center. Based solely on email data, a random forest modeled behavior patterns and accurately classified not only participants in the study but also other members of the center who were connected to participants through email. Furthermore, the data revealed relationships not present in the formal operating structure. The result is a much fuller understanding of the center's internal structure than can be found in the official organization chart.

1 Introduction

Talk about applications of determining work structure from email behavior?
Why problem is important/hard/unsolved

Organization charts do not always accurately reflect relationships within the workplace. This paper seeks to determine if true behaviors are instead exhibited in corporate email communication patterns. However, privacy concerns inhibit most research thrusts into email analysis. In the past, one of the only publicly available, real-world email corpuses available has been the Enron dataset. This dataset is over a decade old, has inconsistencies, and has already been extensively researched. This paper avoids these difficulties by using a new dataset generated from volunteers' present-day emails.

Email is a pervasive medium for communication in modern society - particularly in the workplace. In 2015, there were estimated over 2.6 billion email users, and it is projected that by the end of 2019, over one third of the global population will be using email. In fact, the average business email user sends or receives 112 emails per day. Corporate email alone accounts for 54.7% of worldwide email traffic [Radicati and Levenstein, 2015]. Retention of large email archives has become common practice with decreasing memory size and cost [Fisher *et al.*, 2006]. In that study, out of 600 employees at a high-tech company, the average employee had 28,660 emails stored in 133 folders which is a significant increase from 10 years earlier. This trove of interesting information can be leveraged to analyze the relationships between coworkers.

The following section summarizes related works in this area. Section 3 describes the process of data collection and some statistics of the dataset. The features extracted from the data are described in Section 4, and the methods investigated using these features are covered in Section 5. The results of the analysis are presented in Section 6. Section 7 concludes the paper and presents opportunities for future work.

2 Related Works

Email has been a common research topic over the past decade. This is in part because the Enron email dataset was released in 2004 [Klimt and Yang, 2004], allowing researchers access to a rich collection of real-world corporate emails. This dataset has been extensively researched on topics including spam classification [Martin *et al.*, 2005], [Bahgat *et al.*, 2016], [Shams and Mercer, 2013]; email categorization [He *et al.*, 2014], [Keila and

Skillicorn, 2005]; and recipient prediction [Sofershtein and Cohen, 2015], [Hu *et al.*, 2012]. However, there are known flaws and discrepancies with even the most recent versions of this dataset – ranging from misspelled email addresses [Nordb, 2014] to duplicate emails [Waterman and Bruening, 2014]. In one of the most popular forms of the dataset, [Shetty and Adibi, 2004a], the database includes 253,735 emails sent as "CC" and 253,713 emails sent as "BCC". Further inspection reveals that emails sent as one type or the other were almost always mistakenly recorded as both.

The existing literature on analyzing social email behavior is mainly divided into two categories: feature-based and social-based [Tang *et al.*, 2013]. Feature-based methods calculate statistics based only on email patterns while social-based methods extract information by representing the email traffic as a social graph.

Using features extracted from email metadata, [Yelupula and Ramaswamy, 2008] was able to cluster levels of management at Enron. In addition to email traffic statistics, using features such as the presence of different email attachment types and the length of emails was shown to successfully categorize email behavior in [Martin *et al.*, 2005].

Relational ties can be modeled as a graph network where nodes represent people and edges represent interactions. This is a useful model because many statistics can be calculated from the layout of a social graph [Wasserman and Faust, 1994]. A common metric that has been shown to indicate importance in a social graph is betweenness centrality, which comes in several different flavors, and was first developed by [Freeman, 1977]. Betweenness centrality is a measure of how many shortest paths in a graph travel over each node. A node with high betweenness centrality in a social graph has been shown to represent a high degree of influence on other nodes. As [Tyler *et al.*, 2003] shows, a betweenness centrality algorithm can be used on a social graph to determine community structures within an organization. However, other metrics have been used successfully as well. For example, [Wilson and Banzhaf, 2009] detected the most important email users within a corporate network without using betweenness as a feature. Instead, they used: degree, the number of edges connected to a node; density, the ratio of actual edges to the number of possible edges; and proximity prestige, the ratio of nodes that can reach a node i to the average distance from those nodes to i.

Some research tried to combine the two different types of features. An example of this approach is seen in [Rowe *et al.*, 2007], which combined features such as number of emails, response time, cliques, and degree centrality into a "Social Score", which was used to rank Enron employees. The purpose of this paper is to further unite the two branches of research by aggregating old and novel email traffic statistics with social graph fea-

tures and applying them to a new, clean dataset.

3 Data Collection

Over the past decade, the Enron dataset has been widely used to study email behaviors because it is one of the only datasets available comprised of real-world corporate emails. A list of ground truth job titles was compiled by [Shetty and Adibi, 2004b]. However, there are issues with these labels. For example, Jeff Dasovich had the most emails out of any employee in the database, and is labeled as "employee". In reality, Jeff Dasovich served as the Director for State Government Affairs. Additionally, over the period that the dataset covers, Enron was undergoing turmoil where directors changed and job titles shifted. Instead of working with uncertain labels, we decided to generate a new dataset from an organization with which we had intimate knowledge, the center.

The center divides its employees into six main areas: directors, graduate students, operations, outreach, project management (PM), and research. These labels are also constant over time.

An Internal Review Board approved the study after reviewing a thorough proposal. Each of the 37 participants signed a waiver that detailed the specifics of the study. The following information was extracted from participants' emails:

- Destination and source email address
- Email time stamp
- Subject prefix (e.g. Re:, Fwd:)
- Hash of subject after removing prefix
- Hash of body text
- Length of subject in characters
- Length of body text in characters
- Whether email was signed

Table 1 compares statistics between our dataset and the Enron corpus. Our internal database is more modern, has more emails, and covers a longer time period. However, it is comprised of less people than the Enron dataset. Special care was taken to protect the privacy of those involved in the study. During the collection process, all subject and body text was hashed, and all email metadata was stored in a database using scripts without any researchers observing any email details. Furthermore, any identifying information has been omitted from this report.

	Center	Enron
Time	11/2012-11/2015	1/2000-9/2002
Distinct Addresses	32,118	75,406
Participants	32	149
Distinct Emails	585,096	252,759

Table 1: Our database compared to the Enron email corpus

Statistics were also calculated for former center em-

ployees or others who had known affiliation with the center. These employees' email folders were not used to build the database. However, these second-ring employees were included in the classification algorithm if their job title was known and if they were involved in at least 100 emails in the database, meaning that they had exchanged significant communication with employees directly involved in the study. This added 32 labelled subjects, for a total of 69 employees to analyze.

4   Features

In total, 101 different features were extracted from the email data: 70 traffic-based and 31 graph-based. The traffic-based features are those extracted purely from the collected email metadata. The social features, on the other hand, first model the email patterns in a graphical network and then calculate statistics from this model. Below, all features will be described in both categories. This ranking comes from an information gain ranker which was used to determine the most important features. Section 5 goes into more detail on this feature analysis.

4.1   Traffic-Based Features

Some of the traffic-based features were very basic, such as total number of emails, total sent, and total received. Other features came from the types of emails. For example, the number of emails sent and received were counted for each of the recipient types: to or cc. Similarly, the number of emails sent and received as replies or forwards were also used as features. The number of unique email addresses communicated with and the number of unique email subjects involving each person, both sent and received, were counted as features to be used. The average number of recipients on emails sent and received for each participant were calculated. It was hypothesized that staff members had more inter-center communications while graduate students communicated more with the university. To investigate this, the number of emails sent and received from within the center and within the university, based on the domain of the email address, were calculated.

Other useful information collected from emails included the timestamp, the character counts of the subject and body, and the presence of any attachments. From the time stamp, the time of day for each email was available. Using this information, the average number of emails sent, received, and combined were calculated. The total number of emails sent and received after hours (between 6pm and 7am EST or anytime on weekends) and the number of emails sent and received after hours within the center were also used as metrics. The mean and variance of the number of characters in the subject and body were calculated. These metrics were also broken down between emails sent and received. The raw numbers of attachments sent and received were computed as well as

the average number of attachments sent and received per email. Digitally signing an email is a type of attachment. Additional features were calculated from the total number of signed emails sent and received, unique email addresses with signed emails, and unique subjects from signed emails.

The features above in general involved raw email counts. To normalize some of the features, metrics were additionally calculated as a percentage of all emails. Examples of this include the percentage of emails that after hours out of all emails that were sent or the percentage of all received emails with unique subjects compared to all received emails.

The best traffic-based feature for predicting employee status was the number of unique subjects received. This number represents the number of distinct conversations in which an individual was involved. It is intuitive that the higher the status of a person, the more conversations they would be in. This feature is shown in the histogram in Figure 1 with normalized values.
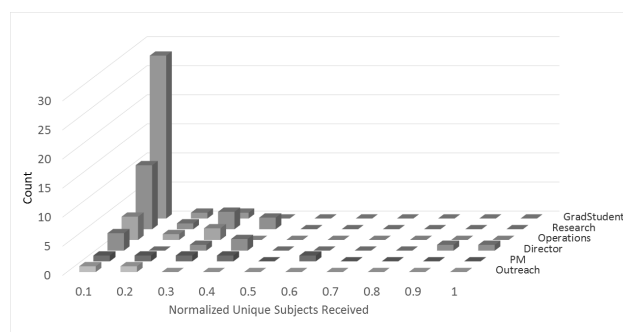

Figure 1: Histogram of unique subjects received by job title. The feature value in this plot has been normalized so that all values fall between 0 and 1. Note that by using different thresholds, meaningful splits in the data can be made. For example, the two people with feature value ¿ 0.8 are exclusively from the director class.

The second best traffic feature was the number of emails received that were signed. Signed emails usually signal sensitive information. Only certain groups within the center deal with this type of information, therefore it is understandable that this feature could help divide the subjects by title. Finally, the third best traffic feature was the number of emails received as forwards. Typically, those higher in the chain of command are forwarded on emails where graduate students and lower-level employees are more likely to receive either replies or emails sent directly to them. Notice that there are intuitive explanations behind all of the features selected by the ranker.

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4.2 Social Network Features

In addition to tracking metadata statistics, features can also be derived from modeling the emails as a social network. A social network is composed of nodes, which represent people, and edges, which represent the emails between people. For this analysis, two different graphs were generated. In the full graph, an edge existed between any two individuals between which at least one email was exchanged. A second graph was generated as a subset of the first. In this partial graph, an edge was drawn between two nodes if they had exchanged at least 10 emails. A representation of the full graph is shown below in Figure 2. This figure is an adjacency matrix. It has two axes, both representing the employees of the center. The color at each coordinate indicates how much communication existed between the two employees. Some employees never exchanged any emails, while others exchanged many.
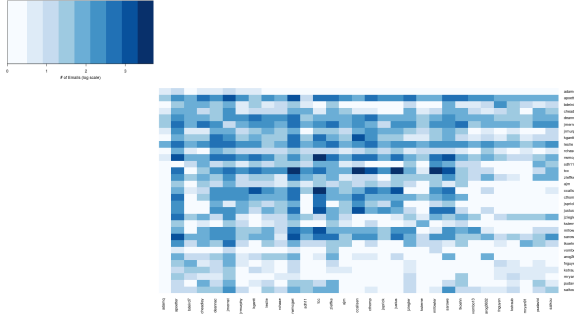

Figure 2: Adjacency matrix representing the social connections of the workplace.

With this representation, several statistics can be calculated about the people in the graph. The average neighbor degree was calculated for both the partial and the full graph. The degree of a node i is the number of other nodes connected to node i. Therefore for a node i, this metric averages the degree of each node in the neighborhood of i, that is all nodes connected to i. Mathematically, this is:

$$k_{avg,i} = \frac{1}{|N(i)|} \sum_{j \in N(i)} k_j \tag{1}$$

where $N(i)$ are the neighbors of node i and k_j is the degree of node j. The distances between nodes were also used to generate some features. The average shortest path metric calculates the length of the shortest paths between node i and all other nodes in the graph G, and it returns the average of these path lengths. Similarly, the maximum shortest path length, or eccentricity, was used as a feature in the learning algorithm.

Many of the social features were based on existing graph theory concepts and algorithms. If a subgraph of a graph G is maximally connected, that is all nodes are connected directly to each other, then this is called a clique. The number of cliques to which a node belongs was used as a feature. The hubs and authorities of each node in both graph were calculated. The terms hubs and authorities come from the Hyperlink-Induced Topic Search (HITS algorithm) developed by [Kleinberg, 1999]. This algorithm was originally designed to rate web pages, but has since been applied to social networks. A node's authority is just that – a measure of its importance over other nodes. A node's hub score is a measure of how well-connected it is to other nodes. The histogram of hub values in the full graph broken down by class is shown in Figure 3. Note that directors on average have the highest hub score and graduate students have the lowest. Another algorithm used to generate features was the pagerank algorithm, developed by Google [Page *et al.*, 1999] also to rank webpages for search results. The assumption is that the most important webpages will be linked to frequently by other pages. Therefore, the ranking is determined by estimating the quality and quantity of links to a node. The square clustering coefficient for each node was used as a feature. This method, developed by [Lind *et al.*, 2005] measures the probability that two neighbors of node i are also neighbors to a fourth node j. The higher the clustering coefficient, the more connected the node is within its neighborhood. The triangle clustering coefficient was also used as a metric. This value, developed by [Saramki *et al.*, 2007], is the same as the square clustering coefficient but instead determines the probability of connected triangles involving each node.
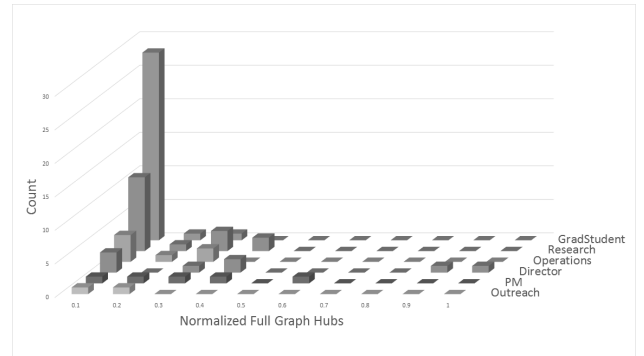

Figure 3: Histogram of hubs from social graph by job title.

The majority of the social-based features were centrality measures. This includes closeness centrality, betweenness centrality, degree centrality [Borgatti and Halgin, 2011], current flow closeness centrality, current flow

betweenness centrality [Brandes and Fleischer, 2005], communicability centrality, communicability betweenness centrality [Estrada and Hatano, 2008], and load centrality [Newman, 2001].

All of these different graph statistics were used as inputs into the machine learning algorithm to characterize each node's importance in the social graph.

5 Analysis

The biggest limitation of this email dataset is the lack of participants. Because of the low sample size, but great number of features, random forests were selected as the classification method. The java-based software package Weka was used to run the random forest algorithm described in [Breiman, 2001].

Random forests are an ensemble method of machine learning. The random forest builds many random trees. A random tree is a machine learning algorithm that uses training data to learn a series of rules for classification. These rules are constructed in a hierarchy that visually resembles a tree. Each decision is based on what rule will maximize the information gained. An example random tree with depth three (i.e., it has three levels of rules) is shown below in Figure 4.
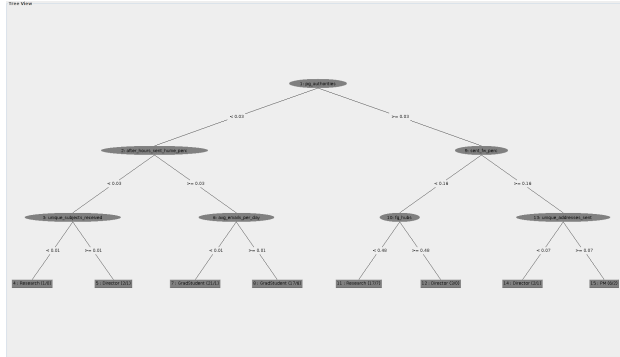

Figure 4: Example random tree of depth 3.

Random forests build many deep random trees with slight random variations. Individually, these random trees will overfit the data. However, these many random trees are combined through a process of bootstrap aggregating, or bagging. This process involves each random tree generating a new training data set by sampling observations from the input training set with replacement. These subsamples are used to build the random trees. For this analysis, one third of the data was used as a test set and the rest was for training. Just as the samples were subsampled, so were the features. For each random tree, a subset of features is selected. Only this subset can be used as rules for that tree. In this implementation, each tree used a subsample of 15 features. Once a tree is built,

the remaining samples from the training set are used as a test set and predicted labels for these points are generated. In this analysis, 750 random trees were generated. After all the trees are built, the majority vote on each sample prediction is the final predicted label. Using this random forest model reduces the overall variance and increases the accuracy of the model compared to a single random tree.

Random forests can be difficult to interpret because the ensemble method obscures which features are more meaningful than others. An attribute analysis helps to better understand which features were better label predictors. Since random trees use information gain to dictate splits, information gain was used as the evaluation criteria for the features. Specifically, each attribute was evaluated by measured the information gain with respect to the class. Information gain is calculated as follows for each attributed:

$$I(Class; Attribute) = H(Class) - H(Class|Attribute) \tag{2}$$

where $I(Class; Attribute)$ represents the mutual information between the class and the attribute. In the above equation $H(Class)$ is the entropy of the class variable, and $H(Class|Attribute)$ represents the conditional entropy of the Class given the Attribute value.

Mutual information represents how much information, typically in terms of bits, knowledge of the attribute informs the prediction of the class. In this model, both the attribute and the class are treated as random variables. The entropy of a random variable is a measure of the uncertainty associated with that random variable. After this information gained value was calculated for each feature, they were ranked in order of most important to least. Table 2 shows the top twenty features from this analysis.

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Feature	Feature	InfoGained
unique_subjects_received	Traffic	0.728
total_received_signed	Traffic	0.728
rec_fw	Traffic	0.719
fg_hubs	Graph	0.589
pg_communicability_cent	Graph	0.554
pg_comm_between_cent	Graph	0.554
rec_cc	Traffic	0.507
rec_fw_perc	Traffic	0.503
pg_degree_centrality	Graph	0.492
pg_pagerank	Graph	0.492
pg_current_flow_close_cent	Graph	0.492
avg_rec_per_day	Traffic	0.489
avg_emails_per_day	Traffic	0.479
pg_avg_shortest_paths	Graph	0.476
pg_closeness_centrality	Graph	0.476
unique_addresses_rec_signed	Traffic	0.457
sent_cc	Traffic	0.43
rec_re	Traffic	0.43
avg_sent_per_day	Traffic	0.404

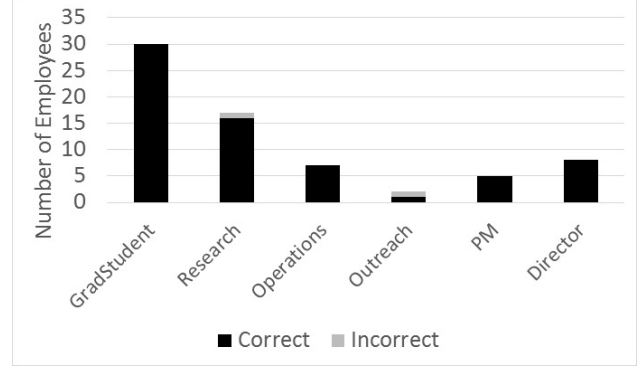Table 2: Top 20 features ranked by the information gain method

Figure 5: Prediction accuracy for test set using Random Forest model. Data was split such that 50% was used as training data and 50% was used as testing data.

6 Results

Two tests were run on the data. In the first, the goal was to classify employees of the center based on their email behavior. In the second, the official hierarchy from the organization chart was compared to relationships displayed in the data. The ultimate goal of this research was to determine if the relationships present in the email data confirmed or conflicted with the official organization chart.

6.1 Classification Results

After splitting the data randomly in half, the training data was input into the random forest algorithm described in Section 5. The model from this algorithm was used to test the remaining data and output prediction labels. These results are shown below in Figure 5. In this figure, the number of people in each class is plotted with the incorrect predictions shown. Note that only two predictions were wrong: one person each in research and outreach were misclassified. The overall accuracy of this method using all features was 97.1%.

It is important to note that the two misclassifications above were for second ring employees. All participants in the study were correctly classified, and 93.75% of second ring employees were correctly classified.

Note that this method relies on some assumptions. One is that employees with the same title exhibit similar email behavior. Overall, based on the success of the algorithm and the distributions of the histograms, this seems to prove true. Another premise underlying this analysis is that peoples' email behaviors are consistent over time. This seems to be true as well.

To determine which features were necessary to the analysis, the algorithm was run several times. The first run used only the top 20 features from Figure 2, and the classification accuracy was recorded. For each subsequent run, the least useful feature according to the feature analysis was removed from the input to the system. Using only the top 20 features resulted in 3 classification errors, or 95.6% accuracy. This is only one more error than was found using all 101 features. Even using just the top thee features resulted in classification accuracy over 80%. Therefore, a very good classifier can be built using much less features if the features are selected properly.
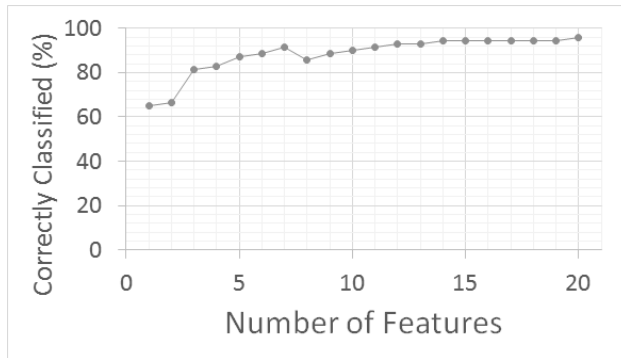
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Figure 6: Prediction accuracy compared to number of features used for analysis.

for this data. They predicted employee job titles based on email data with very high accuracy, even for employees for whom only secondhand data was available. Our intimate knowledge is able to interpret the few classification errors produced by the algorithm. However, there is the possibility of bias within this analysis in that training and testing are performed on the same people. Therefore, in future work we hope to further investigate this dataset and apply this wealth of information to other problems.

6.2 Hierarchy Analysis

To evaluate the organizational chart, we determined the true directors for all non-director employees. Next, we determined which director each of these employees emailed with the most. Surprisingly, only 57.58% of employees communicate most frequently with their official director. This is understandable in cases where the director works in a different location than his or her employees. This result points to possible discrepancies between the official organization chart and the functional relationships within the center.

To further investigate the accuracy of the organization chart, we also compiled a list of the project managers for graduate students and researchers in the study. In the case of an employee being on multiple projects, ground truth was selected to be the project that primarily funds the employee. Some employees in this group were not included in this list because they did not have a project manager or because they worked at the center before an official project structure was in place. This time, 72.73% of graduate students and researchers communicate most frequently with their primary program manager. The relation between employees to project managers appears to be stronger than that with directors. Many of the discrepancies can be explained by employees participating in multiple projects and therefore having multiple project managers.

7 Conclusions and Future Work

This work presented a new dataset, approximately the size of Enron, that was carefully collected from volunteers' emails with particular attention to protect participant privacy. Unlike Enron, we used our inside knowledge to label the people in this dataset with accurate job titles. A variety of statistics were calculated from this dataset, and from these statistics feature selection identified those key to making strong behavioral predictions. Random Forests were shown to be powerful classifiers

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