Assistive Artificial Intelligence for Coping with Memory Loss

Namrata Padmanabhan

Wayzata High School, Plymouth, MN

11th Grade

- **AWARD**: Won Minnesota Department of Education Scholars of Distinction Meritorius Performance in STEM Award, May 2018
- **CONFERENCE PRESENTATION**: Portions of this research were presented at Thirty-Second Association for the Advancement of Artificial Intelligence (AAAI) Conference on Artificial Intelligence, February 2018, New Orleans, USA

TABLE OF CONTENTS

1. ACKNOWLEDGEMENTS 3
2. PROJECT OVERVIEW 4
3. ABSTRACT 6
4. PROJECT INTRODUCTION 7
   - A. Background/Rationale: 7
   - B. Hypothesis and Support: 8
5. MATERIALS AND METHODS 9
   - A. Experimental Phase: 9
   - B. Samples of Code Created in this Project: 13
6. RESULTS & DISCUSSION 17
   - A. Analysis of Results 17
   - B. Future Applications 18
7. CONCLUSION 19
8. OVERALL REFLECTION 20
9. BIBLIOGRAPHY 22

1. ACKNOWLEDGEMENTS

I would like to thank Dr. Maria Gini (Professor, University of Minnesota, Department of Computer Science and Engineering) for her coaching and guidance in general and specifically around artificial intelligence and natural language processing. The experience I gained, with exposure to new types of software and learning how to design and implement a project, was invaluable.

In addition, I would like to thank Ms. Libby Ferland (Graduate Student, University of Minnesota) for her help in different areas within natural language processing and how it can be used to best communicate with users of the technology. She helped me overcome several issues early on, and the knowledge that she was willing to share with me is greatly appreciated.

2. PROJECT OVERVIEW

My project began with a meeting with Dr. Maria Gini on 9/11/17, in which she went over various project options that her graduate students were working on. She described related projects that I could possibly work on. Based on her data and my own research and interests, I decided to do a project on the use of voice technology as an assistant for persons with Mild Cognitive Impairment (MCI).

Before I could start my project, there was a lot I had to learn about the background of artificial intelligence, voice technology, and MCI. For my first few weeks I began reading papers and learning about assistive technology, their results toward people with cognitive impairment, and general technologies for health-related assistance. I also did research on the different capabilities of the voice based intelligent assistant Amazon's Alexa software, and did hands-on tests of these capabilities and Alexa skills using the Amazon Echo device. I also gained some background in natural language processing, specifically *sentence parsing* and *sentiment analysis*, which are two large areas of focus for the demographics that this project focuses on. All this learning allowed me to understand how I could use them to develop a better voice assistant.

I did evaluation of existing algorithms for sentence parsing and sentiment analysis, analyzing the techniques of the Alexa software, as well as comparing side-by-side the pros and cons of this software relative to the software of ELIZA. ELIZA is a communicative "Chatbot" computer program that was created in the 1960s as one of the first forms of artificial intelligence; it was a piece of software that could have conversations with users, but had no way to contextualize events or conversations. In this process, I created a research plan around the different capabilities I would be testing within Alexa and ELIZA.

One difficulty I ran into was around how elderly people interact with devices differently than younger people. A voice assistant needs to be able to account for these differences. I solved this problem by listing out all the potential variations involved in manners of speaking and then writing pseudocode, analyzing how each variation could be addressed.

Furthermore, a challenge presented itself when I was analyzing the human-computer interaction capabilities of the Alexa software; Alexa is not able to carry out a conversation or dialogue and largely can only respond to pre-written sentences that exist in its database with very little variation. This presented a problem since elderly people have been shown to speak conversationally with voice assistants. I went about trying to overcome this obstacle by determining the capabilities of the software of ELIZA, which uses a pattern-matching technique that can respond to larger variations of user input. The software of ELIZA is no longer in mainstream use, but the package it uses to parse input information can still be used for natural language processing.

Many more challenges presented themselves throughout the project, mostly relating to the capabilities of voice technology as it stands today, largely because there has been limited testing done with patients who have MCI. I was able to work around these issues by determining different ways to approach problems and combine elements of different pieces of software, to deliver better performance. Although at times the project felt overwhelming due to the limitations of technology, I was always able to push through the challenges and come to a conclusion.

3. ABSTRACT

Living with memory loss presents many challenges for both patients and caregivers. Intelligent assistive technology can help address care gaps and provide support to patients and caregivers. The short-term objective is to develop an assistive device that can be used by individuals who experience mild cognitive impairment (MCI). The long-term objective of the project is to develop a complete cognitive assistant that can do what it is told to do and be proactive in interacting with its users. The first step in developing an intelligent voice assistant is Natural Language Processing, which involves processing English sentences used in interactions between users and a voice assistant. This project specifically aims to use the Amazon Echo device with its software Alexa as an intelligent assistant. The software that exists to date does not have enough capabilities to be employed as-is toward the demographic of patients that most commonly have MCI. The natural language processing capabilities of ELIZA, known as pattern-matching, were compared with the language processing capabilities of Amazon's Alexa software, with the goal of maximizing the ability of the intelligent assistant to communicate effectively with users. To the best of my knowledge, this is the first time the idea of combining the software of Alexa and ELIZA has been used for the purpose of creating a better voice assistant. The results of the project show that ELIZA contains several capabilities of human-computer interaction which Alexa does not have. Since much of ELIZA's software is out of date (the software is from the 1960s), it was found that *combining* a pattern-matching algorithm with the Alexa software will allow for an intelligent assistant to have optimized capabilities in communicating with its users, and deliver a greater user experience.

4. PROJECT INTRODUCTION

A. Background/Rationale:

One of the key aspects of aging, normal or otherwise, is sensory change associated with physical changes occurring in the brain occurring as the body grows older. Problems such as decreased motor control, difficulty hearing, worsening vision, and Mild Cognitive Impairment (MCI) can be especially noticeable in elderly patients, since MCI can also cause diminished language processing capability. People with MCI and memory disorders require a great amount of support, which is a burden to them in a variety of ways. MCI encompasses a variety of symptoms and is often the one end of a spectrum of cognitive issues that include more severe disorders such as Alzheimer's disease and Dementia. It is estimated that 15-20% of people age 65 or older have some form of MCI, and a significant number of those affected by MCI will go on to develop the more severe disorders. Technology can support people with MCI by managing their everyday life and helping them engage in meaningful cognitive stimulation. The proposed solution in this paper uses a voice assistant as an assistive technology for people with MCI. Technological support for routine tasks can help free up cognitive resources for higher-level tasks, such as engaging in cognitive rehabilitation and the emotional labor of coping with anxiety, depression, and memory loss itself. All of these are vital to successfully treating, managing, or even slowing cognitive decline. The market for voice activated personal assistants is growing rapidly, with choices like Apple Siri, Google Assistant, Amazon Alexa, Microsoft Cortana, etc. Voice technology is the most favorable due to its affordability as well as ease of use, since many software tools from Amazon and Google’s devices have skills/actions that can be added by users. The lack of a keyboard or a small screen makes voice an often chosen method of choice for patients with cognitive impairment; hard-of-hearing users can connect the device to speakers or headsets, low vision users do not have to read any prompts or data, and users with motor control issues do not have to type or write. However, one of the main limitations of voice assistants is the reluctance of people to speak up in public places, inability to understand speech, limited dialog management, and lack of context awareness. Since elderly people tend to interact with intelligent systems in a manner more consistent with the way they would interact with a human (such as using a richer and more variable vocabulary and having a greater incidence of verbal pauses and backtracking), natural language processing will be a critical technology towards managing many of the limitations of voice. The system proposed here is to use the Amazon Echo Alexa software platform with its associated Alexa voice services. However, due to its known limitations in managing dialog histories and context awareness, the software of ELIZA will also be *integrated*, bringing in its more advanced pattern-matching techniques. There are still many limitations in voice activated technology as a whole that make it difficult to extend their functionalities and make them appropriate for new types of users, but with increased context awareness, intent recognition, and language recognition, these devices can be a great help to patients with MCI.

B. Hypothesis and Support:

The hypothesis in this project is that elderly people are more likely to engage in conversation with a voice based assistant if the device is capable of richer conversation than what is currently available. This hypothesis is supported by literature, as has been reported in the Background section. Based on this hypothesis, my work has focused on specific approaches to provide a more meaningful conversation with users of a voice activated device such as the Amazon Echo.

5. MATERIALS AND METHODS

A. Experimental Phase

During the experimentation phase of this project, I compared the capabilities of both ELIZA and Alexa software in terms of their abilities to process and parse sentences that are used when users interact with the voice assistant. I compared the sentence parsing functions that Alexa software uses to what ELIZA uses to analyze sentences from user input. ELIZA's code uses the Natural Language Toolkit (NLTK) as its package for development, and contains many tasks for parsing sentences. NLTK software looks up each word entered by the user into its keyword dictionary to obtain the meaning of the sentence, but responds with a script created using basic pattern-matching. Pattern-matching is the term that describes the type of sentence processing ELIZA does – a certain word in the input is matched with some output phrase from the database, so that there is always a response, even to a partial phrase. This allows the assistant to look intelligent, even though it actually is not; the program goes through the rules that it contains and picks some answer to respond with that corresponds with the user's input. It then stores the user's data, which makes it appear as though the assistant is learning information and becoming intelligent.

The ability of voice activated software to parse sentences is very important, because the problem we are trying to solve – creating a voice activated assistant for people with MCI – comes down to the assistant being able to understand an English sentence and generate a response.

Before I could analyze any code, I created a list of variables that exist in the typical speech of elderly people, which the Alexa software does not have the ability to account for. I also wrote the solutions that the code would have to deliver for each of these variables.

Table 1: The variations in user input, specific to the speech of elderly users. The table describes what will be done to account for each variation.

Variations in user input	What we want the code to do
Word variation: phrasing a question using different potential words	• Input many variables into the code to maximize the amount of different possibilities (Alexa's code only allows for one variable)
Syntax: different styles of sentences (conversational, run-on)	• Respond to specific key words within a sentence (the words that constitute the command)
Pauses midsentence	• Set a timer in the code (keep listening for up to *x* seconds before responding)
Partial phrases, broken-up phrases	• Collect key words and know how to do a task without hearing full phrase
Emotions/moods related with certain phrases (anger, sadness, frustration, happiness)	• Use techniques of sentiment analysis to collect data telling the mood of the sentence and respond accordingly
Different takes (calendar input, reminders, general questions)	• Use specific words to determine the task and respond accordingly

When analyzing the variations that needed to be accounted for, the first discovery I made was that nearly all of them could be addressed by improving the ability of the assistant to parse and analyze sentences. This ability allows the assistant to find key words and understand who or what the sentence is talking about.

I analyzed the code structure of Alexa's software, as well as some examples of conversations users had with Alexa, and found several places that could be improved.

- First, Alexa's code allows for a small number of variables, meaning the amount of allowed variation in the words of a sentence is limited.
- Second, if Alexa does not 'hear' a key word that it recognizes, it will not give a response at all. This is because in the process of parsing sentences, the software checks for certain

key words or phrases and responds accordingly – there is a large database of keywords, but given the potential of elderly people to have conversational language and partial phrases in their speech, it is important for the code to be able to respond to such cases.

- Third, the parsing of sentences in Alexa's software does not actually understand the individual parts of the sentence in order to analyze them; the Alexa software uses the user's input when checking its database for a key word, but it only stores data for one 'cycle' of speech, so that it is not able to carry on a conversation (or dialogue) with the user because it does not actually remember or learn anything.
    - This creates a problem for elderly people, especially those with memory loss, because of their tendency to speak to an assistant the same way in which they would talk with a human.

I knew that all of these issues could not be addressed, but this provided me a broad starting point from which I could begin figuring out solutions and ways to increase the parsing ability of a voice activated assistant that could be used by people with memory loss. The analysis of these problems brought me to ELIZA, one of the first computer programs that used natural language processing to demonstrate communication between humans and machines.

Although ELIZA was initially designed as a Chatbot that acted similar to a therapist, the software uses a pattern-matching technique that allows for more variation in the input of a user. When analyzing the code structure of the ELIZA software, I found many differences between it and Alexa's software. First, since ELIZA uses similar language to a therapist, the types of responses it gives are more applicable to elderly people who would speak to the assistant like a person. Also, the variables can be large phrases, and more variables are allowed in the code, so more types of words can be processed than with Alexa. Additionally, the language that ELIZA recognizes can be extended by users by adding additional rules on how to respond to sentences that march specific patterns; however, the user would need to have access to the ELIZA program and understand how to change it, so this feature does not provide any applications to this project. The computation of the code is separate from its knowledge description – you can change its knowledge or rules (how it responds to a specific question), but this is separate from its basic computation abilities. During the analysis of a sentence, the code creates a semantic representation about the meaning of objects in a sentence using formal logic. This would look like the structure of a parse tree, like shown below. The parse tree shows how natural language processing software takes complex sentences and breaks them down to make them more easily understood in order to generate a response.

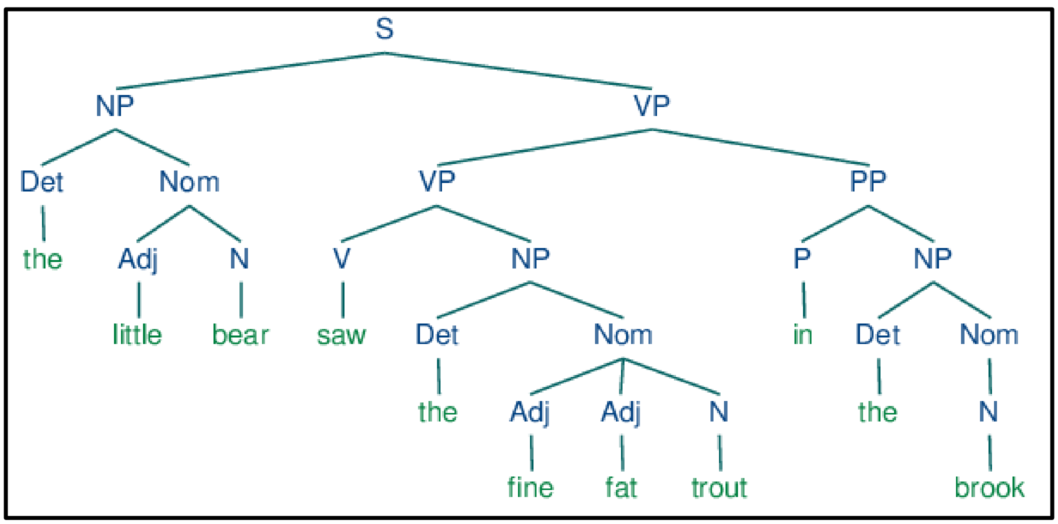


Figure 1: Example of a Parse Tree. This is a pictorial representation of the grammatical structure of a sentence in the way that a machine breaks it down in order to "understand" it. Each word is analyzed individually so the machine appears intelligent. [The acronyms are: S = Sentence; NP = Proper Noun; VP: Verb, base form, PP = Past Participle; Det = Determiner; Nom = Nominative Case; Adj = Adjective; N = Noun; V = Verb]

B. Samples of Code Created in this Project

The NLTK package contains many grammar rules as well. I experimented with the package and its various capabilities and techniques for parsing sentences. Below are different samples of code I wrote using the Natural Language Toolkit to demonstrate the various capabilities the package has for parsing sentences.

These samples of code are examples which represent the various techniques of parsing that I have experimented with and determined to be useful in analyzing sentences. All of these methods of parsing use the pattern-matching technique, rather than Alexa's brute force method. I have determined that this method can be used to more easily parse sentences in order to analyze them and generate a useful response for the user. Additionally, this method is more suitable than Alexa's current method to analyze conversational speech which includes things like varied syntax, emotional phrases, broken up sentences, and word variation.

```
>>> from nltk.corpus import state_union

>>> from nltk.tokenize import PunktSentenceTokenizer

>>> document = 'Today the Netherlands celebrates King\'s Day. To honor this tradition, the Dutch embassy in San Francisco invited the US president.'

>>> sentences = nltk.sent_tokenize(document)

>>> data = []

>>> for sent in sentences:
        data = data + nltk.pos_tag(nltk.word_tokenize(sent))


>>> for word in data:
        if 'NNP' in word[1]:
                print(word)


('Netherlands', 'NNP')
('King', 'NNP')
('Day', 'NNP')
('San', 'NNP')
('Francisco', 'NNP')
('US', 'NNP')
```

Figure 2: Finding Nouns. This technique locates all the proper nouns in a sentence, which can help determine the subject that is being talked about in order for the machine to figure out the action that needs to be done. This piece of code isolates all the proper nouns from the sentence listed in green. [Note: in all figures, the text in blue is the output of the code].

```
>>> from nltk.stem import PorterStemmer
>>> from nltk.tokenize import sent_tokenize, word_tokenize
>>> words = ["game", "gaming", "gamed", "games"]
>>> ps = PorterStemmer()
>>> for word in words:
        print(ps.stem(word))


game
game
game
game
>>>
>>> for word in words:
        print(word + ":" + ps.stem(word))


game:game
gaming:game
gamed:game
games:game
>>> sentence = "gaming, the gamers play games"
>>> words = word_tokenize(sentence)
>>> for word in words:
        print(word + ":" + ps.stem(word))


gaming:game
,:,
the:the
gamers:gamer
play:play
games:game
```

Figure 3: Stemming words. This takes a word and looks at its various stems, which helps find each possible stem of a word when analyzing a sentence, so that any form of a particular word can be recognized. This piece of code finds all possible stems of the word 'game' in a sentence.

```
>>> from nltk.stem import WordNetLemmatizer

>>> lemmatizer = WordNetLemmatizer()

>>> print(lemmatizer.lemmatize("cacti"))

cactus
>>> print(lemmatizer.lemmatize("better", pos="a"))

good
```

Figure 4: Lemmatize Words. This is similar to stemming, but words other than nouns can be supplied. This can help determine the tense of the sentence, as well as the general mood. This piece of code finds the stems of the words 'cactus' and 'better'.

```
['Change', 'my', 'lunch', 'from', '12:00', 'to', '1:00', 'tomorrow', '.']
>>> from nltk import ne_chunk, pos_tag

>>> print (nltk.pos_tag(words))

[('Change', 'NNP'), ('my', 'PRP$'), ('lunch', 'NN'), ('from', 'IN'), ('12:00', 'CD'), ('to', 'TO'), ('1:00', 'CD'), ('tom
orrow', 'NN'), ('.', '.')]
```

Figure 5: Part of Speech Tagging (Method 1). This lists the part of speech of each word in the sentence, which can help the assistant break the sentence down to understand the different parts of the sentence and what they mean.

```
>>> from nltk import PunktSentenceTokenizer

>>> document = "I would like the event for tomorrow night to be cancelled in my calendar."

>>> sentences = nltk.sent_tokenize(document)

>>> for sent in sentences:
        print(nltk.pos_tag(nltk.word_tokenize(sent)))


[('I', 'PRP'), ('would', 'MD'), ('like', 'VB'), ('the', 'DT'), ('event', 'NN'), ('for', 'IN'), ('tomorrow', 'NN'), ('nigh
t', 'NN'), ('to', 'TO'), ('be', 'VB'), ('cancelled', 'VBN'), ('in', 'IN'), ('my', 'PRP$'), ('calendar', 'NN'), ('.', '.')
]
>>> 
```

Figure 6: Part of Speech Tagging (Method 2). This is a more efficient method of tagging the part of speech in a sentence using loops instead of the NLTK built-in function.

```
>>> import nltk

>>> from nltk.tokenize import sent_tokenize, word_tokenize

>>> text = "Change my lunch from 12:00 to 1:00 tomorrow."

>>> sents = sent_tokenize(text)

>>> print(sents)

['Change my lunch from 12:00 to 1:00 tomorrow.']
>>> words = word_tokenize(text)

>>> print(words)

['Change', 'my', 'lunch', 'from', '12:00', 'to', '1:00', 'tomorrow', '.']
>>> 
```

Figure 7: Tokenizing Sentences. This separates a sentence into its individual words, which would allow the machine to look at each word individually within its database.

```
>>> import nltk.classify.util
>>> from nltk.classify import NaiveBayesClassifier
>>> from nltk.corpus import names
>>> def word_feats(words):
        return dict([word, True] for word in words])

>>> positive_vocab = ['awesome', 'outstanding', 'great', 'good', 'fantastic', 'terrific', 'nice', ':) ' ]
>>> negative_vocab = [ 'bad', 'terrible', 'useless', 'hate', ':(' ]
>>> neutral_vocab = ['schedule', 'calendar', 'the', 'sound', 'is', 'was', 'did', 'not']

>>> positive_features = [(word_feats(pos), 'pos') for pos in positive_vocab]
>>> negative_features = [(word_feats(neg), 'neg') for neg in negative_vocab]
>>> neutral_features = [(word_feats(neu), 'neu') for neu in netural_vocab]

>>> neutral_features = [(word_feats(neu), 'neu') for neu in neutral_vocab]
>>> train_set = negative_features + positive_features + neutral_features
>>> classifier = NaiveBayesClassifier.train(train_set)
>>> #prediction
>>> neg = 0
>>> pos = 0
>>> sentence = "The calendar event for tomorrow is bad, change it."
>>> sentence = sentence.lower()
```

Figure 8: Sentiment Analysis (Part 1). Given classes of words that are positive, negative, and neutral, the code determines what percent of the sentence was positive and negative in order to assess the emotions of the sentence/overall conversation.

```
>>> neg = 0
>>> pos = 0
>>> sentence = "The calendar event for tomorrow is bad, change it."
>>> sentence = sentence.lower()
>>> for word in words:
        classResult = classifier.classify( word_feats(word))
        if classResult == 'neg':
                neg = neg + 1
        if classResult == 'pos':
                pos = pos + 1

>>> print('Positive: ' + str(float(pos)/len(words)))
Positive: 0.5714285714285714
>>> print('Negative: ' + str(float(neg)/len(words)))
Negative: 0.14285714285714285
>>> print('Positive words: ' + str(float(pos)))
Positive words: 4.0
>>> print('Negative words: ' + str(float(neg)))
Negative words: 1.0
```

Figure 9: Sentiment Analysis (Part 2) – Output of the Code. These two snippets of code show what percentage of the entered sentence (in green) is positive and negative.

6. RESULTS & DISCUSSION

A. Analysis of Results

The results of the experimentation show that the sentence parsing techniques of ELIZA software can be integrated with Amazon's Alexa software in order to create a voice assistant that is better applicable to elderly people with MCI by creating more meaningful conversations. The samples of code I wrote showcase the various capabilities of ELIZA software in parsing and analyzing sentences in user input. These capabilities are more advanced than the parsing capabilities of Alexa (due to the use of the NLTK package, which contains most of these advanced abilities); because of this, we know that better dialogue will be possible between users and the assistant if this type of pattern-matching technique for parsing is used. Overall, the experimentation proved my hypothesis by creating richer conversation than what is currently available. In the near future I hope to be able to test a prototype of a voice assistant that uses integrated ELIZA and Alexa softwares to study the response from real patients currently in patient care facilities.

The advanced sentence parsing capability provided by ELIZA's software will help the voice assistant be better able to process commands said by users. This creates better communication between the user and the assistant, especially for the purpose of this project, since the targeted demographics have posed multiple variables that the current Alexa software cannot address.

To the best of my knowledge, this is the first time the idea of combining the software of Alexa and ELIZA has been used for the purpose of creating a better voice assistant. The innovative part of this project is the testing that I have done, which has proven that the integration of ELIZA software will enhance the capabilities of a voice assistant, especially as it pertains to this project.

B. Future Applications

Natural Language Processing (NLP) has many applications for the future of voice assistants, because of its critical importance in the communication between a user and a voice assistant. NLP is transforming the interaction and communication between users and machines. The results of this project show how the integration of NLP techniques from two pieces of software (Alexa and ELIZA) will be able to significantly enhance this communication. Enhancement of communication between a voice assistant and its users holds many future applications, not only for an assistant to help patients with MCI, but for all voice technology.

7. CONCLUSIONS

In this study, it was determined that the ELIZA and Alexa softwares can be combined to increase the capability of a voice assistant in having a rich conversation with users, especially patients with MCI, something the existing software does not do. Since this is a relatively new area of artificial intelligence, more research needs to be done based on this study, to determine how to further improve the software to account for all potential variables in the user's speech. Nevertheless, the discoveries made by this research mark a step forward in creating a fully functioning and improved voice assistant to help people with memory loss.

8. OVERALL REFLECTION

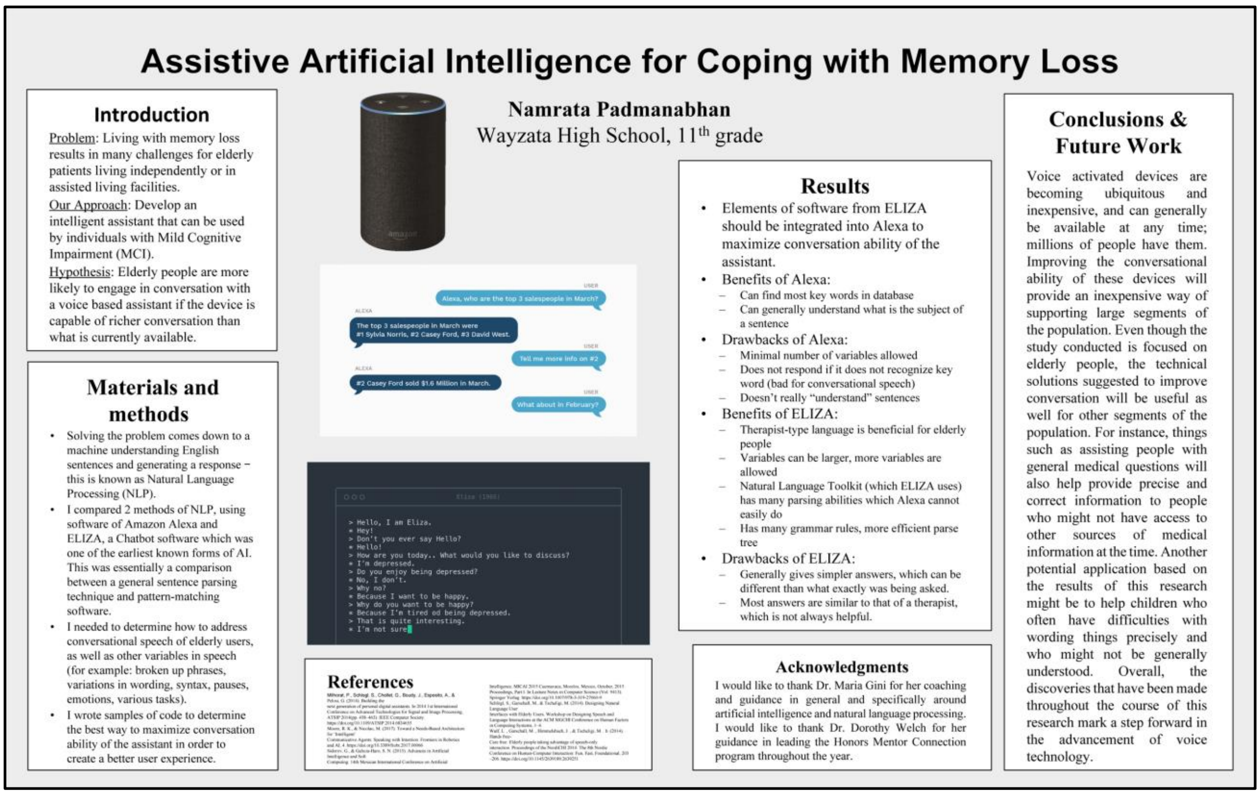
My overall experience conducting research in a professional lab has been exciting and beneficial to my educational development. I learned a lot about the technologies/experiments in computer science and artificial intelligence. In addition, I learned how to manage multiple responsibilities simultaneously and manage my time effectively.

While conducting research at the lab, most of my work was done independently. This was different than what I have been used to in High School where I didn't have specific assignments and hard deadlines. I had to independently figure out what to do for the project and how to do it in a timely manner. I had help and resources from my mentor and graduate students in the lab, but the research pertaining to this project was done individually and reviewed with my Professor when I had concerns over a certain issue. The responsibility that came with doing independent research like this meant that I had to learn how to keep a timeline of my work to hit the deadlines.

My project was not conducted for a grade in school. I was self-motivated to conduct the research and stay on task because I was genuinely excited by the problem for elderly patients and writing code (one of my hobbies) to solve it. I enjoyed reading about past research in artificial intelligence and voice technology, as well as conducting analysis of my own. I was also excited to pursue a project with a very meaningful real world application to help people. Exploring different types of software and their applications was very good. It was great to understand the potential future of this type of technology, which made me very proud of the results I was ultimately able to show.

Although I finished this portion of my project on the comparison between Alexa versus ELIZA methods for natural language processing, my time with this project has not ended. There is more research work to do in the emerging field of artificial intelligence, and I intend on continuing this research. I will continue to work on my life goal of influencing society in a positive way through advancements in intelligent computer technologies.

9. POSTER PRESENTED AT HIGH SCHOOL SCHOLAR'S FORUM (MN DEPARTMENT OF EDUCATION)



10. BIBLIOGRAPHY

Chowdhury, S. A., Stepanov, E. A., & Riccardi, G. (2016). Predicting user satisfaction from turn-taking in spoken conversations. In Proceedings of the Annual Conference of the International Speech Communication Association, INTERSPEECH(Vol. 08-12-September-2016, pp. 2910–2914). International Speech and Communication Association. https://doi.org/10.21437/Interspeech.2016-859

Cowan, B. R., Pantidi, N., Coyle, D., Morrissey, K., Clarke, P., Al-Shehri, S., … Bandeira, N. (2017). “What Can I Help You With?”: Infrequent Users’ Experiences of Intelligent Personal Assistants. Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services - MobileHCI ’17, 1–12. https://doi.org/10.1145/3098279.3098539

Derboven, J., Huyghe, J., & De Grooff, D. (2014). Designing voice interaction for people with physical and speech impairments. In Proceedings of the 8th Nordic Conference on Human-Computer Interaction Fun, Fast, Foundational - NordiCHI ’14(pp. 217–226). New York, New York, USA: ACM Press. https://doi.org/10.1145/2639189.2639252

Himmelsbach, J., Garschall, M., Egger, S., Steffek, S., & Tscheligi, M. (2015). Enabling accessibility through multimodality? In Proceedings of the 14th International Conference on Mobile and Ubiquitous Multimedia - MUM ’15 (pp. 195–199). New York, New York, USA: ACM Press. https://doi.org/10.1145/2836041.2836060

Kato, S., Endo, H., Homma, A., Sakuma, T., & Watanabe, K. (2013). Early detection of cognitive impairment in the elderly based on Bayesian mining using speech prosody and cerebral blood flow activation. Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and

Biology Society. Annual Conference, 2013, 5813–6. https://doi.org/10.1109/EMBC.2013.6610873

Luger, E., & Sellen, A. (2016). “Like Having a Really Bad PA.” In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, (pp. 5286–5297). New York, New York, USA: ACM Press. https://doi.org/10.1145/2858036.2858288

McTear, M., Callejas, Z., & Griol, D. (2016). Creating a Conversational Interface Using Chatbot Technology. In The Conversational Interface (pp. 125–159). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-32967-3_7

Meiland, F., et al. (2017). Technologies to support community-dwelling persons with dementia: a position paper on issues regarding development, usability, effectiveness and cost-effectiveness, deployment, and ethics, JMIR Rehabilitation and Assistive Technologies, 4:1, 2017

Milhorat, P., Schlogl, S., Chollet, G., Boudy, J., Esposito, A., & Pelosi, G. (2014). Building the next generation of personal digital assistants. In 2014 1st International Conference on Advanced Technologies for Signal and Image Processing, ATSIP 2014(pp. 458–463). IEEE Computer Society. https://doi.org/10.1109/ATSIP.2014.6834655

Moore, R. K., & Nicolao, M. (2017). Toward a Needs-Based Architecture for ‘Intelligent’ Communicative Agents: Speaking with Intention. Frontiers in Robotics and AI, 4. https://doi.org/10.3389/frobt.2017.00066

Nunes, E, Nanjanath, M and Gini (2012), M. Auctioning Robotic Tasks With Overlapping Time Windows. In Autonomous Agents and Multi-Agent Systems, pp. 1211–1212.

Peetoom, K., et al. (2015). Literature review on monitoring technologies and their outcomes in independently living elderly people, Disabil Rehabil Assist Technol. 2015 Jul;10(4):271-

94. doi: 10.3109/17483107.2014.961179.

Sidorov, G., & Galicia-Haro, S. N. (2015). Advances in Artificial Intelligence and Soft Computing: 14th Mexican International Conference on Artificial Intelligence, MICAI 2015 Cuernavaca, Morelos, Mexico, October, 2015 Proceedings, Part I. In Lecture Notes in Computer Science (Vol. 9413). Springer Verlag. https://doi.org/10.1007/978-3-319-27060-9

Schlögl, S., Garschall, M., & Tscheligi, M. (2014). Designing Natural Language User Interfaces with Elderly Users. Workshop on Designing Speech and Language Interactions at the ACM SIGCHI Conference on Human Factors in Computing Systems, 1–4.

Schmitter-Edgecombe, M., et al. (2017) Technologies for Health Assessment, Promotion, and Assistance: Focus on Gerontechnology, in J.J. Randolph (ed.), Positive Neuropsychology: Evidence-Based Perspectives on Promoting Cognitive Health, Springer Science+Business Media New York https://doi.org/10.1007/978-1-4614-6605-5_8,.

Wulf, L. , Garschall, M. , Himmelsbach, J. , & Tscheligi, M. . b. (2014). Hands free-Care free: Elderly people taking advantage of speech-only interaction. Proceedings of the NordiCHI 2014: The 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational, 203–206. https://doi.org/10.1145/2639189.2639251