Summary
This contribution introduces the Grounded Experimental-Simulative Method which is a result of research on situated communication. The method combines qualitative and quantitative communication analysis, both supported by an annotated corpus management and analysis system with controlled experiments. The empirical results lead to the formulation of theorems system models with specified input, intervening states and output variables. Finally, these models can be simulated on a computer. The methodology demonstrates the significance of the methods used for empirical and formal analyses in the different branches of linguistics for an integrated system-theoretical development of models.

1. Introduction

This contribution presents a comprehensive methodology for empirical, theoretical, and simulative research in cognitive science. The starting point for this methodology is, on the one hand, the belief that theoretically and empirically backed research on the complex subject of natural language communication needs a systematic and interdisciplinary integration of methods. On the other hand, this kind of integration is possible only on the basis of a system theoretical conception of linguistics, which combines structural with procedural analyses (Eikmeyer, Kindt, Rittgeroth and Strohner, 2005).

The system's framework conceptualizes communication as the interaction of dynamic systems in a given situation using linguistic utterances. Our empirical setting consists of interactions during a construction task. In these interactions a constructor has to put together the model of an airplane while relying solely on the verbal instructions of the instructor. The verbal output of the instructor functions as input for the constructor and is processed in dependency on the external situation and the mental state. At the same time the constructor reacts to the input with his own output by making a construction and linguistic utterances.

As an example of methodology, a study on communicative understanding is chosen. The subject of investigation of this project are the verbal instructions in which the instructor and constructor undertake specific linguistic or mental activities in order to arrive at a successful communication. The specific goal of this project is a model of referential clarification requests in task oriented communication.

Which procedure seems most effective for reaching this goal? In extension to the usual experimental methodology in psycholinguistics and simulation methods in computer science, we conduct discourse analytical research in order to find ecologically valid hypotheses. Consequently, we talk about a Grounded Experimental-Simulative Method. The first step includes an extensive corpus on communication in which relevant phenomena can be observed.

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* Fig 1 about here *
Figure 1: The Grounded Experimental-Simulative Method
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Moving beyond the customary approach in qualitative communication analysis, the search for hypotheses is supported by quantitative methods using computer evaluation for corpora. As a
computer evaluation needs an annotation system as a prerequisite, the respective contextual conditions and features must be identified using formal linguistic indicators.

The next step of the *Grounded Experimental-Simulative Method* is the use of experimental methods for checking the hypotheses found by the communication analyses methodically.

It should not be assumed that a single experiment suffices in order to confirm or falsify the hypothesis tested. Very often it cannot be explained sufficiently to what extent the experimentally varying contextual conditions are responsible for the observed effects. Furthermore, often there are indications that there are other still unconsidered relevant factors. In such cases it can be useful to modify the hypotheses accordingly before conducting the next experiments.

The experimentally confirmed hypotheses are used in the next step, possibly also using the already available theories, in order to construct a theoretical model for the system behavior in question. Generally it can be assumed that not all relevant influential factors from the corpus or the experiments conducted are included or controlled. Therefore certain theoretically and empirically founded intervening variables are added to the model building in order to arrive at an explanation of a wider scope. This allows for a generalization of the model.

The final step of the method is the computer simulation. It checks whether the model constructed is sufficient for a computer system running in real time.

### 2. Qualitative Communication Analysis

Research in conversation analysis has shown that successful communication between people relies to a great extent on the interactive coordination of meanings. This is especially true for task-oriented communication, since specific goals have to be arrived at. In order to assign appropriate and sufficiently similar utterance meanings, speakers have a set of strategies for formulating and understanding at their disposal. The application of these strategies is used for establishing and securing understanding (cf. Kindt 1998, 2002). In case one of the interlocutors notices a problem he may initiate a communicative side sequence which makes the problem explicit and thus allows for solving the problem at hand. Such cases make the application of strategies extremely clear.

Usually, linguistic discourse research deals with corpora consisting of spontaneous speech. Such corpora have the disadvantage that the underlying tasks for interaction and the related communicative expectations vary and the parts taken over by the communication partners can therefore be defined very differently. In order to allow for a higher comparability and a better generalization of the results of the analysis, it is useful to work with experimentally elicited corpora.

The twenty-two dialogs in the CRC-corpus were transcribed and then analyzed for communication strategies. Within the framework of this system, it was checked among other things whether the participants consider the respective communication problem to be a difficulty in formulating or understanding. Furthermore, the participants say which grammatical form of a sentence is used to solve the problem (e.g. a suggestion in the form of a statement or question), and whether several alternatives for solving the problem are offered, etc.

This type of analysis shows circumstances that occur frequently and certain dependencies which form the starting point for the formulation of hypotheses. The constructor in the corpus, for example, very often uses an inference introduced by the conclusive conjunction *so* (also in
German) testing the instructor and the degree of success in understanding, as shown in the following example:

   yes that will be then - this is now the stern of the airplane --- this is – the - ehm elevator.
C: mhm, -- na also ähm ist das dann - quer dazu, |oder wie?
   mhm, -- well so ehm is that then - crossways or what?
I: ja quer dazu.
   yes crossways.

Also striking was the fact that clarification requests were usually formulated as alternative questions (using the conjunction oder/or) or in form of wh-questions (using the question pronoun welch~/what), see the following two examples from the corpus:

I: say we the yellow since I also yellow have and now eh take you one more of the small red bolts
C: eckig oder rund
   C: angular or round
I: rund --nicht die Rauten
I: round – not the rhombi
C: mmh
   C: mhm
I: und dann - nimmst du dir einen von diesen äh Würfeln mit den vielen Löchern drin.
I: and then – you take one of these ehm cubes with the many holes in it.
C: welche Farbe?
   C: what color?
I: das ist eigentlich egal -- wenn ich das richtig sehe, ja, kunterbunt durcheinander
I: that is actually whatever you like – if I see that correctly, yes, motley
C: okay
   C: okay

These examples indicated relatively soon that the number of referential objects to choose from is a relevant independent variable.

3. Quantitative communication analysis

3.1 Computer assisted analysis of linguistic corpora

The computer assisted analysis of linguistic data uses an annotated corpus of linguistic data as its search space. The core of this data is a transcription of the observed verbal behavior or speech. This information is enriched by additional information which characterizes selections of the verbal behavior in a purposeful and dependent way. An unlimited number of annotations can be attached to a stretch of speech. The analysis combines search facilities for both the core data and the annotations. In regard to the first, a full text search with regular expressions is used in our system. It is more powerful than a string search since a regular expression describes not only a single string but a set of strings. In regard to the second, annotations assign a finite number of properties to a selection of verbal behavior. The kind of information covered in an annotation is the central property and other properties are assign by attribute-value-pairs, where the attribute subspecifies the aspect of the information given by its value.
3.1.1 Aim and Functionality

If one wants to implement a software system for handling corpora of communicative interactions from an applied linguistics point of view, one has to consider the three following basic functionalities:

**Transcription:** This is the possibility to represent an interaction between two or more persons in a written form. Interactions include both verbal and non-verbal means. It also means that a representation of the language signal produced by the interlocutors is the core of the gathered data. It has to be ensured that arbitrary information can be added to the core data. The visualization of the data uses a score view with a number of voices for the interlocutor's language signal. Such a view easily codes the relation between an interlocutor and what she is saying and, moreover, depicts overlapping speech.

**Annotation:** This is the possibility of adding meta information to the core data. This type of information is in no way limited with respect to what it is and how many perspectives on the core data it is representing. However, the meta information has to be formally structured to make it treatable for machines. We chose an attribute-value-based approach, i.e. all meta information is represented by attribute-value-pairs in which the attributes to be used have to be specified.

**Analysis:** All information of the corpus, the language signal, and all annotations, has to be accessible for an automatic mechanism which analyzes the data according to the user's requirements. These include full-text search as well as search for attributes, values, or attribute-value-pairs of annotations and combinations of both. All such queries are formulated in a special language.

From a purely practical point of view the two following functionalities are nice to have:

**Accessibility:** All data has to be easily accessible for a group of several researchers and the system has to be accessible from different places and from any software platform. A web-based approach is optimal for these means.

**Re-usability:** All information of the annotated corpora has to be exportable in a suitable standardized output format in order to offer an interface to other systems. For practical reasons and based on the current state-of-the-art in text technology we chose XML as our export language.

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Fig 2 about here

Figure 2: View of a software system for corpora of communicative interactions

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3.1.2 Data Model and Technical Aspects

A theoretical data model has to guarantee the formal integrity of the data. We needed a data model for a corpus which is a set of interactions. An interaction is represented by a directed acyclic graph. These graphs contain two types of nodes: those representing a single contribution of a speaker during the interaction – called text chunks - and those representing annotations.

Text chunks contain an ordered sequence of minimal elements. According to the language transcribed, these may be words, morphemes, phonemes, or anything else that might be
suitable. All text chunks are related by their respective positions: they start somewhere in another chunk, mostly at its end, but possibly somewhere in the middle. An edge in the graph has this position as the value of its start-attribute. Overlapping speech is thus easily represented.

Annotations are coded similarly: they have two edges pointing to a text chunk and the start- and end-attribute of the respective edges to code the relative position of the annotation with respect to the text. Both types of node have a set of attribute-value-pairs attached to them. The set of admissible attributes has to be defined by the user.

Technically, the system uses a client-server architecture. User interaction happens via a web browser communicating with a dedicated web server using the HTTP-protocol. The CGI-interface starts PERL-programs which themselves communicate with a data base (for the persistent storage of the data) and a PROLOG-engine (for data analysis). The theoretical data model was mapped onto a relational data base scheme covering both the graph model and the attribute-value based information. In addition to algorithms for data handling, a transformation interface was implemented, which shows the language data in a score view with HTML. A query language was designed for data analysis.

3.2 The case of requests for clarification

In the framework of this CRC 360 we looked at how interlocutors can ensure that they understand one another. They can do so either in a prospective way when they (try to) make sure that no problem arises, or they can do so in a retrospective way when they already have a problem. In construction dialogs in which an instructor tells a constructor how to manipulate certain objects, a basic problem is to make sure that both talk about the same objects. In case of an object identification problem due to a lack of information on the side of one of the interlocutors this can be tried to be solved with a request for clarification. Several strategies can be applied in such a case, but, based on eclectic analyses, we were able to formulate an initial hypothesis.

For its formulation we use the following terminology: Depending on the situation, a specific or an unspecific request for clarification can be formulated. Specific requests for clarification can be a proposal (a possible partial object description adding more information to the information already available) or a list of two proposals connected with or. Unspecific requests for clarification do not name a certain possibility. They are open questions, preferably in form of wh-questions.

Examples:
I: take a long bolt
C1: the red one? [proposal, specific]
C2: the red one or the yellow one? [list, specific]
C3: what color? [open question, unspecific]

Hypothesis 1
The relevant situational parameter is the number of possible reference objects: in case of exactly two objects a specific or-question is preferred, while a more unspecific wh-question is preferred for more than two possibilities.

In order to validate this hypothesis in the corpus one can, in a first step, apply a full text string search for the word or in order to identify all possible specific requests for clarification and annotate those occurrences which really are such cases. A full text regular expression search for wh-words (they are actually „w“-words only in German and occur in inflected forms as e.g.
Once annotated, one can then search for annotated selections of speech:
• Show all specific requests for clarification
• Show all proposals
• Show all open questions asking for “size”/“color”/“length” information

Moreover, Boolean combinations of search patterns of the kinds mentioned can be used.

The annotation as to form and strategy of a request for clarification is only the starting point for a more detailed analysis, cf. Rittgeroth et al. (2001).

<table>
<thead>
<tr>
<th>number of objects</th>
<th>other</th>
<th>unspecific</th>
<th>specific</th>
<th>sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3 (20.0%)</td>
<td>101 (34.0%)</td>
<td>22 (16.0%)</td>
<td>126 (28.2%)</td>
</tr>
<tr>
<td>2</td>
<td>7 (47.0%)</td>
<td>128 (43.3%)</td>
<td>58 (42.4%)</td>
<td>193 (43.0%)</td>
</tr>
<tr>
<td>3</td>
<td>5 (33.0%)</td>
<td>67 (22.7%)</td>
<td>57 (41.4%)</td>
<td>129 (28.8%)</td>
</tr>
<tr>
<td>sum</td>
<td>15 (3.3%)</td>
<td>296 (66.0%)</td>
<td>137 (30.7%)</td>
<td>448 (100%)</td>
</tr>
</tbody>
</table>

Table 1: The distribution of requests for clarification in relation to the number of possible objects to choose from

Table 1 shows the results of the numerical analysis of the corpus data. More detailed results show that 80% of all requests for clarification found in situations with only one possible object are proposals, i.e. specific requests. This is a significantly higher percentage than that of all proposals. The specific lists with or are the preferred way of formulating requests for clarification in situations with two possible objects (66%). The percentage with respect to all requests is relatively small (17%), but it is significantly higher than the percentage with respect to all requests. The relatively small number of lists is possibly due to the relatively high planning activity needed to produce them. These results are completely in line with the hypotheses formulated above.

4. Human Experiments

As a crucial part of the Grounded Experimental-Simulative Method, experiments serve as a link between Quantitative and Qualitative Communication Analysis and the Theoretical Modeling part of the method.

4.1 Linking Communication Analysis to Experiments

Communication Analysis results in a rich description of the communicative processes going on in the intended research field. Usually, this picture gets even more complicated by different results in different case studies. For theoretical modeling the information resulting from Communication Analysis is often too complex and too vague. What is needed is an evaluation procedure of the theoretical hypotheses which results from the interpretation of the observed behavior sequences. This evaluation procedure is contributed by the experimental method. It includes the following steps.
**Hypotheses.** Clearly formulated hypotheses are one of the first steps towards theory building. Hypotheses are the result of *Communication Analysis* and a necessary precondition for precise experimentation. Hypotheses are formulated as declarative expressions linking two variable groups of the research topic in the form of “If group A has property E1, then group B has property E2.” Usually, the variable group A is termed the independent variable and B the dependent variable. In order to get the A-B relationship in a relatively undisturbed way, other relevant variables C, which may influence it, have to be thoroughly controlled. Thus, hypotheses link dependent and independent variables.

**Research Design.** On the basis of the selected hypotheses the research design spells out the variable types A, B, and C with respect to the experimental setting. If there is more than one variable in the independent group, a factorial design is given. Since in a factorial design the various interactions between the selected variables have to be considered, the number of variables should be restricted to a manageable size. Due to the risk of measurement interferences, the number of dependent variables also should be as low as possible. One of the most difficult experimental tasks consists in controlling the variable group C. If relevant variables are not included in the control, the design may end in an ecologically invalid situation which is not related to the authentic situation observed in *Communication Analysis*. Thus, the research design clarifies the relationships between the various variables involved in the research design.

**Interpretation of Results.** The analysis of the experimental results yields answers to the questions whether the results contradict the hypotheses or not. If the analysis confirms the hypotheses, one is justified to ask for possible generalizations of the original hypotheses and to ask for causal explanations. In cases in which the hypotheses have to be rejected some interpretational work has to be done. What are the possible reasons for the failure? They may be found in the underlying hypotheses or in the experimental design. A crucial part of the experimental method is to give some tentative answers and, even more important, to give some hints about how these problems can be resolved. The overall criterion for these suggestions is their compatibility not only with the experimental results but also with the observations during *Communication Analysis*. Thus, experiments give valuable insight into the mental processes underlying the observable behavior of the subjects.

**4.2 An Experiment: the Form of Questions in Relation to Referential Ambiguity and Time Pressure**

In order to illustrate these functions of the experimental component, we will describe an experiment carried out as part of a larger research project (cf. Kindt, Strohner and Jang 2002). Specifically in the present study we put our focus on the influence of referential ambiguity and time pressure on question strategies. Our hypotheses based on the theoretical approach of situated understanding (e.g. Kindt 1998, 2002) included in addition to the effects of a semantic factor (see Hypothesis 1, section 3.2. above) also a pragmatic factor:

**Hypothesis 2:**

Time pressure has a significant influence on the question strategy: The instruction to react as fast as possible results in more specific descriptions than no such instruction.

The experimental procedure consists of a game of cards between two persons: an experimental confident and a subject without knowledge about the experiment. The cards show arrays of four objects which can be combined in groups of two or three objects, e.g. two large hexagonal bolts, one small hexagonal bolt, and one small round bolt (see figure 1). On each trial the confident names a specific object in the array which the subject has to identify. If the confident says "the small bolt," there are only two alternative target objects. However, if the confident says “the
underspecification

2 candidates

conf: 
S: 
conf: 
S: 
conf:  
S:  
conf:  
S:  
conf = confident  
S = subject

3 candidates

conf:  
S:  
conf:  
S:  
conf:  
S:  
conf = confident  
S = subject
hexagonal bolt,” there are three alternative target objects. If the subject is not sure about the object intended, she or he is encouraged to ask a question for clarification. The type of this question for clarification is the dependent variable in the experiment.

The whole experimental procedure was tape recorded. In addition, the experimenter documented potentially relevant behavior of the subject.

The results (cf. Table 2) were in line with the two hypotheses given above. A referential field of two objects resulted in more specific questions (e.g. “Do you mean the hexagonal or the round one?”) than did a referential field of three objects. In this case, for instance, a preferred question was “Which one do you mean?” Equally, time pressure resulted in more specific questions. These main results of the experiment with humans subjects thus support the hypotheses 1 and 2 from above and they can be transformed into theorems which serve as an input for the theoretical modeling component of the method.

These theorems are also compatible with the results of Communication Analysis of authentic questions for clarification in task-oriented dialogs. Even in cases in which the results obtained from the observation (table 1) seem to be in conflict with the results from the experiment, a more finely grained analysis was able to show the relevance of the experimentally demonstrated strategies.

<table>
<thead>
<tr>
<th>time pressure</th>
<th>number of objects</th>
<th>other</th>
<th>unspecified</th>
<th>specific</th>
<th>sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>no</td>
<td>2</td>
<td>41 (19.5%)</td>
<td>64 (30.5%)</td>
<td>105 (50.0%)</td>
<td>210 (100%)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>42 (18.0%)</td>
<td>93 (39.9%)</td>
<td>98 (42.1%)</td>
<td>233 (100%)</td>
</tr>
<tr>
<td>yes</td>
<td>2</td>
<td>21 (11.2%)</td>
<td>48 (25.5%)</td>
<td>119 (63.3%)</td>
<td>188 (100%)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>30 (13.3%)</td>
<td>71 (31.6%)</td>
<td>124 (55.1%)</td>
<td>225 (100%)</td>
</tr>
</tbody>
</table>

Table 2: Main results in absolute and relative numbers of question types

4.3 Linking Experiments to Theoretical Modeling

Theoretical models consist of a logically consistent network of propositions. As already mentioned, experimental hypotheses are formulated to fulfill these requirements. The basis of experimental hypotheses is the conditional relation between the independent variables A and the dependent variables B with respect to the controlled variables C. Since the knowledge of conditional relations is a crucial precondition for intervening during the practical application of the theory, the confirmation of conditional relations is a central task for scientific research. Once established, the conditional relation or dependency between variables A and B can be interpreted in a more specific way: Often it raises the suspicion of a causal relation or the person modeling bases the assumption of causality on the neutral dependency relation, thus enhancing the theoretical impact.

Somewhat similar to the discussion of the term “causal” analysis is the explanation of the term “mental” analysis. By trying to explain the confirmed relations between the independent and dependent variables, researchers rely on certain intervening variables which characterize internal states of the model. However, the important question is how to interpret these hypothesized structures or processes. Are they believed to be real instances of mental life or do they serve only a formal function in order to connect the input and output of the observed
organism? Researchers have to be careful not to fall back onto the ideologically based positions of mentalism or behaviorism. One procedure generally agreed upon in the experimental community is to stick closely to the operationally defined independent and dependent variables. Anyhow, experiments serve as a valid heuristic basis for formulating hypotheses and intelligent and well-founded speculations on mental structures and processes.

5. Theoretical Modeling

The theoretical modeling component is the central link between the human and computer experiment components. A theoretical model integrates the experimentally confirmed theorems into a coherent system (cf. Eikmeyer, Kindt, Rittgeroth, and Strohner, 2005), which relates the independent variables to the dependent variables. In most cases this is possible only if certain intervening variables between independent and dependent variables are constructed. These hypothetical instances and their functional relations form the creative part of the model and often give reason for critical discussions.

***************
Fig 4 about here
Figure 4: A simple model of the observed question strategies with its independent, intervening, and dependent variables and its main activation routes
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In order to illustrate the theoretical modeling component we start our argumentation with a simple model of the described scenario for clarification requests. The model is given in the form of a diagram (cf. fig. 4), which tries to catch the two theorems which are the main results from the experiment with human subjects. This model has been made up in a way which we think is quite typical for models proposed in psycholinguistics and psychology, but diagrams like these ultimately rely on the interpretation of their readers. Such diagrams certainly have a high heuristic value, but we will propose a simplified input-output model (section 5.1), which is explicit in the sense that it is formulated with mathematical concepts. This guarantees that the model can be subject to an evaluation leading to a refusal or the acceptance for the time being (cf. Eikmeyer 1983, 1988, 2003; Schade and Eikmeyer 1993). Modifications of this model are proposed in order to show that the model constructor has several degrees of freedom and to discuss ways to extend the model (section 5.2). Finally, we derive a full quantitative model from the input-output model (section 5.3).

Before we go into detail, we should make clear what it is that is to be modelled. In a dialog two people communicate. Linguistic acts can be referential (i.e. they indicate which “thing” is being talked about) or predicative (i.e. one says something about a “thing”). A listener can be unable to understand a referential act and then she or he makes a clarification request. The model shows the linguistic structure of this request by indicating whether it is a specific question, an unspecific question, or an expression of some other kind.

5.1 A Simple Input-Output Model

Variables in models have values, but the range of possible values has to be specified as well as the exact way of their combination. The values ‘low’ and ‘high’ used in figure 4 can be meant to represent (a) two discrete values the variable can have or (b) values on a continuous scale ranging from a minimum to a maximum value with ‘low’ being close to the minimum and ‘high’ being close to the maximum. We will set out with the first proposal here and turn to the alternative in section 5.3.

All variables can take a value of their range, however, the assignment of values follows strict rules:
The control variables take their values due to the experimental design, the intervening variables
• (1) receive their values directly from the control variables or
• (2) combine values of intervening values and
the dependent variables receive values from intervening variables or their combinations.

The model has three independent or control variables representing the experimentally controlled factors. According to the rules specified above, the values of the control variables have to be brought from the real world into the model. This happens usually by some arbitrary coding scheme, which, however, has to be strictly applied. We use combinations of characters as values which are chosen relying on mnemonic techniques:

**Communication type.** Communication can occur in different forms. One relevant dimension for these forms is the cooperativeness: political discussions are often very uncooperative, task-oriented communication is usually cooperative. This variable has two possible values: “to” means that the communication type is task-oriented, “nto” means that it is not so.

**Time pressure.** Psychological studies often have come to the result that cognitive processes change when time pressure is exerted on the participants of experiments. We controlled this factor in the above mentioned experiment, because it is a productive source for gaining insight. This variable has two possible values: “tp” means that time pressure is exerted, “ntp” means that it is not so.

**Number of objects.** Problems of reference are one of the most frequent sources for misunderstandings (Bazzanella and Damiano, 1999). Incomplete or ambiguous referential noun phrases can lead to side sequences with clarification requests in case the referential field and the linguistic expression do not simply match. The relevance of this variable became clear already during Qualitative Communications Analysis. This variable has two possible values: “3+” (= three or more) means that there are more than two objects in the semantic field, which can be referents of the linguistic expression. “2” means that there are exactly two objects. This variable will be addressed again in section 5.2.

The model uses three hypothetical intervening variables. We give a heuristic description of their role first and add a precise assignment of values afterwards. We use a numerical coding scheme for the intervening variables, since we want to express the output-relation with the help of mathematical formulae.

**Cooperativeness.** Since a necessary precondition for a successful task-oriented communication is cooperativeness, this intervening variable dominates the whole interaction process. Only if the cooperativeness is high enough, the two variables collaborative efficiency and referential certainty can function in a predictable way. Otherwise, the results will be some other reaction of the subjects. Cooperativeness has value “1”, if the communication type has value “to” and value “0” otherwise.

**Collaborative efficiency.** If the subject tries to react cooperatively and there is a moderately high time pressure, the subject should select the most efficient question strategy. Undoubtedly, the most efficient strategy is to ask a question which includes as much information as possible. In this case, the cognitive effort may be higher, yet the efficiency of the question will also increase. Collaborative efficiency has value “1”, if time pressure has value “tp” and value “0” otherwise.
Referential certainty. If the referential field consists only of two possible objects, the related knowledge of these two objects and their critical differences should be very good. This referential knowledge is an excellent precondition for planning a specific question, e.g. in the form of “X or Y?” If the referential field consists of three or more potential objects, the knowledge is more diffuse and the preferred question strategy might be something like “Which one do you mean?”

Referential certainty has value “1”, if number of objects has value “2” and value “0” otherwise.

Let us begin with making proposal (a) more explicit: For a model with two discrete values we need two discrete entities, let us call them 0 and 1.

Using two discrete values for the range of a variable has a direct impact on the theorems 1 and 2 formulated above, since preferences turn into binary differences as shown below, where we indicated the textual changes for comparison (new text in italics after the older version). The same holds for all variables as there is no “more or less” any longer, but a “yes or no.” The discreteness thus leads to a coarser picture and thus to an oversimplification.

Theorem 1 (oversimplified version)
The relevant situational parameter is the number of possible reference objects: in case of exactly two objects a specific or-question is preferred used, while a more unspecific wh-question is preferred used for more than two possibilities.

Theorem 2 (oversimplified version)
Time pressure has a significant influence on the question strategy: The instruction to react as fast as possible results in more leads to specific questions than no such instruction, while no pressure leads to unspecific questions.

This is the exact meaning of the informal specification given in figure 4 for an oversimplified model with discrete values. The two hypotheses also determine the values of the three dependent variables other reaction, unspecific question, and specific question. The relations between all variables are described formally explicitly and completely by the matrix shown in table 3. The inherent oversimplification has to be kept in mind.

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Intervening variables</th>
<th>Dependent variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Communication type</td>
<td>Time pressure</td>
</tr>
<tr>
<td>1 nto</td>
<td>ntp</td>
<td>3+</td>
</tr>
<tr>
<td>2 nto</td>
<td>ntp</td>
<td>2</td>
</tr>
<tr>
<td>3 nto</td>
<td>tp</td>
<td>3+</td>
</tr>
<tr>
<td>4 nto</td>
<td>tp</td>
<td>2</td>
</tr>
<tr>
<td>5 to</td>
<td>ntp</td>
<td>3+</td>
</tr>
<tr>
<td>6 to</td>
<td>ntp</td>
<td>2</td>
</tr>
<tr>
<td>7 to</td>
<td>tp</td>
<td>3+</td>
</tr>
</tbody>
</table>
Table 3: Value matrix of a discrete model

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<th></th>
<th></th>
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<th>1</th>
<th>1</th>
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<th>0</th>
<th>1</th>
</tr>
</thead>
</table>

The matrix specifies the eight possible combinations of values of the three independent variables in the corresponding rows. Since the dependent variables represent three mutually exclusive ways of behavior, only one of the three final columns can have value 1 in the same row, the others have value 0. Rows 1 to 4 cover theorem 1 from above, rows 5 and 8 cover theorem 2. Rows 6 and 7 are not at all mentioned in figure 4, but in line with the overspecification we do not assume a specific question (but see definition 2c below).

Moreover, one can specify the values of the dependent variables by arithmetic operations with the values 0 and 1 (** indicates multiplication and `-` indicates subtraction. The names of the intervening variables are shortened in order to enhance readability in this and the following definitions.)

**Definition 1:**

\[
\text{other reactions} = 1 - \text{coop} \\
\text{unspecific question} = \text{coop} \times (1 - \text{coll} \times \text{ref}) \\
\text{specific question} = \text{coop} \times \text{coll} \times \text{ref}
\]

However, figure 4 tells us more than the story of the value combination (which it does not even tell in a very explicit fashion). Figure 4 is a flow chart diagram in which all variables appear as boxes: rhombic boxes are used for the three intervening variables mentioned in table 3 and rectangular boxes are used for the others. The rhombic boxes are used in order to describe alternatives to be considered or decisions to be taken. All three such boxes have two possible outcomes. There are, moreover, small operator-boxes which indicate that some process is taking place. One could be inclined to interpret figure 4 in such a way that a high value of cooperativeness is propagated to collaborative efficiency and referential certainty in order to induce the consideration of alternatives. This, however, is pure folklore and it would have to be made explicit in addition to the input-output-behavior. The same holds for the temporal relation between information flow and operations carried out: if they are important, they have to be spelled out explicitly.

**5.2 Modifications of the Simple Model**

Instead of using variables which can take one of two values only, as discussed above, one can equally well use a single variable with more values. In a variant of the model under discussion one could use a single dependent variable named linguistic reaction with three different values, let us say 1, 2, and 3, where 1 would stand for some other reaction, 2 for an unspecific question, and 3 for a specific question. One can easily define this variable with the following equation:

**Definition 2 (a):**

\[
\text{linguistic reaction} = 1 \times (1 - \text{coop}) + 2 \times \text{coop} \times (1 - \text{coll} \times \text{ref}) + 3 \times \text{coop} \times \text{coll} \times \text{ref}
\]

The three terms added in this equation correspond to three dependent variables discussed above, each multiplied with a factor. Since exactly one of them has value 1 and the others have value 0, the desired result is arrived at by adding two zeros and one non-zero value. Using a few mathematical operations yields the shorter version:
Definition 2 (b):

\[ \text{linguistic reaction} = 1 + \text{coop} - \text{coop} \times \text{coll} \times \text{ref} \]

Both definitions will give the value 3 for line 8 of table 3 and the value 2 for lines 5 and 6, and 7. Lines 1 to 4 have the value 1.

Moreover, it is not necessary to use only the natural numbers \((0, 1, 2, 3, \ldots)\) as values. One can use real numbers as e.g. 0.0, 0.5, and 1.0 and define alternatively:

Definition 2(c):

\[ \text{linguistic reaction} = \text{coll} \times 0.5 \times (\text{coll} + \text{ref}) \]

This will yield value 1.0 in line 8 of table 3, value 0.5 for lines 6 and 7, and value 0 in the other lines. Notice that this formula is the first one which connects two variables additively. This always indicate that there is no interaction between the two. This mirrors the fact that there was no tendency towards an interaction between the pragmatic and semantic factors. In oversimplified models this cannot be modeled directly.

Another variant of our model can be arrived at by specifying the substructure of a variable. The variable \textit{linguistic reaction}, for example, can be replaced by a complete language production model. This approach will add lots of new intervening variables and a new dependent variable \textit{linguistic expression}, which does not simply indicate the type of the linguistic reaction by a number, but specifies its wording explicitly. This would certainly be a challenging enterprise, but obviously too complex for this contribution (see Eikmeyer et al. 1999; Schade 1992, 1999; Schade and Eikmeyer 1998 for proposals). A graphical representation of this change and another proposal discussed immediately below can be found in figure 5.

***************

Figure 5 about here

***************

5.3 A Continuous Model

Experiments do not only lead to a description of the outcome of some sort of processing; they often result in absolute numbers of cases and percentages and the task of a model can be to approximate this distribution by an arithmetical law. Such a distribution has been presented above in section 4.2., table 2 as a result of an experiment on the form of questions in relation to \textit{collaborative efficiency} and \textit{number of objects}. The communication type in this experiment was not varied. For this reason the upper half of the table is blank due to a lack of data. In the columns for the independent and intervening variables of the lower half, the value 0.8 is used for a high degree of relevance of one of the variables and the value 0.2 for a low degree. This pair was deliberately chosen to start with. In the lower right-hand corner there is a replica of the percentages given in table 2 as decimal numbers. Thus, the possible range for the values is the closed interval \([0, 1]\).
Table 4: A continuous model for the distribution of reactions/questions

The task is to approximate the values of each of the three dependent variables by a function or formula expressed with the help of the intervening variables. We thus want to arrive at three formulae as in definition 1 above, but this time we do not ask, if we have a certain processing result or not. This time we ask for the probability of a processing result.

With respect to the variable other reaction, the old formula specified for the discrete case can still be used for definition 3, even with a relatively small error (see table 5).

Definition 3:
other reactions = 1 – coop
unspecific question =
0.45 * coop * (1 + coll * ref – coll ) + 0.3 * coll *(1 – ref ) =  
0.45 * coop * (1 – coll * ref – coll ) + 0.3 * coll *(1 – ref )
specific question =
0.8 * coop * (1 + coll * ref – ref ) + 0.42 * (1– coll )*ref - 0.1

The formulae for the two other dependent variables are in fact modifications of the formulae for the discrete case. The overlap is indicated with a gray background and in bold print in definition 3. The formulae for both questions are structurally very similar. This is already to be seen in the data in which both columns have an almost identical value in rows 5 and 6 and 8. The value in row 7 is higher in one case and lower in the other. This is reflected in the formulae by the large bracket after 'coop *': there is a negation and 'coll' subtracted in the formula for unspecific questions, while there is no negation and 'ref' subtracted in the other. Everything following this large bracket has to do with the relation of the value in row 7 to the value in row 6. The formulae specify polynomial functions and the approximation is quite good; see the absolute errors in table 5. Definition 4 results from the application of simple algebraic laws to the formulae from definition 3. This definition shows the similarity and differences between the two variables in still another way.

Definition 4:
unspecific question =
0.45 * coop * (1 – (1 – ref ) * coll ) + 0.3 * coll * (1 – ref )
specific question =
0.8 * coop * (1 – ref * (1 – coll ) ) + 0.42 * (1 – coll ) * ref - 0.1
An important difference between the discrete model and the continuous one is that for a model with two values 0 and 1 (or true and false) there is an algorithm which allows to construct a formula out of a table as the six columns on the right of table 3. For the continuous model there is no such algorithm, but methods of numerical mathematics can be applied. Sometimes it even suffices to approximate by intelligent guessing and trial-and-error.

This discussion is by no means the end of the story. The model approximates the distribution of different kinds of linguistic reaction with a constant value 0.80 for cooperativeness and four combinations of 0.2 and 0.8 for the two remaining intervening values. Nothing is known empirically about other combinations, but definition 3 makes a theoretical prediction, which can be tested empirically in the next round of the methodological cycle shown in figure 1.

6. Computer Simulation

At this stage we have transformed the model into a formal system and now it has to be implemented as a computer program. We do this by following the guidelines proposed by Marr (1982).

A model is a reduced and simplified description of a section of reality (cf. Eikmeyer 2003). There is a similar relation between the model and reality. This can be characterized by the fact that the model highlights the essential aspects while it neglects the unessential ones. In addition to this relation the connection between a model and its theory has to be kept in mind. This connection can be better understood through the three levels of description proposed by Marr (1982) for information processing models. Such a process takes information as input and turns it into output. On the first level, a computational theory has to be specified, i.e. a theory which describes what the transition from input to output aims at and why this is suitable. The latter means the specification of the necessary and sufficient conditions of the transformation. These are based on empirical evidence of the process to be described. The second level of description asks for both the representations of the information assigned to the input and the output variables. Moreover, it requires the specification of an algorithm for the transition in the formulation of which the intervening variables play a central role. These two levels can be called the model. Marr’s third level, finally, deals with the physical realization of the algorithm. If this realization is done by a computer, it is called a simulation.

The model shown in figure 4 is an input-output system, in which the control and independent variables make up the input and the dependent variables make up the output to be specified on
the first level. The intervening variables and their connections are used to formulate the algorithm for the transition from input to output. The results which the algorithm has to deliver are specified in either table 1 or 3. Definition 1 specifies the formulae to which the algorithm can apply. Since the values for the input and the output have been specified and since the algorithm is sufficiently characterized, all requirements for the second level of description have been fulfilled.

Once a model has been specified, it has to be evaluated, i.e. it has to be found out, in what respect the model correctly describes reality and in what respect it is false. A computer simulation can be used as a tool for model evaluation. Tests can be repeated almost endlessly, all parameters can be modified, and new hypotheses or predictions can be derived. For a simple model, as the one discussed here, a spreadsheet program is all one needs:

- enter the values for the columns of the intervening variables from table 3 into columns A, B, and C, respectively
- enter ‘=1-A1’ into field D1, copy it and paste it into fields D2 to D8
- enter ‘=A1*(A1-B1*C1)’ into field E1, copy it and paste it into fields E2 to E8
- enter ‘=A1*B1*C1’ into field F1, copy it and paste it into fields F2 to F8

According to Popper (1971), falsifiability is a minimal requirement for scientific models. Marr (1982) claims that modeling has to aim at the specification of representations and algorithms. Johnson-Laird (1988, p.52) further adds that “... theories of the mind should be expressed in a form that can be modelled in a computer program.”

7. Conclusions

The Grounded Experimental-Simulative Method can be looked at from several perspectives. We will start with a justification for it from a narrower linguistic perspective and then turn to the broader context of cognitive science in general.

The methodology proposed above tries to clarify which significance the methods used for structure- and process-analysis in the different branches of linguistics have for an integrated system-theoretical development of models. These methods are – in contrast to common appreciation and practice – not to be regarded as concurrent but as complementary. Our project was able to show that the analysis of the structure of communication has to combine communication analysis (qualitative and quantitative) with grammar- and semantic-theoretical methods. At the same time, the relevance of postulated structures in language and communication can be backed up by process-analytic studies of the systems involved. On the other hand, psycholinguistic experiments might have little impact if they are not based on a differentiated language- and communication-analytical fundament.

The future development of cognitive sciences depends not only on progress in theory construction but also on methodological innovation. We need new methodological concepts and procedures which will contribute to a better integration of the cognitive subdisciplines. This paper presents one possible strategy of relating some of the disciplines to each other. Specifically, we propose that communication analysis, experimental research, and computer simulation cooperate in order to build up a new integrated method named Grounded Experimental-Simulative Method.

The core of this new approach consists of a close relation between human and machine experiments. The obligatory link between these two types of experiments results from precise theoretical models, which can be formalized in adequate computer programs. If the classic experimental-simulative method is applied to complex discourse, it must be grounded. The methods of communication analysis have to be included in order to relate the human
experiments to ecologically valid discourse. Since authentic corpora are hard to analyze due to their complexity, computer assisted analysis of these corpora is added to the method.

The *Grounded Experimental-Simulative Method* is not only able to contribute to the methodological integration of cognitive sciences but can also form a basis for theoretical progress. If all authors in cognitive sciences could agree that good theories should be transformed into formal models, which are to be confirmed in human and computer experiments, then efficient criteria for theory testing would be available. In our opinion these criteria will be better met by system theoretically derived models than by other types of theory.

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**References**

Bazzanella, C. and Damiano, R.

Eikmeyer, H.-J.

Eikmeyer, H.-J. and Schade, U.


Johnson Laird, P.

Kindt, W.

Kindt, W., Strohner, H. and K. Jang
Popper, K.

Rittgeroth, Y., Birkemeier, S., Poncin, K. and Kindt, W.

Schade, U.

Schade, U. and Eikmeyer, H.-J.