Visualizations for Mental Health Topic Models

by

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Submitted to the Department of Electrical Engineering and Computer
Science
in partial fulfillment of the requirements for the degree of

Master of Engineering in Electrical Engineering and Computer Science

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2014

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Abstract

In this thesis, I designed and implemented a compiler which performs optimizations that reduce the number of low-level floating point operations necessary for a specific task; this involves the optimization of chains of floating point operations as well as the implementation of a "fixed" point data type that allows some floating point operations to simulated with integer arithmetic. The source language of the compiler is a subset of C, and the destination language is assembly language for a micro-floating point CPU. An instruction-level simulator of the CPU was written to allow testing of the code. A series of test pieces of codes was compiled, both with and without optimization, to determine how effective these optimizations were.

Thesis Supervisor: Henry A. Lieberman
Title: Principal Research Scientist

Acknowledgments

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Chapter 1

Introduction

Crisis Text Line (CTL) is an organization that provides counseling services to young people in crisis through texting. The goal of this thesis is to supply CTL counselors with assistive tools in order to offer their clients the best possible service. This section explains the motivation behind this research project, the problems we want to solve, the approaches to implement and evaluate, and the contributions made.

1.1   Motivations for Mental Health Visualizations

The main motivating factor for this thesis is to help people with mental health crises. Many people suffer from depression, suicidal thoughts, and emotional stress every day. Crisis Text Line provides an outlet for clients to discuss their issues and ask for support. However, there is a shortage of counselors compared to the number of people seeking aid. Each counselor may have to manage various conversations continuously for several hours. Counselors spend time on extraneous things such as reports. In addition to maximizing counseling time for clients, we want to assist counselors because crisis counselors tend to have a high attrition rate due to burnout and low morale. Many of these counselors are simply volunteers who undergo a short period of training. These constraints motivate us to maximize the amount of time and brainpower counselors spend on client support. Time is a critical factor in mental health situations because clients may be at risk of suicide or physical harm.

Fortunately, the unique thing about a texting hotline is that the use of written communication allows computer programs to analyze and extract meaningful data from the text. Topic modeling is a machine learning technique that discovers abstract topics occurring in a set of documents. It can be useful for summarizing large amounts of text. Counselors may benefit from summaries of their various conversations with clients, but topic modeling is a complex and advanced artificial intelligence concept. Therefore, we would like to provide counselors with an easy method of understanding the data through visualizations. Visualization is a powerful approach for presenting data that most people are familiar with.

1.2   Problem Definition

As mentioned in the motivation section, some main difficulties with Crisis Text Line are that there are not enough counselors to talk with all of the clients in crisis, the counselors are usually context switching between multiple different client texts at a time, they spend a nontrivial amount of time on other necessary tasks, and counselors may feel burned out. Since it is more difficult to control external factors such as the number of available counselors, we focus on tackling two specific problems:

1. Reduce the amount of time counselors spend not talking to clients.

2. Reduce the cognitive load of counselors so they feel less burned out.

1.3   Hypotheses

We believe a variety of topic model visualizations will offer assistance in solving the proposed problems. Using topic models, mental health conversations may be summarized by a combination of topics, such as job-related issues, family troubles, relationship difficulties, or self-injurious behavior, to name a few. Topic models also provide indexing information, which tells us where each specific topic can be found in the conversation text.

1.3.1 Context Switching

As the medium of texting usually involves gaps in response time during a conversation, counselors often switch context between talking to different clients. When a counselor returns to a previous conversation after a client response, he or she may have to spend time recalling what that particular conversation was about. However, if the counselor was given a visual summary of the conversation, with the option of quickly reading through chat details, less time may be spent recognizing the conversation topics. This approach can minimize both the time a counselor spends not talking to a client and the cognitive load that context switching has on the counselor.

1.3.2 Shift Changes

Counselors usually handle incoming client texts in shifts. A shift change may occur in the middle of conversations, in which case the leaving counselor gives the incoming counselor a brief summary of the talking points so he or she can take over. However, this summary is general and transient, and the incoming counselor would have to take time scanning through the existing conversation text for details. We suspect that a permanent visual summary computed using topic models would be more helpful for the incoming counselor. The visualizations can provide different levels of detail depending on what the counselor needs to know about the conversation history. Visual indexing can quickly point him or her to the parts of the conversation related to a certain topic. This technique minimizes the amount of time necessary to search through the text for details and potentially improves the quality of client service by better preparing the new counselor for the interaction.

1.3.3 Automated Reports

Certain crisis organizations require their counselors to complete reports on their conversations with clients. Although these reports may be helpful to some, they can be time-consuming to manually fill out. That time could be better spent interacting with clients. Given that we can use algorithms to analyze conversation text and

extract information, we believe that this information can be used to automatically pre-populate reports. Another idea is to use visual summaries as a complementary form of a report.

1.3.4 Conversation Trends

As previously mentioned, counselors must keep track of multiple conversations at a time. These conversations may also contain gaps of time due to the use of texting. In order to aid the counselor's memory, we believe that displaying topic trends over time for each conversation could be useful. Showing trends, including where topics appear in the course of a conversation and how they accumulate, may potentially improve the quality of client service. A chart of topic trends could alert the counselor to important focus points. For example, if the topic of self-injurious behavior is on the rise, the counselor might want to react in a certain way to prevent escalation of injury. Conversation trends may also be useful for organization leaders to detect patterns that might be of use in supporting clients.

1.4 Contributions

Based on a topic model developed from a collection of real mental health conversations, I designed and implemented a website prototype for Crisis Text Line with four visualizations. These visualizations were designed based on four different levels of granularity, so the counselor can choose the amount of detail he or she wants.

The **Topic List** visualization lists the topics discovered in a conversation that are above a certain threshold. Topics are ordered from highest to lowest percentage detected in the conversation. This visualization is a quick, glance-able summary of the conversation topics.

The **Donut Chart** visualization adds a small level of detail by displaying the topic proportions in a pie chart variation to show the parts of the whole relationship. User interaction by hovering over the chart or the legend provides the topic percentages for quantitative information.

The **Line Chart** visualization reaches finer granularity by revealing topic proportions at the message level, where each client message in the conversation is analyzed for topics. A line exists for each topic above a certain threshold that shows the trend of that topic throughout the conversation timeline. There is also the option of viewing the accumulation of topic proportions across the conversation. When the user clicks on a topic, points are displayed to reveal the client messages in the conversation that contain the topic.

The **Scatter Plot** visualization is the deepest detail level, allowing the user to click on the topic instances that occur throughout the conversation. The conversation text then automatically scrolls to the appropriate message. The size of the scatter plot points represent the proportion of that topic in the corresponding message.

1.5   Thesis Outline

Chapter two presents related work, consisting of topic models, visualizations of topic models for other fields, and mental health topic modeling. The scope and limitations of the thesis is also included in this chapter.

Chapter three describes the contextual inquiry done with crisis counselors to analyze the needs of our users for a better design.

Chapter four discusses the design of the four visualizations contributed in this this thesis: a topic list, a donut chart, a multi-series line chart, and a scatter plot.

Chapter five explains how the system was implemented and lists the existing technologies that were used.

Chapter six evaluates the visualizations based on the user test results.

Chapter seven explores ideas for future work, some of which could not be completed due to time, resource, and technological constraints.

Finally, chapter eight discusses the main contributions presented in this thesis.

Chapter 2

Related Work and Scope

In this section, we first summarize relevant research presented in three categories: topic modeling, topic model visualizations, and mental health topic modeling. We then provide the scope and limitations of this thesis project.

2.1 Topic Modeling

Probabilistic topic models [1] are algorithms that aim to extract the main themes from a large collection of documents. These algorithms use statistics to analyze the words in each document's text and organize them into topics. Topic modeling can be used to aid summarization and information retrieval for various types of data without the need for humans to manually annotate a large amount of text.

The simplest topic model is *latent Dirichlet allocation* (LDA) [1]. LDA uses a statistical process to discover the topics in a corpus of documents. A *topic* is formally defined as a distribution over a fixed vocabulary. For example, a *genetics* topic should have the words *genetics* and *genes* with high probability. LDA consists of reverse-engineering an imaginary generative process. This process begins by taking a random distribution over topics. Each word for each document is then generated by randomly choosing a topic from the distribution over topics and randomly choosing a word from that topic's distribution over words. We refer to the topics, the per-document topic distributions, and the per-document per-word topic assignments as

the topic structure. This generative process must be reverse-engineered because the words in the documents are observed, while the hidden topic structure that most likely generated the words must be inferred.

We will not go further into the specifics of topic modeling in terms of probability and statistics because this thesis is concentrated on visualization. The purpose of this overview is to familiarize the reader with the concept of topic modeling, focusing on how it is used to extract a set of topics from a document corpus and annotate documents with themes based on the document words.

2.2   Visualizing Topic Models

Topic model visualizations vary in design due to different goals and audiences. Many projects focus on visualizing relationships between documents instead of summarizing each document. Some were created for non-technical users to improve understanding, while others were made for technical users to evaluate a certain model. A few systems also aim to show topic changes over time.

2.2.1   Document Relationships

Numerous research projects revolve around visualizing documents to show similarities based on their latent topics. *Probabilistic Latent Semantic Visualization* (PLSV) [8] is a topic model approach to visualizing documents and topics as coordinate points in a visualization space. The distances between documents and topics are based on the topic distribution of a document. *Topic maps* [12] and *Exemplar-based Visualization* (EV) [3] provide similar graphs of a large collection of documents, with document points color-coded by their dominant topic. The Stanford Dissertation Browser [5] is also a notable visualization developed to evaluate word and topic similarities between the Ph.D. theses of different departments over time. The general purpose of these visualizations is to show documents with similar topics in clustered areas for a global overview of the corpus.

2.2.2   Thesis-Relevant Projects

Now we turn to a few systems that are more relevant to our research in terms of their goals, end-users, or visual design. We are focused on summarizing individual documents using topics, revealing topic trends of a document over time, and indexing topics within document text using simple visualizations for non-technical users. Our developed visualizations were inspired by different aspects of these projects.

The Wikipedia navigator [2] was specifically designed to summarize the corpus and show relationships between textual content and topics for non-technical users. Three straightforward visualizations were produced: an overview page that lists the set of topics associated with all documents, a topic page that displays associated words as well as related document and topic links, and a document page showing the content in addition to related document links and a pie chart of related topics. These visuals allow the user to be completely unaware of the underlying LDA topic models.

The interactive visual text analysis tool TIARA [11] summarizes a corpus over time using a stream graph with topic layers and distributed keywords. ThemeRiver [7] provides the same type of graph without keywords. The height of the topic layer areas illustrate the strength of each topic at a certain point in time. Although I personally find stream graphs difficult to comprehend, these visualizations show that area or line charts can be useful for expressing topic trends over time.

Finally, Termite [4] is a visual analysis tool for evaluating the quality of topic models. The main visualization of this tool is a term-topic matrix that can be described as a scatter plot of words for each topic, with the size of each point proportional to the word frequency for that topic. Clicking on a topic in this matrix shows its representative documents and a one-dimensional plot of where topical terms can be found within each document. These simple designs seem effective for visually indexing topics in each document.

2.3　Mental Health Topic Modeling

Very little research has been done related to the application of topic models to the mental health domain. The Software Agents Group at the MIT Media Lab first began branching into this area with their previous story-matching research and now our Crisis Text Line project. The topic models for both projects, developed by Karthik Dinakar, use similar approaches. We will first describe the previous project and then outline the topic model differences used for our CTL system.

2.3.1　Story Matching Project

The previous research revolved around an ethics website where teenagers share stories about their mental health issues [10]. Researchers aimed to mitigate the effects of cyberbullying by presenting teens with stories similar to their own. The approach uses LDA to discover themes within the stories [6]. First, LDA extracts topics, in the form of word clusters, and a distribution over the topics for each document. Each word cluster is then analyzed by a human and interpreted as a theme if possible. This process iterates with an increasing number of desired topics until a satisfactory collection of themes have been extracted. Each document has a distribution over the themes. Using the output of this process, *Reflective Interfaces* [9] displays stories with common themes in order to help the teenagers relate to each other.

2.3.2　Thesis Topic Model

The topic model algorithm used for the visualizations in this thesis is very similar to the story-matching approach with a few main differences. The documents are conversations between a client and a counselor, so only the words in the client messages are analyzed. After the algorithm is applied to a large set of sample conversations, the extracted topics and word distributions are used to analyze each client message in a conversation. Having the themes at the message level allows us to: 1) provide indexing information regarding where topics occur within a conversation and 2) dynamically apply the topic model to new messages. The topic model summary of a conversation

is produced by normalizing the topic distributions for each client message.

2.4   Scope and Limitations

We will now give an assessment of the scope and limitations of this thesis project. First, the goal of this research is to provide a prototype for a Crisis Text Line website that makes use of topic model visualizations. It is designed on a development server and is not deployment-ready. The CTL developers may use the system design and implementation as guidelines or inspiration for future work. We do not have the time or resources to fully test and deploy this system to real users due to thesis deadlines and lack of additional developers.

We are also focused on crisis hotlines that use texting because we are mainly limited to conducting contextual inquiries and tests with the Crisis Text Line organization and the Boston Samaritans, which is a local hotline that uses texting. Some of the problems we are trying to solve, such as context switching and cognitive recall, are also unique to texting due to the longer and more frequent gaps in conversation.

In this thesis, the evaluation of the visualizations is emphasized rather than topic model accuracy. These are two different aspects of the group project, so we are concentrating our efforts on visualization effectiveness. We realize that the topic model may be improved with counselor feedback, such as having counselors interpret themes from the word distributions, merging topics they find to be too similar, or allowing them to indicate confusing topic assignments.

Finally, we have additional ideas that may improve the quality of counseling but choose not to implement them at the moment due to constraints on time and external resources. For example, topic-specific resources may be provided to counselors as they are having an ongoing conversation. Resources could be specialized hotline numbers or training documents on how to deal with a specific situation, as determined by counseling experts. Exploring this avenue would require controlled testing on whether this addition is distracting or helpful and gathering resources for predetermined topics.

Chapter 3

Contextual Inquiry

This chapter covers a contextual inquiry [13] on mental health counselors working at a crisis hotline organization. We spoke with three Boston Samaritans counselors for two hours each on three different days. It is important to gain background and perform analysis of users by observing and interviewing them in their natural environment. User-centered design allows an interface to focus on solving specific needs.

3.1   Counselor Workflow

Counselors talk with clients using a chat-based web application on the Crisis Text Line platform. Clients access the hotline using SMS text messaging and are placed in a waiting queue if a counselor is not available at the moment. Counselors handle two or more conversations at a time because the incoming texts are asynchronous and sometimes sporadic. The observed workflow is described as follows:

1. **Accept client:** Each time the system receives an incoming text from a new client, an alert is sounded and the client is placed in the queue. Counselors select a client from the queue when they are ready to take on another conversation by maintaining a balance of new and repeat clients. If a fellow counselor has become overloaded because they are managing more than three clients at once or one of the conversations has increased in severity, one of the conversations

can be *warm-transferred.* This simply means that a new counselor takes over the conversation while it is still ongoing. To get up to speed, the new counselor can read conversation notes taken by the original counselor or consult with them if necessary.

2. **Examine profile:** If the client is a repeat caller, the counselor can refer to a client profile consisting of previous counselor notes and a transcript of the three most recent conversations. Otherwise if the client is new, the counselor fills out the profile by asking them questions. Even with prior information to gain context, counselors are trained not to let the client know that they have access to that information because each conversation should be treated separately. We observed that it was time-consuming to read notes on previous conversations and even more time-consuming to read full transcripts.

3. **Provide counseling:** Counselors are trained to handle clients following this three-step system:

   (a) ***Risk assessment:*** Determine the amount of risk involved in a client's situation. High risk might be if the client is in physical danger or may potentially hurt someone. A client that mostly wants someone to talk with in order to reduce stress might be lower risk.

   (b) ***Issues and emotional state:*** Learn what the main issues are and how the client feels about them. Issues can range from job-related worries to relationship problems.

   (c) ***Action plan:*** Develop a concrete plan with the client that may help them deal with their pressing crisis or general problems. For example, if the main issue is a lack of financial means, one plan might be an outline of steps to take to apply for jobs.

4. **Take notes:** For each conversation, counselors take notes to cover the significant aspects of the interaction based on the three-step system. Some counselors take notes while the conversation is ongoing, and others take notes at the end.

Our observations determined that roughly more than one third of the counselor's time was spent taking notes.

5. **Complete report:** At the end of each conversation, the counselor must fill out a separate report using a static template. The template has high-level categories of client problems and counselor responses. Completing the report was also time-consuming.

6. **Monitor queue:** Each counselor must keep an eye on the queue in addition to maintaining their own conversations. This is done because clients in the queue could be having a high-risk crisis, and therefore minimizing their wait time is important.

Based on our observations of the typical counselor workflow, we concluded that there were many time-consuming tasks that reduced client-counselor interaction time. Taking over a *warm-transferred* conversation requires reading prior notes or additional consultation. Counselors also read previous conversation notes or transcripts to gain context for a repeat caller. Taking the notes manually and filling out the end report took up a substantial amount of time as well.

3.2 Interview Results

In addition to observing the counselors as they managed conversations, contextual inquiry also involves interviewing them to gather their opinions. The three counselors we interviewed all discussed similar aspects that they wanted to change, which agreed with our observations:

1. Taking detailed notes while handling multiple conversations in parallel was time-consuming.

2. For repeat clients, reading through previous conversation notes and transcripts was very helpful but also labor-intensive.

3. The conversation reports were determined to be both time-consuming and not useful. None of the three counselors even read previous reports, only taking the time with notes and transcripts. They explained that the report was too simple and rigid to be able to capture the complexity of most client problems.

Our takeaway from the contextual inquiry was that we need to design our interface to solve or mitigate the problem of manual note-taking and reading. We believe that using topic modeling to automatically read and extract information from conversation transcripts will reduce or complement note-taking, while visualizing the extracted information will be a faster alternative to reading written text.

Chapter 4

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Appendix A

Tables

Table A.1: Armadillos

Armadillos	are
our	friends

Appendix B

Figures

Figure B-1: Armadillo slaying lawyer.

Figure B-2: Armadillo eradicating national debt.

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