A Project Summary

Integrative Approaches to Communicative Interaction
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It is difficult to think of a research area that is now less integrated than the scientific study of communicative interaction. Such research takes place in disciplines including Anthropology, Biology, Computer Science, Electrical Engineering, Linguistics, Neurology, Philosophy, and Psychology, with researchers in any of these disciplines focusing on problems including animal communication, linguistic and non-linguistic communication among humans, human-computer interaction, and human communication disorders, while using methods ranging from field observation to single-cell recording, and from game theory to Hidden Markov Models.

We propose to establish an integrative educational foundation for students in eight different Penn graduate groups interested in empirically-based scientific studies of communicative interaction. This will include two new common courses in mathematical foundations, a new jointly-managed program of summer research projects, and an additional year of educational and research “cross-training” for each student.

The new Mathematical Foundations courses will be a two-semester sequence, based on practical computer exercises, drawn from real problems in the associated disciplines. The cross-training year will fund students to take courses and do a research project in an area outside of their core discipline. The summer research program will enable students to learn a variety of perspectives and methods in other disciplines via practical experience.

Students will learn to do research based on observations of natural behavior (as in ethology, corpus linguistics and clinical observation), as well as research in a laboratory setting (using both behavioral and physiological measures), and research based on algorithmic models of interacting agents. Students’ common mathematical foundation will enable them to perform sophisticated analyses of signals, and to model the form and information flow of behavioral sequences, whether the object of study is a conversation among friends, a negotiation with a computer to obtain services, or a baboon barking bout.
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*Computer and Information Science*
Empirically-based scientific study of communicative interaction now takes place in many different disciplines. At Penn, relevant graduate programs include Anthropology, Biology, Computer Science, Electrical Engineering, Linguistics, Neurology, Philosophy and Psychology. Relevant research areas include animal communication ([1], [2]), linguistic and non-linguistic communication among humans ([3], [4], [5], [6]), human-computer interaction ([7], [8], [9]), and human communication disorders ([10], [11]). Depending on the discipline, a wide range of methods and tools may be used. Data may come from ethological field observation, ethnographic participant-observation, clinical or sociolinguistic interviews, psychological tests, corpora of transcribed conversations ([12], [13]), controlled behavioral experiments or physiological recordings, or computer simulations. Tools include quantitative analysis of recorded (acoustic, visual or physiological) signals, synthesis of signals for perceptual experiments, various sorts of inferential and exploratory statistics, and hand-built or statistically trained grammatical models ([14], [15]).

The different disciplines focus to some extent on different basic problems, but their methods and tools differ even more. These differences are largely complementary rather than contradictory, and researchers often find themselves adapting or re-inventing techniques that have been perfected in other disciplines. Psychologists find themselves doing signal processing, computer scientists wind up doing ethological observations on task-oriented dialogues, linguists start experimenting with machine learning, neurologists begin doing discourse analysis, and so on.

This long-standing cross-disciplinary borrowing reflects the fact that none of the traditional academic disciplines are a particularly good fit to the study of communicative interaction. As a result, researchers at all levels struggle as outsiders to understand or re-develop concepts, methods and techniques whose natural home is in other disciplines. The effort is needlessly difficult, and there is often an initial period of failure or poor-quality success. What is worse, some interesting strands of research in this area are neglected, because they are cross-disciplinary in their conceptual foundations, not just in their methods.

Building on Penn’s strong research groups within the relevant disciplines, and on a well-established tradition of cooperation among them, we propose to establish an integrative educational foundation for students in several different Penn graduate groups interested in empirically-based scientific studies of communicative interaction. Penn is an ideal home for such a graduate training program, with internationally-renowned faculty in all the subdisciplines mentioned above, and an excellent record of turning out students who go on to be intellectual leaders themselves. Given space constraints, we will cite only a few of the current faculty who are participants in the proposed program: Dorothy Cheney (Biology) and Robert Seyfarth (Psychology), leaders in the fields of ethology and animal communication; William Labov (Linguistics), founder of the discipline of quantitative sociolinguistics; Aravind Joshi (Computer Science), a key figure in computational linguistics and one of the inventors of centering theory, the most influential computational account of coherence in discourse; Ellen Prince (Linguistics), a dominant figure in linguistic pragmatics, and Lila Gleitman (Psychology), renowned for ground-breaking work on child language acquisition.

Students in this program, whatever their home discipline, will share two new common courses in mathematical foundations of communication, will participate in a new jointly-managed program of summer research projects, and will spend a year in educational and research cross-training. Such a program would give graduate students the tools necessary to integrate more effectively the relevant methods of these related disciplines – methods that in many cases are necessary for the ultimate success of their project.

To illustrate this more concretely, we sketch three hypothetical graduate student research projects, and show in each case how the student’s participation in the proposed training program would affect the outcome. In fact, these examples are based loosely on recent research here at Penn, where partial solutions were found by somewhat more ad-hoc cross-disciplinary faculty cooperation, or by individual student cross-training.

1. An animal communication student has developed an annotated corpus of baboon vocalizations, and
is particularly interested in one of the sounds produced by adult males, a loud two-phased bark known as a "wahoo." This call appears (along with other types of calls) during predator encounters, during inter-group encounters, and during aggressive interactions with other males. Its acoustic character also varies, in terms of the relative length and amplitude of the two parts, the relative sharpness of the onset ("wahoo" vs. "bwahoo"), the F0 contour, and in other ways. The student’s questions include whether this is really a single type of call, and what relationship its acoustic variation has to its different contexts of use. To address these questions, she needs to design and implement some signal processing functions of a kind that are familiar to phoneticians and speech engineers. Having taken our mathematical foundations course, and done a research rotation in a phonetics lab, she is easily able to annotate her audio files at key time points, to try out various signal analysis functions, and to go over her results with an expert in acoustic pattern recognition.

2. A computer science student working on virtual human behavior within graphical user interfaces needs to simulate the natural eye movement patterns of an avatar during conversation. In particular, she needs to uncover the information content of eye movements in conversation, such as for expressing emotion and possibly for reference to objects in the world. She would like to design studies to collect such data, but as a computer science student, she would normally have no experience in experimental design, nor in meeting Institutional Review Board (IRB) guidelines for research with human subjects. However, as a result of the IGERT program she has taken relevant graduate coursework in psychology, including a recently developed graduate-level course in research methods. In addition, she spent a research rotation in the psycholinguistic eye movement lab at Institution for Research in Cognitive Science (IRCS), where she helped run an experimental study of eye movements in face-to-face conversation. Therefore she is easily able to design and collect a conversational eye-movement database, from which she derives improved avatar eye-movement rules. It turns out that her work also leads to benefits for the psycholinguists, who start using virtual humans for controllable stimulus displays in research on the dynamic effects of eye movements in conversation.

3. A psychology student is interested in examining how the distributional properties of lexical items in child-directed speech could inform verb learning and/or modulate the development of language parsing procedures. However, he notes that the linguistic input to the child is riddled with disfluencies (ums, ahs, restarts, and frequent repairs). He wonders whether these disfluencies act as disruptive noise, or could instead be informative to a device that is learning to analyze the input structurally. As an IGERT graduate student, he has learned enough in the mathematical foundations course to investigate this question by comparing the behavior of statistical grammar-learning models provided with linguistic input with the disfluencies kept in or removed. In fact, he has already been exposed to some research from the speech recognition field that bears on these questions, and needs only to adapt the methods and apply them to published child language corpora. The speech engineers were interested in perplexity measures of language models for automatic speech recognition algorithms, but this student is able to frame, compare and test different hypotheses about human speech processing and its development.

c Major Research Efforts

Our theme is "communicative interaction," where the interacting entities may be human beings, other animals, or algorithmic agents. We feature three types of research, typically in combination: evidence from records of communication in ecologically natural settings; evidence from controlled behavioral and physiological experiments; and use of mathematical models to analyze communicative behaviors, social and environmental contexts, and the connections between them.

Communicative interaction involves behavior patterns that are adapted for natural social and environmental circumstances. Any approach that ignores this fact risks extrapolating from partly artifactual relations between limited, denatured behaviors and limited, denatured contexts. At the same time, the space of
possible behaviors and possible contexts is usually so large that it cannot be explored adequately without experimental intervention to create controlled datasets. Furthermore, many interesting sources of evidence are only available in a laboratory setting: controlled measurement of gaze location or reaction time, physiological recordings, functional brain imaging, and so forth. Thus, successful research programs in this area often go back and forth between field and laboratory, or between passive observation and active experimentation ([1], [2], [3], [16], [4]).

Whether the data is from the field or the laboratory, improved understanding of communicative interaction depends crucially on mathematical modeling at several levels. The communicative signals themselves – whether acoustic, visual or otherwise – need to be carefully analyzed and synthesized. Human language involves potentially complex lexical and grammatical organization ([17], [14], [15]), and communicative systems of other species may also have properties that motivate a grammatical analysis of sequential structure ([18]). Expectations created by the statistical structure of large-scale experience of human text and speech are believed to play a key role in human language processing ([19], [20]), and animal systems seem to have similar properties ([21]). Human language learning, of course, depends on experiencing the relations among speakers, utterances and settings, and work on vervet monkey alarm calls shows that even for apparently instinctive animal vocalizations, referential details need to be learned by experience (e.g. the aerial predator alarm call should be given for eagles, but not for storks). At larger time scales, humans show complex discourse and narrative structures that vary to a considerable extent from one culture to another, and therefore must be modeled as learned patterns rather than solely as by-products of general laws of communication. At least some animal species (e.g. some whales and songbirds) have temporally-complex vocal displays with a similarly “cultural” patterning ([22]).

Several recent developments make this integrative approach to communicative interaction increasingly promising. First, bigger, cheaper and faster computers (and other digital hardware) make the creation, publication and analysis of large annotated corpora easier and also more useful ([12]). This has already revolutionized fields as disparate as speech recognition and child language acquisition, and a similar process is underway in studies of animal communication and human discourse structure. Advances in pattern recognition, sensor arrays and so on mean that the acquisition of very large databases can be increasingly automated.

At the same time, new mathematical techniques offer new analytic possibilities. Probabilistic latent variable models and other latent representations have been widely used in psychology and the social sciences. Separately, researchers in mathematical statistics, pattern recognition and machine learning have created a new body of mathematical tools and algorithms for latent representations, including Hidden Markov Models, the expectation-maximization method for parameter estimation, Bayes net and random field models and their algorithms, independent components analysis, model selection techniques based on statistical learning theory, as well as efficient computational implementations of parameter estimation and statistical inference algorithms.

These advances have already enabled improved modeling of many biological and social phenomena, including speech, document word distributions, information networks, syntactic patterns in language, neuron firing patterns, and biological sequences. By viewing language production and comprehension as branching processes with latent state variables, we can bridge symbolic generative theories of linguistic competence with probabilistic models of linguistic behavior. More generally, modeling of communication can take advantage of structured latent variable models to represent not directly observable factors in communication, such as the abilities and preferences of participants, their attention state, or their place in social networks.

In general, modern mathematical and computational concepts and tools provide an important common language for psychologists, linguists, social scientists, biologists, neuroscientists and computer scientists. These techniques permit effective exploration of large, heterogeneous digital datasets, development of probabilistic models that relate observable variables to hypotheses about internal representation, and use of
acoustic or visual simulations to probe the mechanisms for information flow in communicative interaction.

d Education and Training

The proposed graduate training program would provide students with an educational foundation necessary to accomplish integrative research on communicative interaction. This would include: (1) Two new common courses in the mathematical foundations of communication, (2) a jointly-managed program of summer research projects, (3) an additional year of educational and research “cross-training” for each student, and (4) educational opportunities to promote interactions with researchers from other institutions.

Mathematical Foundations. The new Mathematical Foundations courses will form a two-semester sequence, based on practical computer exercises dealing with real problems in the associated disciplines. The course, taught in a proposed computer/media lab setting, will cover relevant aspects of a wide range of topics, including information theory, game theory, formal language theory, automata theory, the logic of information flow, signal processing, machine learning, and probabilistic models. Despite the great range of material and of student backgrounds, experience in teaching a subset of this material to a similar range of students convinces us that all students can get a basic practical understanding, while even the best-prepared students broaden and deepen their knowledge.

This common mathematical foundation will enable students to perform sophisticated analyses of signals and to model the form and information flow of behavioral sequences, whether the object of study is a human conversation, a negotiation with a computer to book an airplane flight, or a baboon barking bout. These two semesters obviously cannot substitute entirely for the dozen or more semesters that today would be required to cover a similar range of topics. However, they can give students the ability to understand and implement algorithms from published descriptions, especially given appropriate libraries of basic function, and to discuss alternative approaches with experts in a well-informed way.

Summer Research Program. Funds from the grant will be used to support a summer research program, in which students will learn a variety of perspectives and methods in other disciplines by practical experience, as in medical school rotations. Students will be able to experience research based on observations of natural behavior (as in animal field research, corpus linguistics and clinical observation), as well as research in a laboratory setting (using both behavior and physiological measures), and research based on algorithmic models of interacting agents. In most cases, these experiences will be laboratory or field apprenticeships, in which students help to carry out an existing research project rather than designing one of their own. The students involved in the summer program will meet regularly, to get special training (such as in research ethics and IRB procedures), to hear research presentations, and to make presentations on the projects they are involved in.

Cross-Training Year. The cross-training year will fund students to take courses and to do a larger research project in an area outside of their core discipline. The research project will often be an aspect of the student’s dissertation research, viewed from the perspective of another discipline. For example, a psycholinguistics student interested in the role of facial expressions in conversation might spend a year taking courses in computer graphics, and working on improved control of facial animation for creation of stimulus materials. A neuroscience student interested in clinical aprosodias might spend a year studying the form and function of normal prosody, and working on reliable quantitative measures of hypo- and hyper-prosodicity. This aspect of the training will be planned on a case-by-case basis.

External Training Opportunities. A small amount of grant funds will be used to promote training opportunities not available from existing Penn faculty. First, distinguished researchers from other institutions will occasionally be invited to provide graduate students and faculty with intense 1 to 2 week seminars on relevant topics. This would offer students perspectives different from those of Penn faculty, and would foster collaborations with researchers in other institutions. Second, we will encourage graduate students affiliated
with the program to help organize interdisciplinary workshops on topics that they propose. This will expose students to a wider range of perspective, but will also involve them in actively shaping the research agenda in developing areas. These workshops would take place at IRCS, with local arrangements managed by the IRCS staff. Third, students in this program will form an annual regional graduate student conference, with participation by students from other universities as well as Penn.

**Diversity Promotion.** Because the proposed program will involve students from up to eight different graduate groups, the first mode of diversity promotion is provided by the recruiting programs of these diverse groups. In addition, we will recruit specifically for the IGERT program through outreach methods such as the undergraduate summer workshop run annually by the Institute for Research in Cognitive Science and the Center for Cognitive Neuroscience. Finally, the proposed program has an in-built propensity to promote diversity, because the different disciplines involved have very different distributions of sex and ethnicity.

**Research Ethics Training.** The question of research ethics is especially urgent in interdisciplinary work, because students in disciplines such as computer science may get little or no training in the ethical treatment of humans and animals in research. Yet as a result of the cross-disciplinary pressures that we have noted, these students already may launch themselves into observational and even experimental research with little understanding or awareness of IRB guidelines for such research. Students also need to learn where the ethical boundaries are in ensuring honest reporting of empirical evidence. When a program doesn’t work, one just fixes the bug without mentioning it. When an experiment doesn’t work, it may not be appropriate simply to “fix” it, without also reporting the failure.

We will put several training mechanisms in place to address these issues. First, the summer research programs will include formal workshops on IRB guidelines for human and animal research, and on more general ethical issues. In addition, students involved in cross-training will be exposed to the ethical guidelines of the related discipline, simply by the close interactions established by working within an existing research group. Supervising faculty will take care to stress this aspect of the training.

e  Management and Evaluation

The PI together with the co-PI’s will be responsible for all aspects of the program, and will make decisions about the resource allocations, overall policy decisions, overall monitoring of the budget, and setting up of special committees as needed for the development of the educational programs. However, we expect and will encourage active involvement by other faculty participants, and will set up an advisory committee including at least one member from each associated subdiscipline, to set policy for the overall program and to review student cases.

Infrastructure and administrative resources will be provided by IRCS (Institute for Research in Cognitive Science), which has been funded since 1992 by an NSF STC grant. IRCS was founded by Penn in 1990, and will continue to exist after the expiration of the NSF STC grant in 2002. Liberman, who is a co-PI, is the Director of IRCS, whose staff consists of an Administrative Director and several administrative and technical support staff. The Administrative Director will be responsible for the detailed monitoring of the budget, assisting in evaluations, and in the preparation of relevant reports. The staff members will provide administrative support for the interdisciplinary seminars and the management of the IGERT educational programs described in this proposal.

IRCS has an external advisory board which meets roughly once a year. We will ask a subset of this committee to look specifically at the IGERT program. In addition, review of IGERT will form part of the regular internal review of IRCS, during which the opinions of participating departments and participating students are actively solicited.
f Expected Resource Commitments

There are two relevant multi-site projects that are partly based at Penn, whose activities will mesh helpfully with the proposed IGERT program: the Linguistic Data Consortium (LDC) and the TalkBank Project.

The LDC (http://www.ldc.upenn.edu) is an open consortium of universities, companies and government research laboratories. It creates, collects and publishes speech and text databases and other resources for research and development purposes. Since its foundation in 1992, the LDC has published nearly 200 digital databases, which have been delivered to researchers at nearly 1,000 institutions. Many LDC databases involve human/human or human/computer interaction, sometimes with linguistic or functional annotation as well as audio or video signals and transcripts. The LDC will provide funding to create and publish additional materials suitable for teaching and student research on communicative interaction. The fact that Penn is the LDC’s host institution, and its director is one of this proposal’s co-PIs, will facilitate this cooperation.

TalkBank (http://www.talkbank.org) is an interdisciplinary research project funded by NSF, and hosted by CMU and Penn. Two of TalkBank’s co-PIs are among the organizers of this proposal. The goal of TalkBank is to foster fundamental research in the study of human and animal communication, by providing standards and tools for creating, searching, and publishing primary materials via networked computers. So far, efforts have focused on five disciplinary groups: animal communication, classroom discourse, linguistic exploration, gesture and sign, and text and discourse, in additional to work on generally-applicable standards, libraries and programs. Students in the proposed IGERT program will participate in TalkBank working groups, attend TalkBank workshops, and have the opportunity to work with TalkBank researchers from many other institutions. TalkBank will also serve as a medium to publicize the proposed IGERT-supported integrative approach to graduate training.

In addition to these two organized inter-institutional entities, participating faculty have many active research ties with companies and government laboratories, where IGERT-program students will be placed for summer or term-time research positions, as many students have been in the past. These include AT&T Research, ARL, BBN, Bell Laboratories, CHI Systems, CoGenTex, Face2Face Inc., General Electric Corp. Research, IBM, Intel, Lockheed-Martin (Camden), Lockheed-Martin (Moorestown), Lockheed-Martin (King of Prussia), Microsoft Research, MITRE, NASA Ames, NASA Johnson Space Center, NIST, Unigraphics, and Xerox PARC.
References


