A Generative Model for Statistical Determination of Information Content from Conversation Threads

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Abstract. We present a generative model for determining the information content of a message without analyzing the message content. Such a tool is useful for automated analysis of the vast contents of online communication which are extensively contaminated by uninformative content, spam, and broadcast. Content analysis is not feasible in such a setting. We propose a purely statistical methodology to determine the information value of a message, which we denote the Information Content Factor (ICF). Underlying our methodology is the definition of information in a message as the message's ability to generate conversation. The generative nature of our model allows us to estimate the ICF of a message without prior information on the participants. We test our approach by applying it to separating spam/broadcast messages from non-spam/non-broadcast. Our algorithms achieve 94% accuracy when tested against a human classifier which analyzed content.

1 Introduction

With ever-increasing Internet accessibility, various electronic media, such as online forums, message boards, blogs, and emails, are available for people to exchange ideas and opinions worldwide. People utilize these tools to communicate with strangers, friends, or experts, to just socialize or to seek help. The volume of such electronic data has increased tremendously. The enormous data can easily overwhelm people interested in analyzing the data for social science purposes [1, 2]. Needless to say, the data contain valuable information. For example, the sentiments from a stock message board have been analyzed to show that they could influence the stock market [3–5]. On the other hand, huge amounts of spam and noise also exist in the data. Consider a stock analyst observing a stock message board to extract useful tips. It is not feasible to analyze every post given that there is much spam. How should the analyst determine which posts stand a good chance of being "interesting"? Removing the spam from the data set is as important as identifying the important messages. When studying interactions

between people (e.g., social group dynamics) by looking at senders and recipients of messages, the spam should be removed since it does not represent interactions. The existence of a significant number of spam and broadcasts will distort the communication pattern that forms the basis for Social Network Analysis. The task of distinguishing useful information from spam among millions of messages is difficult [5]. A straightforward method to separate the informative messages from uninformative ones is to examine the content of the messages; however, for large data sets this approach is not practical.

We propose a generative model to determine the information value of a message, which we call the Information Content Factor (ICF). Our approach does not examine message content. We take as input, a set of conversation threads which have been preprocessed from the raw digital data. A conversation thread is defined as a collection of messages in response to a message. The message, which initiates the conversation, is called the root message. The parent-child relationship between messages is determined by the reply function. All replies to a message are children of that message, and a message is the parent of its replies. Thus, a root message generates a tree of replies (the thread). The depth of the thread is the depth of the tree. The total number of replies to the root message is the summation of messages at each generation summed over all generations. The general intuition behind our generative model is that the more replies, the larger the ICF of the root message is. We propose the ICF, which ranges from 0 to 1, to measure how informative a message is based upon the reply structure to that message. The ICF can be used to separate the informative messages from uninformative messages without examining the content. We apply this methodology to identify broadcasts in the Enron email data set, and we test against a human who has access to the content. Our approach gives a 94% success rate, treating the human as ground truth.

The outline of the paper is as follows. In Sect. 2, two essential essential elements of our generative model are described, then three reply processes and their expected number of replies are presented afterwards. The statistical method to determine the ICF of the root message is discussed in the last part of this section. In Sect. 3, we apply the method under the framework of our generative model to Enron emails to identify broadcast messages. We conclude with suggestions for future research.

2 Generative Statistical Model

We assume a message with ICF 1 will be replied with probability 1 by each of the recipients of that message, and a message with ICF 0 has no replies. More generally, the ICF is related to the probability of obtaining a reply. There are two elements in our generative model. The first determines the probability that a message is replied given its ICF b. The second determines how the ICF of a reply is related to the ICF of the parent message. Intuitively the higher b, the more likely a reply, and the ICF of a reply should be smaller than the ICF of the parent. Let p^* denote the probability of being replied when ICF is 1, then by our

definition $p^* = 1$. For any root message with ICF b, whose probability of being replied is denoted as p, we assume p is proportional to p^*, that is, $p = bp^* = b$. To capture the decay in ICF from parent message to child message, we define the ICF-propagation function $f(b)$, $0 < f(b) < 1$. Thus, for a message with ICF b, p[reply] $= b$, and ICF[reply] $= bf(b)$. That is, if the ICF of the root message is b, the probability of a reply occurs is b, and its ICF is $bf(b)$. If we let b_i denote the ICF at depth i, it is a function of b as follows:

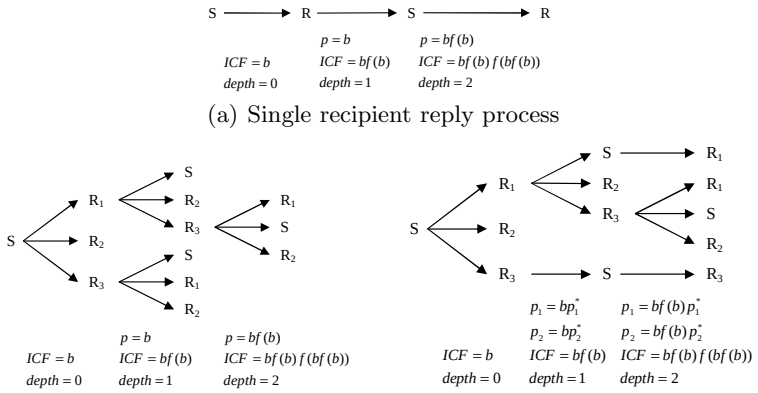
$$b_i = \begin{cases} b & \text{if } i = 0 \\ b_{i-1} f(b_{i-1}) & \text{if } i > 0 \end{cases} \tag{1}$$

The probability of a message at depth $i \geq 1$, p_i, is given as:

$$p_i = b_{i-1} \tag{2}$$

One interesting special case is $f(b) = f$, where f is a constant decay factor. The ICF of a message at depth i will be bf^i.

Assume a sender S initiates a message M, two cases in terms of number of recipients may happen: the message M has one recipient; and, the message M has multiple recipients. Let R denote the recipient set. In the case of multiple recipients, $R = \{R_1, R_2, ..., R_i, ..., R_n\}$, where $n \geq 2$ is the number of recipients. The generative model is applied to the three reply processes, namely, single recipient, multiple recipients, and mixed reply process. To better understand their characteristics, Fig. 1 illustrates how they work with one example for each reply process. The detail will be described in Sect. 2.1, 2.2, and 2.3 respectively. The idea behind the generative model will become clear from the three reply processes. The specific details are however application dependent and it should be possible to extend our framework to accommodate different domains.



(a) Single recipient reply process

(b) Multiple recipients reply process

(c) Mixed reply process

Fig. 1. Three examples for three reply processes

2.1 Single Recipient Reply Process

In this reply process, the sender S initiates the root message to the recipient R, and R may take 2 actions: reply to S or don't reply. If R chooses to reply, S again has two options, reply to R or don't reply, and so on. The conversation between S and R continues until one of them fails to reply. An example of such a conversation between S and R is given in Fig. 1(a). The ICF, depth, probability of each message are indicated in the figure. For example, when S initiates a message at depth 0, the probability p that R replies is b. If R replies, the ICF of this replied message is $bf(b)$, and its depth is 1 in the reply process, and so on.

This reply process is recursive with decreasing ICF. The recursion shows that the expected number of replies of the parent message is a function of the expected number of replies of the child message. Let X denote the total number of replied messages to the root message with one recipient. Let $\mathcal{E}(b) = E[X|b]$ be the expected number of replies to the root message with ICF b. We derive $\mathcal{E}(b)$ recursively as

$$\mathcal{E}(b) = b\,(1 + \mathcal{E}(bf(b))) \tag{3}$$

The first term is the expected number of replies to the root message, and the second recursive term captures the expected number of messages for the single recipient reply process initiated by the first reply. It turns out that it is hard to solve (3) analytically. We give an approximate recursion to calculate $\mathcal{E}(b)$. First we approximate $\mathcal{E}(b)$ when b is small using a Taylor series expansion to second order, and then use (3) to calculate $\mathcal{E}(b)$ recursively. The Taylor series expansion of $\mathcal{E}(b)$ at $b = 0$ is given by

$$\mathcal{E}(b) = \mathcal{E}(0) + \mathcal{E}'(0)b + \frac{\mathcal{E}''(0)b^2}{2} + \dots \tag{4}$$

Since b is small, we ignore the orders higher than 2. When $b = 0$, the probability of reply for each recipient is 0, therefore, $\mathcal{E}(0) = 0$. To find $\mathcal{E}'(0)$ and $\mathcal{E}''(0)$, the first and second derivative of $\mathcal{E}(b)$, $\mathcal{E}'(b)$ and $\mathcal{E}''(b)$, are obtained first.

$$\mathcal{E}'(b) = 1 + \mathcal{E}(bf(b)) + b(f(b) + bf'(b))\mathcal{E}'(bf(b)) \tag{5}$$

$$\mathcal{E}''(b) = 2f(b)\mathcal{E}'(bf(b)) + b\,(4f'(b) + bf''(b))\,\mathcal{E}'(bf(b)) + b\,(f(b) + bf'(b))^2\,\mathcal{E}''(bf(b)) \tag{6}$$

From (5) and (6), we have $\mathcal{E}'(0) = 1$ and $\mathcal{E}''(0) = 2f(0)$. Thus, $\mathcal{E}(b)$ can be calculated numerically as in Algorithm 1. The expected number of replies

Algorithm 1 Numerical analysis of $\mathcal{E}(b)$

if $b \leq 10^{-5}$ **then**
  $\mathcal{E}(b) \leftarrow b + b^2 f(0)$
else
  $\mathcal{E}(b) \leftarrow b\,(1 + \mathcal{E}(bf(b)))$
end if

to any of the messages in the stream can be obtained by replacing b with the corresponding ICF for that message.

2.2 Multiple Recipients Reply Process

In this reply process, the sender S initiates the root message to the recipient set $R = \{R_1, R_2, ..., R_i, ..., R_n\}$, where $n \geq 2$. R_i may take 2 actions: reply to the sender and the other recipients or not to reply. We assume that a recipient chooses to reply or not independently of the other recipients. The conversation among $\{S\} \bigcup R$ along a particular message path dies when a recipient fails to reply. The conversation ends when every message path dies. An example of such a conversation between S and $R = \{R_1, R_2, R_3\}$ is given in Fig. 1(b). The ICF, depth, probability of each message are indicated in the figure. For example, when S initiates a message to R at $depth = 0$, the probability p that each of R_1, R_2, and R_3 replies is b. If R_i replies, the ICF of this replied message is $bf(b)$, and its depth is 1, and so on.

This reply process is also recursive with decreasing ICF. Let Y denote the total number of reply messages to the root message. Let $\mathcal{F}(n, b) = E[Y|n, b]$ denote the expected number of replies to the root message with ICF b and number of recipients n. We derive $\mathcal{F}(n, b)$ recursively as

$$\mathcal{F}(n, b) = nb\,(1 + \mathcal{F}(n, bf(b))) \tag{7}$$

The logic behind this expression is that S starts n independent threads of the same form (note the factor n). For each thread, the expected number of messages is $1 + \mathcal{F}(n, bf(b))$ with probability b because R_i starts exactly the same process with lower ICF $bf(b)$. Following the same procedures in Sect. 2.1, we can obtain $\mathcal{F}(n, 0) = 0$, $\mathcal{F}'(n, 0) = n$ and $\mathcal{F}''(n, 0) = 2n^2 f(0)$. When b is small, $\mathcal{F}(n, b)$ can be approximated by Taylor series to second order. Thus, $\mathcal{F}(n, b)$ can be calculated numerically as in Algorithm 2.

Algorithm 2 Numerical analysis of $\mathcal{F}(n, b)$

if $b \leq 10^{-5}$ **then**
  $\mathcal{F}(n, b) \leftarrow nb + n^2 b^2 f(0)$
else
  $\mathcal{F}(n, b) \leftarrow nb\,(1 + \mathcal{F}(n, bf(b)))$
end if

2.3 Mixed Reply Process

The mixed reply process is a mixture of the single recipient and multiple recipient reply processes. In the mixed reply process, sender S initiates the root message to the recipient set $R = \{R_1, R_2, ..., R_i, ..., R_n\}$, where $n \geq 2$. R_i may take

3 actions: reply to the sender only ("Reply Sender"), reply to the sender and all the other recipients ("Reply All"), or not to reply. We assume that each recipient acts independently. We denote the probability of reply to the sender only as $p_1 = bp_1^*$, and the probability of reply to the sender and the other recipients as $p_2 = bp_2^*$, where p_1^* and p_2^* denote the probability of reply using the "Reply Sender" and "Reply All" options respectively when the ICF is 1. Note that $p_1^* + p_2^* = 1$ because the probability of reply is assumed to be 1 when ICF is 1. The conversation among $\{S\} \bigcup R$ along a particular message path dies when a recipient fails to reply. The conversation ends when every message path dies.

An example of such a conversation between S and $R = \{R_1, R_2, R_3\}$ is given in Fig. 1(c). In this particular reply process, at depth 1 R_1 chooses "Reply All", R_2 chooses "No Reply", and R_3 chooses "Reply Sender". The ICF, depth, probability of each message are indicated in the figure. For example, when S initiates a message to R_1, R_2, and R_3 at $depth = 0$, the probability of replying to the sender only, $p_1 = bp_1^*$, and the probability of replying to the sender and the recipients, $p_2 = bp_2^*$, and the probability of no action is $1 - p_1 - p_2$, which is $1 - b$. The ICF of this replied message is $bf(b)$, and its depth is 1 in the reply process, and so on. What we should notice is that once the "Reply Sender" option is chosen, the reply process followed will be the single recipient reply process.

Let $R_i' = \{R_1, R_2, ..., R_{i-1}, R_{i+1}, ..., R_n\}$ denote $R \setminus \{R_i\}$. We assume that when a message is replied, two options, "Reply Sender" and "Reply All", are to be used, which correspond to "S" and $\{S\} \bigcup R_i'$ respectively as the recipient(s) in the reply message of R_i. Let p denote the probability of reply, $p = p_1 + p_2$, in which $p_1 = bp_1^*$ is the probability of reply using the "Reply Sender" option, and $p_2 = bp_2^*$ is the probability of reply using the "Reply All" option.

Of the three actions, "No Reply", "Reply Sender", "Reply All", the last two actions may result in more replied messages. Take recipient R_3 in Fig. 1(c) as an example, at depth 1 R_3 chooses "Reply Sender", the reply process followed is the single recipient reply process; the probability of reply to a parent message is the summation of probability of "Reply Sender" and "Reply All", i.e, $p = bp_1^* + bp_2^* = b(p_1^* + p_2^*) = b$. On the other hand, R_1 chooses "Reply All", the reply process followed is the recursive process with a lower ICF.

Let Z denote number of replies of this process, and X denote number of replies when a "Reply Sender" option is selected when multiple recipients exist. Let $\mathcal{G}(n, b) = E[Z|n, b]$ be the expected number of replies to the root message. Since the "Reply All" option leads to a recursive reply process with a lower ICF, $\mathcal{G}(n, b)$ is given recursively as

$$\mathcal{G}(n, b) = n(bp_1^*(1 + \mathcal{E}(bf(b))) + bp_2^*(1 + \mathcal{G}(n, bf(b)))) \tag{8}$$

The logic behind this expression is that S starts n independent threads. The term $bp_1^*(1 + \mathcal{E}(bf(b)))$ captures the expected number of messages for the single recipient reply process initiated by the "Reply Sender" option at depth 1; the term $bp_2^*(1 + \mathcal{G}(n, bf(b)))$ captures the expected number of messages for the mixed reply process initiated by the "Reply All" option at depth 1 because the same process with lower ICF $bf(b)$ is started. Since $\mathcal{E}(b) = b\,(1 + \mathcal{E}(bf(b)))$ from

(3), $\mathcal{G}(n, b)$ can be written as:

$$\mathcal{G}(n, b) = np_1^*\mathcal{E}(b) + nbp_2^* + nbp_2^*\mathcal{G}(n, bf(b)) \tag{9}$$

Again, we approximate $\mathcal{G}(n, b)$ using a second order Taylor expansion. We can obtain $\mathcal{G}(n, 0) = 0$, $\mathcal{G}'(n, 0) = n$ and $\mathcal{G}''(n, 0) = 2np_1^*f(0) + 2n^2p_2^*f(0)$. The calculation of $\mathcal{G}(n, b)$ is shown in Algorithm 3. The expected number of replies for any message in the thread can be obtained by replacing b with the corresponding ICF of the message.

Algorithm 3 Numerical analysis of $\mathcal{G}(n, b)$

if $b \leq 10^{-5}$ **then**
  $\mathcal{G}(n, b) \leftarrow nb + nb^2p_1^*f(0) + n^2b^2p_2^*f(0)$
else
  $\mathcal{G}(n, b) \leftarrow np_1^*\mathcal{E}(b) + nbp_2^* + nbp_2^*\mathcal{G}(n, bf(b))$
end if

2.4 Statistical Determination of ICF

Given a thread generated from root message M, we would like to determine the ICF b of message M. We select b to match the observed tree. The approach we propose here is to select b to match the expected number of messages to the observed number of messages. This can be done at every level of the tree, treating each node as the root of its subtree-thread. The ICF of this subtree-root is determined from b and the ICF propagation function.

For a given root message with ICF b, assume the depth of the reply process is m, and there are n_i messages at each depth i. Let x_{ij} denote the total number of observed replies to the j^{th} message at depth i, b_i denote the ICF of messages at depth i, and $E[X_{ij}|n_{ij}, b_i]$ denote the expected number of replies to this message. We select b to minimize the summation of the squared difference between expected and observed number of replies for every message in the reply process. Thus, we define the error function

$$\Sigma(b) = \sum_{i=0}^{m}\sum_{j=1}^{n_i}\left(x_{ij} - E[X_{ij}|n_{ij}, b_i]\right)^2, \tag{10}$$

where b_i is defined in (1). The ICF b is then selected as argmin $\Sigma(b)$.

3 Detecting Broadcasts in Enron Emails

The methodology is applied to a subset of Enron emails to detect broadcasts. A broadcast is defined as an email which is sent to multiple recipients, but the

conversation triggered by this email dies down quickly. The purpose of detecting broadcasts is to eliminate the emails that inspire little or no interaction between sender and recipients and hence are misleading for Social Network Analysis. In this paper, only those root messages with 5 or more recipients are tested.

3.1 A Brief Description of Enron Email Data

Enron Corporation was founded in 1985. It became the seventh largest business organization in the USA in fifteen years [6, 7]. Enron's stock price was as high as $90 in August of 2000, however, Enron declared bankruptcy in December 2001 without any warning [6, 7]. After Enron's bankruptcy numerous investigations were conducted by authorities. Many employees' emails were also collected and released by Federal Energy Regulatory Commission (FERC) to the public for investigation [8].

The data set we are testing on is extracted from the March 2, 2004 Version of Enron emails posted by Cohen [9]. This corpus contains 517,431 messages dated from November 1998 to June 2002 organized into 150 employee folders. The researchers identified 156 employees from this data set, and most of them were senior managers of Enron [10]. Because the communication among these 156 employees was our interest, 22,099 emails among these 156 employees were extracted from the March 2, 2004 Version. The conversation threads are constructed and tested by our methodology.

3.2 Constructing Email Threads

Methods for threading emails into conversations have been discussed in previous research [11–13]. Although it is argued that language processing should be used to thread electronic messages [11, 12], we adopt a simpler but efficient method.

In an email system, usually two options, "Reply Sender" and "Reply All", are available for replying a message. Note that in most email software the "Reply Sender" option is symbolized as a "Reply" button. We ignore the slight possibility that neither of them is used in replying. We assume that when one of these two options is used to reply a message, the subject will not be changed except a "Re:" may be added. We examine the "Subject", "From", "To", "Cc", and "Date" headers to construct the parent-child relationship. If the "Subject" header of a message contains "Re:", we consider it as a child message. To find its parent message, we compare header fields of two messages. If the "Reply Sender" option is used, the recipient of the replied message will be the sender of the parent message; and if the "Reply All" option is used, the recipient of the replied message will be the sender and the other recipients of the parent message. For both options, the sender of the child message should be one of the recipients of the parent message. The "Date" field will be used as a time constraint to determine the parent-child relationship for any two messages, since the response time should not be long. We use 96 hours as the response time window.

3.3 Experiments

In this experiment, we assume the ICF propagation function $f(b) = f$ is a constant ranging from 0 to 1. Nine settings, $f \in \{0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9\}$ are tested. The probabilities of "Reply Sender" and "Reply All" when ICF is 1 (p_1^* and p_2^*) are approximated by their relative frequencies of having been used. It turns out p_1^* and p_2^* don't differ significantly, therefore, $p_1^* = p_2^* = 0.5$ is used in this experiment. We randomly select 50 threads as a training set, and another 50 as a testing set. For each thread in the test and training sets, we read the content of the email to determine if it is a broadcast message; if a message is to inform of a decision, a result, news, a meeting time, or anything that doesn't require a reply, we categorize it as a broadcast, otherwise it is considered as a normal message. The ICF of each thread at each f setting is calculated by minimizing (10). A threshold is then chosen to determine if a thread is a broadcast, i.e., a thread is a broadcast if the ICF of the thread is not larger than the threshold, and it is a normal message otherwise.

Let C and H be the variables indicating if a message is a broadcast from the statistical method and the content of the message respectively. They can be either 0 or 1, in which 0 represents normal message, and 1 represents broadcast. Let T denote the threshold. For any message i, C_i is defined as:

$$\mathrm{C}_i(T) = \begin{cases} 0 \text{ if } ICF_i > T \\ 1 \text{ otherwise} \end{cases} \tag{11}$$

The error is defined as the cumulative absolute difference squared between C_i and H_i in (12). The threshold T^* is determined as argmin $\Sigma(T)$.

$$\Sigma(T) = \sum_{i=0}^{50} \left(C_i(T) - H_i\right)^2 \tag{12}$$

3.4 Results

The result shows that the magnitude of f doesn't effect the error greatly for a given threshold. Figure 2 shows the nine f values with their corresponding optimal threshold T^* and error $\Sigma(T^*)$. When $f \in \{0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8\}$, the error is 2; however, when $f = 0.9$, the error is 3. A linear relationship between f and T is clear from Fig. 2. The regression analysis shows the adjusted $R^2 = 99.4\%$ with slope -0.1596 and intercept 0.2910. Therefore, $T = 0.2910 - 0.1596 * f$ can be used to estimate the threshold for a given f value. However, we notice that the error when $f = 0.9$ is larger than the error when f takes the other eight values. We further investigated the effect of f on the ICF with an example.

In this example four threads are illustrated in Fig. 3(a). All of their root messages have 5 recipients, but the generated threads are different. Thread (a) shows one of the five recipients replies to the sender; thread (b) has two of the five recipients reply, one chooses "Reply Sender" and the other chooses "Reply All"; thread (c) shows one of the recipients replies to the sender, and the sender follows up

f	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
T*	0.28	0.26	0.24	0.22	0.21	0.20	0.18	0.17	0.15
Σ	2	2	2	2	2	2	2	2	3

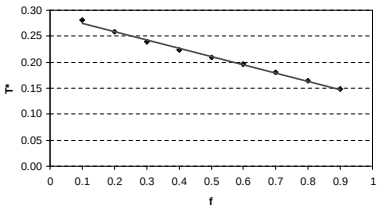
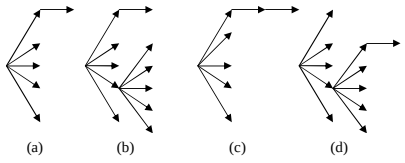
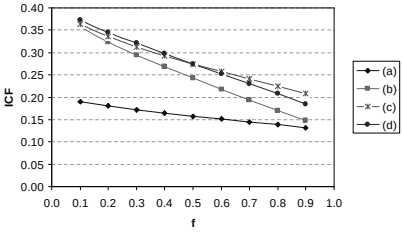


Fig. 2. f and its associated threshold T

with another message; thread (d) shows one of the recipients replies to the sender and the other recipients, and one of them follows up. The ICFs for thread (a), (b), (c), and (d) are shown in Fig. 3(b) for $f \in \{0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9\}$. As expected, the ICF decreases when f increases, and the rate of decrease is almost a constant for each thread. However, the decreasing rate varies from thread to thread. For instance, thread (a) has a flatter slope compared with (b), (c), and (d). As a result, the ICF of (a) is very close to that of (b) at $f = 0.9$ although they are quite apart from each other at $f = 0.1$ because thread (b) expects more replies when f is large. Thread (b), (c), and (d) cluster when f is small but separate when f is large. Threads (c) and (d) intersect when f is around 0.55 because the ICF of (d) is more sensitive with higher f values. The difference in slopes is identified as the reason that the error changes with f. Compared with two replies in (b), (c), and (d), thread (a) has only one reply; therefore, (a) should be distant from the others in terms of ICF. From Fig. 3(b), we notice that when f is small, (a) is indeed separated from the other three threads, therefore, small f values are recommended.



(a) Four threads as an example



(b) ICF vs. f for four threads

Fig. 3. An example to illustrate the selection of appropriate f

Another reason that we recommend small f values (≤ 0.3) is justified as follows. Consider the thread "A→B→A→B", three emails between A and B. Communication patterns like this are very common in real life. Intuition suggests that the ICF of the root message should be high (≥ 0.9). It shows that if ICF

is at least 0.9, $f \leq 0.3$. On the other hand, f cannot be too small since we also need to differentiate the interesting root messages which have triggered heated discussions. Therefore, $f \in [0.1, 0.3]$ is our recommendation.

The Relative Operating Characteristic, or ROC curve, is plotted for $f = 0.1$ in Fig. 4 using the training set data. The X axis is the false positive rate (FPR), which means it is categorized as a normal message from the content but it is classified as a broadcast using our methodology; and the Y axis is true positive rate (TPR), which means the message is categorized as a broadcast from both the content and our methodology. The area under the ROC curve is larger than 90%, which proves that our methodology is very effective (on the training set). We applied the combination of $f = \{0.1, 0.2, 0.3\}$ and its associated threshold $T^* = \{0.28, 0.26, 0.24\}$ to the test data set, which produced 3 disagreement out of 50 threads with accuracy 94%. The confusion matrix is shown in Fig. 5, in which "B" represents Broadcast and "NB" represents non-broadcast. Since the error doesn't deviate much from the error of the training data, our method is believed to be robust.

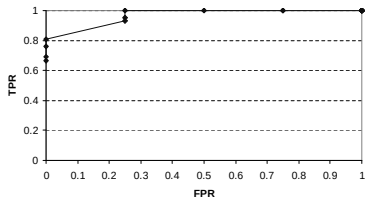


Fig. 4. ROC curve of the training data when $f = 0.1$

		Human	
		B	NB
Our Methodology	B	41	2
	NB	1	6

Fig. 5. Confusion matrix for the test data

4 Conclusions

We have developed a statistical method to evaluate how informative a message is by the conversation thread it triggered. This method is then applied to a subset of Enron email data to detect the broadcast messages. We conclude that the threshold to differentiate the broadcast from the normal message is a linear function of information decay factor f, and $f \in [0.1, 0.3]$ is recommended. The method is proved to be effective and robust in detecting broadcast messages

by applying it on both the training and testing data. The proposed method, in general, helps to process the data for various analyses and achieve a better understanding of the data. Our future research includes applying the methodology to detecting interesting topics from conversation threads.

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References

1. Berghel, H.: Cyberspace 2000: dealing with information overload. Communications of the ACM **40**(2) (1997) 19–24
2. Losee, Jr., R.M.: Minimizing information overload: the ranking of electronic messages. Journal of Information Science **15**(3) (1989) 179–189
3. Tumarkin, R., Whitelaw, R.: News or noise? internet message board activity and stock prices. Financial Analysts Journal **57** (2001) 41–51
4. Antweiler, W., Frank, M.Z.: Is all that talk just noise? the information content of internet stock message boards. Journal of Finance **59**(3) (2004) 1259–1294
5. Gu, B., Konana, P., Liu, A., Rajagopalan, B., Ghosh, J.: Predictive value of stock message board sentiments. In: the Social Science Research Network Electronic Paper Collection. Social Science Electronic Publishing, Inc. (2007)
6. McLean, B., Elkind, P.: Smartest Guys in the Room: The Amazing Rise and Scandalous Fall of Enron. 1st edn. Portfolio (2003)
7. Swartz, M., Watkins, S.: Power Failure: The Inside Story of the Collapse of Enron. 1st edn. Doubleday (2003)
8. Federal Energy Regulatory Commission: Addressing the 2000-2001 western energy crisis. http://www.ferc.gov/industries/electric/indus-act/wec/enron/info-release.asp
9. Cohen, W.W.: Enron email dataset. http://www.cs.cmu.edu/~enron/
10. Zhou, Y., Goldberg, M., Magdon-Ismail, M., Wallace, W.A.: Strategies for cleaning organizational emails with an application to Enron email dataset. In: 5th Conference of NAACSOS, Emory, Atlanta, GA (June 7–9 2007)
11. Comer, D.E., Peterson, L.L.: Conversation-based mail. ACM Transactions on Computer Systems **4**(4) (1986) 299–319
12. Lewis, D.D., Knowles, K.A.: Threading electronic mail: A preliminary study. Information Processing and Management **33**(2) (1997) 209–217
13. Venolia, G.D., Neustaedter, C.: Understanding sequence and reply relationships within email conversations: a mixed-model visualization. In: CHI '03: Proceedings of the SIGCHI conference on Human factors in computing systems, New York, NY, ACM Press (2003) 361–368