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### **Author**

Matessa, Michael

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# Interactive Models of Collaborative Communication

Michael Matessa (mmatessa@arc.nasa.gov)

NASA Ames Research Center, Mail Stop 262-4

Moffett Field, CA 94035 USA

## Abstract

The collaborative nature of communication has been demonstrated by research on the increased efficiency (Hupet & Chantraine, 1992) and the adaptive behavior (Giles, Mulac, Bradac, & Johnson, 1987) of interacting pairs, but these two lines of research have never been explicitly related. This paper reports empirical results showing that adaptively matching word use can increase communication efficiency and also gives an ACT-R (Anderson & Lebiere, 1998) modeling account of the processes involved.

## Efficient Communication

Imagine that two people have to communicate a number of times about abstract figures that are difficult to name. Typically, the pair will initially use a long referential phrase and with subsequent references shorten that phrase to one or two words (Clark & Wilkes-Gibbs, 1986; Krauss & Fussell, 1991; Krauss & Weinheimer, 1966). For example, in an experiment run by Krauss and Fussell (1991), a pair shown the figure in Figure 1 referred to it over five trials as

a Martini glass with legs on either side  
Martini glass with the legs  
Martini glass shaped thing  
Martini glass  
Martini

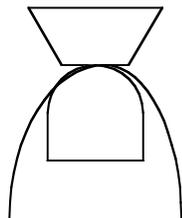


Figure 1: An abstract figure

This process is evidence of the collaborative nature of communication since subsequent phrases tend to make reference to previous phrases and since the phrase eventually agreed on to describe the object would not likely be able to describe the object without the benefit of the prior history of the evolution of the phrase.

Several partner-related factors have been shown to influence the number of words used in the referential

communication task. If subjects are asked to create referential phrases for an imagined partner who will later read the phrases, the phrases tend not to decrease over time (Hupet & Chantraine, 1992). If a partner is present but not allowed to give feedback, the rate of decrease is slowed (Krauss & Weinheimer, 1966).

## Accommodating Communication

In this discussion, accommodation is the matching of partner behavior in a conversational setting. These behaviors can include lexical choice (Fais, 1998; Garrod & Anderson, 1987; Garrod & Doherty, 1994) and syntactic choice (Bock, 1986; Fais, 1994) as well as speech styles, dialect, non-verbal behavior, vocal intensity, prosody, speech rate and duration and pause length (Giles, Mulac, Bradac, & Johnson, 1987).

Examples of accommodation can be seen in the maze game of Garrod and Doherty (1994), where subjects must decide how to describe their positions in a two-dimensional maze. Some subjects came to describe their positions in a line notation, giving first the line and then their location in that line:

A: Third row two along.  
B: Second row three along.

Other subjects developed a matrix notation, giving horizontal and vertical locations:

A: Correct, I'm presently at C5.  
B: E1.

Most research on accommodation has focused on dependent measures of converging/diverging behavior or recipient evaluations of that behavior. One hypothesis of this paper is that diverging behavior (non-accommodation) can not only influence the evaluation of behavior, but can also reduce the efficiency of referential communication. Support for this hypothesis would be shorter messages for subjects interacting with accommodating partners as compared to subjects interacting with non-accommodating partners. To do this manipulation with human partners, either confederate partners or partners motivated with positive and negative social group pressures would need to converge or diverge to communication behavior. Either choice would introduce extraneous social complications

into a question about informational processing. Ideally, the decision to diverge or converge should be independent of other communication processing in the partner. One solution is to use computational agents as partners. Two agents could be created that would either converge to or diverge from word choice of a human partner, with other communication processing being exactly the same. If both agents accommodated to the message length used by the human partner, then message length could be used as a dependent measure of efficiency. This would then test the effect of lexical accommodation on message length. The generality of the results would be greater if the behavior of the agents were psychologically plausible. One line of research involving computational theory of human cognition is ACT-R.

### **ACT-R & Communication**

ACT-R (Anderson & Lebiere, 1998) is a computational theory of human cognition incorporating both declarative knowledge (e.g., addition facts) and procedural knowledge (e.g., the process of solving a multi-column addition problem) into a production system where procedural rules act on declarative chunks. At a subsymbolic level, facts have an activation attribute which influences their probability of retrieval and the time it takes to retrieve them. Rules have a reliability attribute which influences their probability of being used.

Support for this declarative/procedural viewpoint has been found in many ACT-R language projects. One project emphasizing declarative representation is Boyland and Anderson's (1997) model of syntactic priming. Research has shown that the use of a specific syntax can be primed in experimental settings if a subject repeats presented sentences (Bock, 1986). Boyland and Anderson created a model that explained this phenomenon as priming of declarative structures built from the comprehension of sentences.

With a procedural representation, Matessa and Anderson (2000) showed that the ACT-R rule reliability learning mechanism predicts a blocking effect in cue learning where the use of highly available cues can block the learning of more reliable cues, since the sequential nature of productions allows only one cue to be chosen at a time. This prediction was supported by experimental evidence of blocking for linguistic actor choice cues such as word order, case marking, and verb/noun matching. Taatgen and Anderson (2000) used a model that combined both declarative and procedural learning to explain the U-shaped learning of irregular verbs, and Lewis (1998) created a parsing model with retroactive and proactive interference of declarative knowledge and procedural attachment processes.

Any interactive model of communication must be able to establish mutual knowledge, interpret the communicative intent of a partner, follow basic communicative obligations, and use communication to further some goal. These abilities have been the focus of a number of lines of research in the communication literature (Clark & Schaefer, 1989; Core & Allen, 1997; Poesio & Traum, 1998; Traum & Allen, 1994) and the ACT-R model of communication presented in this paper is guided by theories in this literature. ACT-R itself is a method for describing human cognition in terms of facts and rules, but the content of the facts and rules used in communication must be guided by current theories of communication. This model of communication was used to test the effect of accommodation (the matching of partner vocabulary) on communication efficiency by having two ACT-R models created from the basic communication model, one accommodating to word use and one non-accommodating.

### **Experiment**

Communication is usually motivated by the desire to complete a certain task. Subjects were given parts of a graph with the goal of creating a whole graph. The graphs are colored objects connect by lines (similar to those used by Levelt (1982) to study communicative reference) and are designed so that similarly colored objects on the parts can overlap and form a larger graph.

Communication using text is more conducive to modeling, so the subjects send messages by way of a chat window from two different computers. In addition to creating a whole graph from two parts, subjects also have the goal of confirming each of the circles. This is done by each subject selecting one circle at a time -- if the circles are the same, their score is increased, but if the circles are different, the score is decreased. This confirmation goal gives an objective measure of task performance in terms of a score, and it allows for the use of more complicated dialogue acts such as requesting that the other person confirm a circle or committing to confirming a circle.

In a similar spirit to the COLLAGEN project (Rich & Sidner, 1998), this modeling effort is not aimed towards the processing of unrestricted English syntax but in modeling the higher-level communicative acts accomplished with English. So like the COLLAGEN project the models interact with people with a restricted set of English phrases. This restricted interface need not drastically hinder the communication process or task performance. In a study comparing a restricted interface to an unrestricted interface for students solving physics problems, Baker and Lund (1997) showed that the restricted communication interface did not interfere with task performance. In fact, it promoted a more task-

focused and reflective interaction.<sup>1</sup> Still, for the current task, unrestricted and restricted communication were compared to see if the restricted interface had any effect on task performance. The restricted interface allows the composition of a text message by first choosing a topic of discussion and dialogue act to address the topic. The topics of conversation are paired connections (how one circle relates to another), multiple connections (rows or columns of circles), numbers (how many of a specific kind of circle there are), correspondences (what circle in one person's graph corresponds to in the other person's graph), confirmations (talking about mutually confirming a circle), and experiment phases.

Also, to allow more problems to be solved in a single experimental session which would allow the development of communication over time, the problems were simplified to have six total objects with one marked as common. From previous research (Clark & Wilkes-Gibbs, 1986; Krauss & Fussell, 1991; Krauss & Weinheimer, 1966) it was expected that the message length would decrease over time. To facilitate this decrease in the restricted interface, the manner of composing messages in the template was changed from choosing words from a pull-down menu to typing words that were displayed in a menu. The menu for the word choice could be skipped over with the Tab key, and in this way shorter messages could be produced. This new method permits a closer correspondence to the unrestricted interface (unrestricted typing) and gives a time benefit to skipping words by not having to spend time in typing them. Additional dimensions of size and shape were added to the color dimension of the circles in order to provide more redundant information in the problem that could later be left out of messages, resulting in a shorter message length. These dimensions were redundant, so that red objects were always small and thin, green objects were always medium and round, and blue objects were always large and fat.

## Subjects

One hundred Carnegie Mellon University undergraduates attempted the graph completion task. Twenty-two were paired and used the unrestricted interface, thirty-two were paired and used the restricted interface, twenty-two were paired with an accommodating ACT-R model, and twenty-four were paired with a non-accommodating ACT-R model. This created eleven pairs in the unrestricted interface condition, sixteen pairs in the restricted interface condition, twenty-two pairs in the accommodating model condition (pairs consisting of a subject and a model), and twenty-four pairs in the non-accommodating model condition.

## Method

Each pair was told that they would each be given part of a graph and their goal was first to create a whole graph as a result of circles overlapping from each part of the graph, and then to confirm each circle in the whole graph. They were told they would be sitting in different rooms and would be using a chat window to talk to each other. They were shown a drawing pad which contained an example graph part consisting of connected colored circles, and were shown how to add and erase circles representing circles from the partner's graph. They were also shown a chat window which could send eighty-character messages and only displayed the partner's last message. In the restricted interface condition, subjects were told that messages were composed in a communication window that allowed the creation of restricted sentences and were led through the creation of each kind of message. After making sure subjects understood the task, they were then given individual practice problems which used the adding, erasing, and confirming functions of the drawing pad. Finally, the subjects were given their graph parts and were told there were no time constraints in solving the problem.

## Results

Figure 2 shows the average time that pairs in each condition took to solve problems. Error bars in this and subsequent figures represent standard error. Results are averaged for the first three problems, the second three, third, and fourth. Since there were an unequal number of pairs in each condition for any particular problem, statistics are performed on each group of three problems.

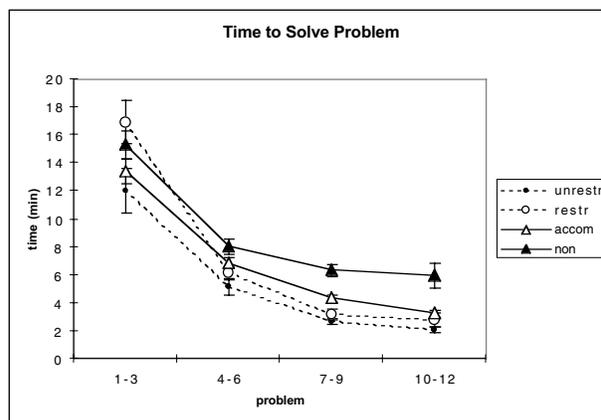


Figure 2: Time to solve problem

There was no significant effect of condition on time to solve problems in the first two groups of three problems ( $F(3,65)=2.12$ ;  $F(3,56)=1.72$ ), but there was an effect in the last two groups of three problems ( $F(3,37)=8.58$ ,  $p<.0005$ ;  $F(3,28)=5.76$ ,  $p<.005$ ). This effect is driven

<sup>1</sup> For an alternate viewpoint, see Suchman (1997).

by slower times in the non-accommodation condition, which was significantly slower than the accommodation condition in the last two groups of three problems ( $t(24)=3.71, p<.001$ ;  $t(18)=2.61, p<.05$ ). Since the results were similar between the restricted and unrestricted conditions for errors and time to solve problems, the unrestricted condition will not be included in subsequent discussions.

Figure 3 shows how many words were typed, or message length, for sentences concerning connections of objects. Message length tended to decrease with time, for example, a message such as The small thin red object is above our large fat blue object in the first problem could be reduced to messages such as red above blue by the twelfth problem.

Messages in the non-accommodation condition tended to be longer than those in the accommodation condition, not significantly in the first two groups of three problems ( $t(43)=0.55$ ;  $t(39)=0.83$ ) but significantly in the second two groups of three problems ( $t(24)=1.97, p<.05$ ;  $t(18)=1.81, p<.05$ ).

### Human Model

The accommodating and non-accommodating models are able to solve the communication task, but cannot by themselves explain the effect of accommodation. This is because they are "passive" in that they are not the first to decide to skip words in messages descriptions or to skip messages describing confirmation actions. Instead, they follow the lead of their partner and skip words when their partner skips words and skip messages when their partner skips messages. What is needed is an "assertive" "human" model that can decide to skip words and messages first. This model should also be able to account for differences found when subjects interact with accommodating and non-accommodating models.

This "human" model was created by extending the accommodation model with extra rules for actively skipping words. Since time is saved by not typing, these rules make solving the problem more efficient. This effect is achieved in the current situation by having the efficiency rules be sensitive to cooperative actions of the partner (with accommodative word matching signaling cooperative behavior). Two of the rules, skip-word-match-eff and skip-confirm-match-eff, attempt to retrieve memories of their partner matching their own word use. This gives these rules a sensitivity to whether their partner is accommodating or non-accommodating. The other rules do not attempt to retrieve matching memories. The rationale behind these rules is that the decision to skip a word or confirmation message will more likely lead to success if the partner has been cooperative in their behavior, and memories of word matching by the partner give evidence of this cooperation. Rules that find this evidence have a higher

reliability because the evidence increases the probability that skipping will lead to success. The rule to continue confirmation

These rules have a subsymbolic value, reliability, associated with them that affects the probability with which they will be used -- rules with higher reliabilities have a higher probability of being used. The efficiency rules added to the accommodation model were skip-word-match-eff (skips a nonessential word if partner matches word) with a reliability of .735 and skip-word-nomatch-eff (skips a nonessential word) with a reliability of .730. The reliability values were set with regard to subject performance with the accommodating and non-accommodating models. These values were then used in runs of the human model with another human model to make zero-parameter predictions of subject performance with other subjects in the restricted interface condition.

Looking at message length, Figure 3 shows results of twenty runs of the "human" model (shown as a dashed line) interacting with the accommodating model, the non-accommodating model, and another human model compared to the results of subjects interacting with the accommodating model, the non-accommodating model, and another human subject.

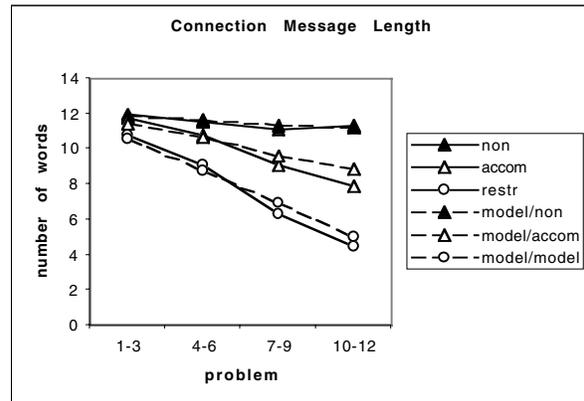


Figure 3: Connection message length

### Conclusions

Data from the main experiment show that subjects interacting with accommodating models that match their word choice can solve problems faster than subjects interacting with non-accommodating partners. This result ties together results from the referential communication literature showing partner-based effects on efficiency with results from the accommodation literature showing accommodating behavior motivated by efficiency.

Having a theory of communication in a computational form allowed testing of the theory by having it directly interact with subjects. In terms of errors and time to solve problems, subjects generally

reacted to the accommodating model incorporating the theory much like any other human. In fact, in a post-experiment questionnaire subjects guessed they were interacting with a human 43% of the time they were interacting with the accommodating model (subjects guessed the non-accommodating model was human 48% of the time, but the difference is not significant). There is still room for improvement however, since only 10% of subjects interacting with human partners thought their partners were computers.

The computational nature of the theory also allowed predictions to be made without the use of human subjects. The reliability of the efficiency rules for the human model were set based on human performance with the accommodation and non-accommodating models, but the results of the human model communicating with another human model represent a zero-parameter prediction that closely matched human performance in the restricted interface condition.

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