Thesis Proposal: Disambiguation of Imprecise User Input Through Intelligent Assistive Communication

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Thesis

Intelligent interfaces can mitigate the need for linguistically and motorically precise user input to enhance the ease and efficiency of assistive communication.

Abstract

Many people with severe speech impairments use icon-based augmentative and alternative communication (AAC) systems. These systems typically present users with hierarchical arrays of icons that are sequentially selected to construct messages, which are then spoken aloud by text-to-speech (TTS) engines. Although ease and speed of message construction are essential, current systems are often slow and require repetitive physical movements that are fatiguing. This dissertation challenges three main assumptions common to icon-based AAC systems. These assumptions influence interface design decisions and place increased demands on the user rather than the system. The current work leverages natural language processing, machine learning, and context-sensing capabilities to design intelligent communication interfaces that shift the cognitive and physical burden from the user to the system to allow for faster, less fatiguing communication. This work also has broader impact for continuous modalities, such as brain wave and eye gaze activity, for other communication and entertainment applications.

1. INTRODUCTION

Spoken communication is a complex cognitive and motor skill that many people take for granted. The transition from infant babble to well-formed utterances by toddlers can appear seemingly effortless. Yet, for over 2 million Americans with craniofacial deformities or neurological conditions such as stroke, cerebral palsy (CP), or amyotrophic lateral sclerosis (ALS), speech is not a viable mode of communication [Matas et al. 1985]. Many of these individuals also have physical impairments that limit the use of sign language or written forms of communication [Light et al. 2003]. These individuals rely on augmentative and alternative communication (AAC) to interact with the world around them. An estimated 53% of people with CP [Jinks and Sinteff 1994] and 75% of people with ALS [Ball et al. 2004] use AAC. In the general population, approximately 1 to 15 people in every group of 1,000 may require AAC at some point in their lives [Beukelman and Ansel 1995; Beukelman and Mirenda 2006; Lindsay et al. 2010].

AAC methods include:

— Unaided techniques, in which the user relies on gestures, facial expressions, vocalizations, or sign languages;
— Low-tech displays or boards, in which the user composes messages by selecting a series of letters or icons; and
— Speech-Generating Devices (SGD), in which the user's selections on an electronic system are spoken aloud using speech synthesis.

This dissertation focuses on speech-generating devices, sometimes called Voice Output Communication Aids (VOCA). Communicating via current VOCAs is slow and physically demanding because it requires considerable effort in searching for, and navigating to, desired items [Udwin and Yule 1990]. This dissertation seeks to shift the burden of communication from the user to the system by leveraging natural language processing and artificial intelligence techniques to familiarize the system with the user's abilities, usage patterns, and contextual needs. The ultimate goal is to create an assistive communication prosthesis that enables users to seamlessly engage in timely, meaningful interactions in educational, vocational, and social settings.

In the SMCR model, communication consists of four key components: a source, a message, a channel, and a receiver [Shannon and Weaver 1949; Schramm 1954; Berlo 1960]. The integrity of a transmitted message can be compromised by distortion to any component, regardless of whether the communication involves face-to-face interaction, telephones, radios, or assistive devices. The risks of distortion can be alleviated by endowing components with some level of user-specific, adaptive, or context-aware "intelligence." Almost every communication technology available today has some level of intelligence: desktop computers, video game consoles, and even Web browsers are now designed to accommodate multiple users with different preferences and capabilities. Similarly, personal mobile devices are increasingly adept at detecting the user's location and time of day in order to provide highly relevant information with minimal prompting. Vocabulary usage and typographical error statistics also aid in accelerating text entry on these systems.

In contrast, current AAC systems are relatively passive conduits for translating user intentions into spoken output. While frequency statistics and natural language prediction are used in letter-based AAC systems, they are largely absent from icon-based AAC systems, and no commercial devices to date have made use of adaptive or context-sensitive information. Reconceptualizing AAC as an active, adaptive technology that leverages multiple information sources to facilitate and predict user intentions may have a profound impact on the ease, efficiency, and effectiveness of assistive communication.

1.1. Background

Current VOCAs can be grouped into two general categories: sub-lemma construction systems and super-lemma construction systems. Sub-lemma construction systems include those that use letter-based approaches, but also those based on phonemes [Trinh et al. 2012], morphemes [Baker 1986], or any other units of construction that are more linguistically granular than lemmas. Super-lemma construction systems include those that use word-based approaches, but also those that leverage text or images to represent combined lemmas, phrases, or full utterances.

Dominant among sub-lemma construction systems is the letter-based orthographical approach; for the purposes of this document, the term "letter-based" will be used to generally refer to sub-lemma construction methodologies. Similarly, the majority of super-lemma construction systems use icons or symbols, either primarily or as cues to assist in visual search; the term "icon-based" will be used to generally indicate a reliance on images, words, or phrases. "Icons" will also be used to refer to both symbols and words because many systems provide users with the option of displaying any combination of images and associated text labels.

An advantage of letter-based AAC systems is that users can create any possible utterance in the target language. Although icon-based AAC systems are typically not fully generative, icon-based systems can be advantageous because they have the potential to support faster and more efficient message construction by allowing whole words and phrases to be accessible via a single keystroke [Todman et al. 1994]. Aided message construction is often an order of magnitude slower than spoken interaction: approximately 15 words per minute (WPM) compared to over 150 WPM for speakers of American English [Beukelman et al. 1989; Todman 2000; Higginbotham et al. 2007]. Thus, icon-based systems are often preferred over letter-based systems for face-to-face conversation and other real-time scenarios to minimize communication delay. They are also useful for non-native speakers and individuals with limited or emerging literacy skills [Beukelman and Mirenda 2006], such as young children or those with language impairment due to neurological conditions.

Although the average college student uses approximately 5,000 unique words per day [Mehl et al. 2007], most icon-based AAC systems have much smaller vocabularies, often with several hundred words or phrases [Beukelman et al. 1989]. Given that the vocabulary cannot be displayed all at once, typical icon-based AAC systems organize their vocabularies as arrays of icons in hierarchically nested pages categorized according to lexical, semantic, or thematic similarity [Marvin et al. 1994]. Message construction in these systems requires users to complete two major tasks: (1) to search for desired icons by navigating through the available vocabulary, and (2) to select the desired icons. When users have finished composing an utterance, it can be sent to a Text-to-Speech (TTS) engine for vocalization.

1.2. Problem Statement

Current icon-based AAC systems place the burden of communication on the user and make three fundamental assumptions:

(1) **Syntactic Order**: The user will select icons in the syntactically correct order of the target language;
(2) **Intended Set**: The user will select exactly the icons that are desired, no fewer or more; and,
(3) **Discrete Entry**: The user will make discrete movements or selections, either physically or with a cursor.

1.3. Syntactic Order

Current AAC methods passively preserve the order of selected icons in the output, regardless of syntactic accuracy. Thus, if a user selects “hamburger,” “I,” and “want,” the system would output “hamburger I want” rather than the syntactically accurate order for American English: “I want hamburger.” Detecting semantic ambiguity becomes a problem when icons are selected in an unusual order. While some verbs are non-directional with regard to the subjects and objects that they allow (e.g. “Alice is near Bob” is semantically equivalent to “Bob is near Alice”), some verbs are directional (e.g. “Alice likes Bob”) and word order affects meaning.

The Syntactic Order assumption is problematic for a number of reasons. First, there is evidence that users do not always select icons in syntactic order [Van Balkom and Welle Donker-Gimbrere 1996]. This may be because of motor impairments, which often accompany speech impairments, that prevent users from making complex or repetitive movements. Second, because communication with AAC devices is so much slower than spoken communication, users may maximize speed by constructing simplified utterances [Wolpaw et al. 2002; Muller and Blankertz 2006]. Third, many users may have limited or emerging literacy skills in the target language, making them unfamiliar with all of its syntactic rules. Regardless of the reason, outputting unusual or incomplete utterances has social implications: listeners may have diminished expectations or perceptions of the user’s abilities [Alant et al. 2009].

1.4. Intended Set

Text entry systems on mobile devices often use dictionary-based approaches to account for scenarios in which the user types fewer or more letters than desired; however, such strategies have not been implemented for icon-based systems. There are two major issues: (1) subset completion, in which the system suggests additional items after the user has selected a subset of desired icons; and (2) superset pruning, in which the system removes undesirable items that the user may have accidentally selected. Previous efforts in subset completion have either focused on missing function words, such as prepositions and conjunctions [McCoy et al. 1998], or have operated under the Syntactic Order assumption [Bickel et al. 2005; Van Den Bosch 2006; Van Den Bosch and Berck 2009]. Although AAC users can manually add and remove icons prior to speech synthesis, automated strategies have not been integrated into current devices. The result is that AAC message construction is slow, impeding real-time interaction, and users with fine motor impairments are burdened with the task of trying to avoid accidental selections.

1.5. Discrete Entry

Current icon-based AAC systems require discrete entry of each desired icon. Movements are often executed via a cursor that is manipulated physically, such as with a finger, hand, or eye; however, research has been conducted on other ways of manipulating an on-screen cursor, including vowel sounds [Guenther et al. 2009; Brumberg et al. 2010] and brain waves [Wolpaw 2007]. The assumption of Discrete Entry implies that the path of the cursor between desired icons is irrelevant to icon selection. Recent work in letter-based text entry has explored the use of continuous and relative motion to shift the burden of lexical disambiguation from the user to the system [Goldberg 1997; Rashid and Smith 2008]. Several continuous text entry systems have been commercially successful for non-AAC users, especially on mobile platforms [Kristensson and Zhai 2004; Kushler and Marsden 2008]. Adapting these techniques for icon-based AAC involves adding semantic components, but may reduce the physical burden faced by users with motor impairments when making discrete navigation and selection movements. Additionally, continuous motion input would support stronger integration with input mechanisms that are naturally continuous, such as vowel sounds, brain waves, or electro-muscular signals.

Recent advances in touchscreen sensitivity, brain-computer interfaces, and miniaturized location sensors are just some of the reasons why challenging these three assumptions can allow us to rethink the design of assistive communication technology. This dissertation aims to endow assistive communication systems with enhanced intelligence to support free-order icon selection, prediction and error correction, and continuous motion input. Our approach leverages both semantic knowledge and contextual cues to reduce physical effort and improve the efficiency of message construction.

2. PRELIMINARY WORK

This dissertation extends previous work in the areas of message composition, prediction, and alternative inputs. Some work has been done in the area of free-order message construction [Karberis and Kouroupetroglou 2002], especially using a verb-first approach in combination with semantic frames [Patel et al. 2004]. We have expanded on this work recently by demonstrating that semantic frames provide a viable approach to free-order message construction, even when allowing users to change the verb during message construction [Wiegand et al. 2010]. This work, called RSVPiconCHAT, is currently being integrated with a brain-computer interface intended for users with locked-in syndrome. This prior work is evidence that we can address the assumption of Syntactic Order by supporting free-order selection, as well as enable the alternative input modality of brain waves for icon-based AAC.

We have provided evidence that it is not only possible to suggest semantically salient words in a subset completion scenario, but that accurate suggestions can be made without assuming a prescribed order for the input words [Wiegand and Patel 2012a]. We have also recently developed a related approach for accurately pruning supersets of icons, also without assuming syntactic order. These approaches use our method of measuring sentence-level co-occurrence, called semantic grams, supplemented by semantic frames [Fillmore 1976] to determine statistical outliers during message construction. Together, these approaches will form the foundation for addressing the Intended Set assumption by providing contextual prediction and error correction.

We have implemented a prototype icon-based system, called SymbolPath, that reenvisions assistive communication as a transfer of information between a user and a communication partner via an intelligent mediator. SymbolPath is an overlay system that can be integrated with existing icon-based AAC devices, allowing for continuous motion input of superset selections in free order [Wiegand and Patel 2012b]. We are currently conducting iterative, user-guided modifications to this system and its algorithms, but initial user feedback suggests that it may be both a desirable and effective new approach for a range of populations.

3. PROPOSED WORK

This dissertation comprises two types of experiments: corpus studies and user studies. The corpus studies will address the theoretical elements of the thesis statement, specifically that algorithms and design approaches can "mitigate the need for motorically and linguistically precise user input." User studies will address the applied portion of the thesis statement by quantifying the effects of the current work on the "ease and efficiency" of communication. Each of the proposed experiments will require implementation of at least one prototype system and the translation of theoretical behaviors into practice.

3.1. Corpus Studies

The following corpus studies and associated implementations will focus on algorithms and design approaches to enable free order, continuous input with prediction and error correction based on context. Ideally, the targeted corpora would include realistic conversations of current AAC users; however, because no such corpora currently exist [Lesher and Sanelli 2000], approximations are often used [Wandmacher and Antoine 2006; Trnka and McCoy 2007; Vertanen and Kristensson 2011]. The proposed corpus studies will target the following corpora:

- The Blog Authorship Corpus, a corpus of over 140 million words collected from 19,320 bloggers in August 2004 [Schler et al. 2006]
- The Crowdsourced AAC-Like Corpus, a set of fictional AAC-like communications solicited from workers on Amazon's Mechanical Turk [Vertanen and Kristensson 2011]
- The Human Speechome Corpus, a corpus of over 8 million words transcribed from over 100,000 hours of video recordings within a single-family household [Roy et al. 2012]
- TalkBank, a collection of corpora in both audio and transcribed forms that includes CHILDES, a corpus of children's conversations [MacWhinney 2000; 2007]

All of the following studies will use two potential evaluation metrics. The first evaluation metric will require that each algorithm generate a list of potential reorderings or modifications; each algorithm will be scored based on the position of the target reordering/modification, with lower scores being better. The second evaluation metric will require each algorithm to generate a single ordering or icon set; each algorithm will be scored on the edit distance between the generated output and the target output, with lower scores being better.

The following venues will be targeted for publication of the results of these corpus studies:

— **ACL**, the conference for the Association for Computational Linguistics
— **ASSETS**, the ACM SIGACCESS Conference on Computers and Accessibility
— **EMNLP**, the ACL SIGDAT Conference on Empirical Methods in Natural Language Processing
— **NAACL-HLT**, the Human-Language Technologies Conference for the North American Chapter of the Association for Computational Linguistics
— **SIG-SLPAT**, the meeting of the ACL and ISCA Special Interest Group on Speech and Language Processing for Assistive Technologies

Corpus Study #1: Syntactic Reordering

The purpose of this study will be to compare methods of addressing the Syntactic Order assumption and supporting free-order message construction. The task will consist of reordering a set of shuffled input words into a semantically and syntactically meaningful utterance. The goal is to demonstrate that words within an utterance do not need to be entered in syntactically correct order for a system to produce a syntactically correct utterance. "Syntactically correct order" is operationally defined as the original order of the words, prior to shuffling.

Hypothesis: An intelligent language model can support free-order word entry, alleviating the need for the Syntactic Order assumption.
Input: A shuffled set of words
Output: The original sentence from the corpus
Candidate Approaches:

(1) N-gram-based reordering, in which the permutations of the input set are rated for their likelihood based on ordered n-gram statistics
(2) Frame-based reordering, in which the input set is rearranged based on the likely roles of each word combined with a generational grammar

Corpus Study #2: Predicting and Pruning Selections

The purpose of this study will be to compare methods of addressing the Intended Set assumption with statistical semantics. The task will be to remove words from, or add words to, an input set such that the resulting set is more semantically cohesive, demonstrating that the set of words in an utterance need not be an exact selection in order for the system to suggest useful modifications. For the purposes of this study, "more semantically cohesive" will mean closer to the original set of input words.

Hypothesis: Statistical semantics can be used for prediction and error correction in free-order word entry to reduce the need for the Intended Set assumption.
Input: A shuffled set of words, with either one word removed or one word added
Output: The original sentence from the corpus
Candidate Approaches:

(1) Semantic grams, in which sem-gram statistics are used to suggest modifications to the given set
(2) Semantic frames, in which likely semantic frames are identified and associated semantic role statistics are used to suggest modifications to the given set
(3) Tuples, in which three-part tuple statistics (left words, verb, right words) are used to suggest modifications to the given set

Corpus Study #3: Comparison of Contextual Influences

The purpose of this study will be to assess the impact of leveraging contextual information to address the Intended Set assumption. The task will be to remove words from, or add words to, an input set such that the resulting set is more semantically cohesive, demonstrating that the set of words in an utterance need not be an exact selection in order for the system to suggest useful modifications. For the purposes of this study, "more semantically cohesive" will mean closer to the original set of input words.

Hypothesis: Contextual cues can be leveraged to disambiguate imprecise, free-order word entry, reducing the need for the Intended Set assumption.
Input: A shuffled set of words, with either one word removed or one word added, as well as contextual information, such as location, time of day, and discourse markers
Output: The original sentence from the corpus
Candidate Approaches:

(1) Location-based, in which the statistical relationship between possible words and the known location are used to suggest modifications to the input set
(2) Time-based, in which the statistical relationships between possible words and the current time are used to suggest modifications to the input set
(3) Discourse-based, in which the statistical relationship between possible words and the current stage of the conversation are used to suggestion modifications to the input set
(4) Combined contextual cues, in which two or more contextual input streams are combined to further boost prediction

3.2. User Studies

The following user studies and associated implementations will focus on quantifying the impact of free-order, continuous-motion message construction on communication speed and user fatigue. AAC users are a highly diverse population with a wide range of speech, motor, and cognitive impairments, so it is unlikely that they will respond consistently to a particular design. With this in mind, a primary goal of the user studies will be to determine the feature set that optimally enhances communication ease and efficiency for each user profile.

Each study will consist of a within-subjects experimental design with between 12 and 20 current and potential AAC users, depending on observed effect sizes. Participants will be recruited using clinical contacts and a database of past participants. Additional participants may also be drawn from the pool of 34 users who have been following the SymbolPath application on the Google Play store. Outcome metrics will include the speed of message construction, subjective reports of feature desirability, and reports of workload using NASA's Task Load Index (TLX) assessment tool [Hart and Staveland 1988; Bustamante and Spain 2008]. Population demographics will include age, gender, and the results from assessments of the participant's speech, motor, and cognitive abilities.

Speech and language abilities will be assessed by a certified speech-language pathologist using the Assessment of Intelligibility of Dysarthric Speech and the Revised Functional Communication Profile (FCP-R). Cognitive abilities will be assessed using the Montreal Cognitive Assessment (MoCA). Finally, motor abilities will be assessed using both the Archimedes Spiral Test and the ISO 9241-9 standard multi-directional pointing task.

The following venues will be targeted for publication of the results of these user studies:

- **ASSETS**, the ACM SIGACCESS Conference on Computers and Accessibility
- **CHI**, the ACM SIGCHI Conference on Human Factors in Computing Systems
- **ICCHP**, the International Conference on Computers Helping People with Special Needs
- **ISAAC**, the biennial conference for the International Society for Augmentative and Alternative Communication
- **UIST**, the ACM Symposium on User Interface Software and Technology

User Study #1: Select vs. Draw

The purpose of this study will be to determine the potential benefits to AAC populations of allowing continuous motion entry rather than requiring discrete selection. This study will involve a "copy phrase" task in which users will be asked to input a given utterance. In addition to speed, desirability, and workload, this study will also track the order in which the words are selected and the contours of the physical path, including missed touches.

Hypothesis: Allowing for continuous motion can result in faster and less fatiguing message construction than requiring discrete selection.
Prompt: An input sentence, such as "I like to play chess with my brother," possibly with stop-words removed
Task: Select all words in the given sentence from a superset of possible words
Candidate Approaches:

(1) Discrete selection, in which each word is a button that must be pushed to select it
(2) Continuous selection, in which the user may draw a path, or multiple non-contiguous paths, that collides with each word in the input sentence

User Study #2: Prompted Response

The purpose of this study will be to determine the potential benefits to AAC populations of removing all three design assumptions (Syntactic Order, Intended Set, and Discrete Entry) and allowing free order, superset selection via continuous motion. This study will involve a "prompted response" task in which users are asked to describe a simple picture scene. In addition to speed, desirability, and workload, this study will also track the length of constructed utterances, the order in which words are selected, and the contours of the physical path, including touches.

Hypothesis: Removing all three design assumptions can result in faster and less fatiguing message construction.
Prompt: A flashcard depicting a simple, single-action picture scene, such as "a woman smelling flowers" or "a man talking on the phone"
Task: Describe the given picture scene using the superset of possible words
Candidate Approaches:

(1) Discrete selection, in which each word is a button that must be pushed to add it to the current utterance
(2) SymbolPath, in which the user may draw a path, or multiple non-contiguous paths, to generate utterances

Potential User Study #3: Enhanced AAC

This study will be performed if the results of User Study #2 indicate that full Symbol-Path functionality is not effective for some users. This study will identify which feature combinations optimize ease and efficiency of communication for each user profile. This study will involve the same "prompted response" task in which users are asked to describe a simple picture scene, and will track the same metrics.

Hypothesis: Combinations of various system features are optimal for different user profiles.
Prompt: A flashcard depicting a simple, single-action picture scene, such as "a woman smelling flowers" or "a man talking on the phone"
Task: Describe the given picture scene using the superset of possible words
Candidate Approaches:

(1) Discrete reordering, in which the user must discretely select each button, but words are syntactically reordered so that users may minimize their motor movement and select words in any order
(2) Discrete prediction and pruning, in which the user must discretely select each button, but words are automatically highlighted or dimmed by the system based on their statistical relevance to the current utterance being constructed, assisting the user's visual searches

4. SCHEDULED MILESTONES

The following dates and milestones are guidelines that will be adjusted as progress is made and more accurate estimates can be determined:

June 1, 2013 - August 31, 2013 (3 Months)

— Results of User Study #1 submitted for publication
— Results of Corpus Study #1 submitted for publication

September 1, 2013 - November 30, 2013 (3 Months)

— Results of Corpus Study #2 submitted for publication
— Results of Corpus Study #3 submitted for publication

December 1, 2013 - February 28, 2014 (3 Months)

— Results of User Study #2 submitted for publication
— Dissertation chapter about the Syntactic Order assumption submitted to committee for review

March 1, 2014 - May 31, 2014 (3 Months)

— Results of User Study #3 submitted for publication
— Dissertation chapter about the Intended Set assumption submitted to committee for review

June 1, 2014 - August 31, 2014 (3+ Months, As Necessary)

— Dissertation chapter about the Discrete Entry assumption submitted to committee
— Full dissertation submitted to committee for review
— Dissertation defended

5. THESIS COMMITTEE

The thesis committee for this dissertation is composed of four members:

Rupal Patel, Ph.D.

Dr. Rupal Patel is an Associate Professor at Northeastern University and holds joint appointments in the Department of Speech-Language Pathology and Audiology (SLPA) and the College of Computer and Information Science (CCIS). She specializes in understanding neuromotor control of speech disorders and designing and developing assistive communication technologies that leverage the user's capabilities. Given her domain knowledge and experience with the end user group, Dr. Patel will provide overall guidance across several domains, including the design of the predictive algorithms, the user interface, and the usability studies.

Role: Thesis Advisor
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Javed Aslam, Ph.D.

Dr. Javed Aslam is a Professor in the College of Computer and Information Science at Northeastern University. He specializes in information retrieval and machine learning, both areas that are highly relevant to this work. In particular, much of the latest research in language modeling, text prediction, and semantic distance comes from the field of information retrieval, while machine learning is an integral part of predictive behavior and corpus linguistics.

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Amy Sliva, Ph.D.

Dr. Amy Sliva is an Assistant Professor at Northeastern University and holds joint appointments in the Department of Political Science and the College of Computer and Information Science. She specializes in artificial intelligence and agent behavior, both of which are core requirements for predictive behavior and contextual discourse models.

Note: Due to an unexpected family emergency, Dr. Sliva is temporarily on leave.

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David Smith, Ph.D.

Dr. David Smith is an Assistant Professor in the College of Computer and Information Science at Northeastern University. He specializes in natural language processing and computational linguistics and has worked extensively in the areas of machine translation, information retrieval, and digital humanities.

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Shaun Kane, Ph.D.

Dr. Shaun Kane is an Assistant Professor in the Department of Information Systems at the University of Maryland, Baltimore County. He specializes in assistive technology and human-computer interaction, especially for mobile devices in distracting environments, and has published research in the areas of gestural interfaces and AAC.

Additionally, Dr. Kane served on the committee that reviewed an early draft of this work at the Doctoral Consortium of ACM ASSETS 2012.

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