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CLiFF Notes: Research in the Language Information and Computation Laboratory of The University of Pennsylvania

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CLiFF Notes: Research in the Language Information and Computation Laboratory of The University of Pennsylvania

Abstract

This report takes its name from the Computational Linguistics Feedback Forum (CLIFF), an informal discussion group for students and faculty. However the scope of the research covered in this report is broader than the title might suggest; this is the yearly report of the LINC Lab, the Language, Information and Computation Laboratory of the University of Pennsylvania. It may at first be hard to see the threads that bind together the work presented here, work by faculty, graduate students and postdocs in the Computer Science, Psychology, and Linguistics Departments, and the Institute for Research in Cognitive Science. It includes prototypical Natural Language fields such as: Combinatorial Categorial Grammars, Tree Adjoining Grammars, syntactic parsing and the syntax-semantics interface; but it extends to statistical methods, plan inference, instruction understanding, intonation, causal reasoning, free word order languages, geometric reasoning, medical informatics, connectionism, and language acquisition. With 48 individual contributors and six projects represented, this is the largest LINC Lab collection to date, and the most diverse.

Comments

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CLiFF Notes:
Research In The
Language, Information and Computation Laboratory
Of The University of Pennsylvania

MS-CIS-93-52
LINC LAB 249

Faculty
and
Graduate Students

University of Pennsylvania
School of Engineering and Applied Science
Computer and Information Science Department
Philadelphia, PA 19104-6389

June 1993

CLiFF Notes

Research in the Language, Information and Computation Laboratory of the University of Pennsylvania

Annual Report: Spring 1993, No. 3

Technical Report MS-CIS-93-52
LINC Lab 249

Department of Computer and Information Science
University of Pennsylvania
Philadelphia, PA 19104-6389

Editors: Libby Levison & Matthew Stone

Contents

Part I
Introduction

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It may at first be hard to see the threads that bind together the work presented here, work by faculty, graduate students and postdocs in the Computer Science, Psychology, and Linguistics Departments, and the Institute for Research in Cognitive Science. It includes prototypical Natural Language fields such as: Combinatorial Categorial Grammars, Tree Adjoining Grammars, syntactic parsing and the syntax-semantics interface; but it extends to statistical methods, plan inference, instruction understanding, intonation, causal reasoning, free word order languages, geometric reasoning, medical informatics, connectionism, and language acquisition. With 48 individual contributors and six projects represented, this is the largest LINC Lab collection to date, and the most diverse.

Nevertheless, this volume does present related research undertaken in a common spirit. Participants share an interest in the representations and mechanisms that make reasoning and communication possible; they just approach this interest from very different perspectives. The example of language—don't forget that in a language, information and computation lab, language IS just an example which epitomizes but does not exhaust such representations—illustrates both this variety among our approaches and its importance. Language is a psychological function, language is amenable to concise and elegant descriptions at many levels, and people put into their use of language all their intelligence and creativity; at the same time, a comprehensive model of language must integrate information from all these perspectives.

Naturally, this introduction cannot spell out all the connections between these abstracts; we invite you to explore them on your own. The abstracts describe the researchers' many areas of investigation, explain their shared concerns, and present some interesting work in Cognitive Science. We pride ourselves on the close working relations among research groups, as we believe that interdisciplinary communication and research not only improves the quality of our work, but makes much of it possible.

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Part II

Abstracts

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Graphical Behaviors and Animated Agents

Keywords: Graphics, Animation

One concern of the Computer Graphics Research Lab is in simulating human task behavior and understanding why the visualization of the appearance, capabilities and performance of humans is so challenging. Our research has produced a system, called *Jack*, for the definition, manipulation, animation and human factors analysis of simulated human figures. *Jack* permits the envisionment of human motion by interactive specification and simultaneous execution of multiple constraints, and is sensitive to such issues as body shape and size, linkage, and plausible motions. Enhanced control is provided by natural behaviors such as looking, reaching, balancing, lifting, stepping, walking, grasping, and so on. Although intended for highly interactive applications, *Jack* is a foundation for other research.

The very ubiquitousness of other people in our lives poses a tantalizing challenge to the computational modeler: people are at once the most common object around us, and yet the most structurally complex. Their everyday movements are amazingly fluid, yet demanding to reproduce, with actions driven not just mechanically by muscles and bones but also cognitively by beliefs and intentions. Our motor systems manage to learn how to make us move without leaving us the burden or pleasure of knowing how we did it. Likewise we learn how to describe the actions and behaviors of others without consciously struggling with the processes of perception, recognition, and language.

Present technology lets us approach human appearance and motion through computer graphics modeling and three-dimensional animation, but there is considerable distance to go before purely synthesized figures trick our senses. We seek to build computational models of human-like figures which manifest animacy and convincing behavior. Towards this end, we

- Create an interactive computer graphics human model.
- Endow it with reasonable biomechanical properties.
- Provide it with "human-like" behaviors.
- Use this simulated figure as an agent to effect changes in its world.
- Describe and guide its tasks through natural language instructions.

There are presently no perfect solutions to any of these problems; ultimately, however, we should be able to give our surrogate human directions that, in conjunction with suitable symbolic reasoning processes, make it appear to behave in a natural, appropriate, and intelligent fashion. Compromises will be essential, due to limits in computation, throughput of display hardware, and demands of real-time interaction, but our algorithms aim to balance the physical device constraints with carefully crafted models, general solutions, and thoughtful organization.

The *Jack* software is built on Silicon Graphics Iris 4D workstations because those systems have the 3-D graphics features that greatly aid the process of interacting with highly articulated figures such as the human body. Of course, graphics capabilities themselves do not make a usable system. Our research has therefore focused on software to make the manipulation of a simulated human figure easy for a rather specific user population: human factors design engineers or ergonomics analysts involved in visualizing and assessing human motor performance, fit, reach, view, and other physical tasks in a workplace environment. The software also happens to be quite usable by others, including graduate students and animators. The point, however, is that program design has tried to take into account a wide variety of physical problem-oriented tasks, rather than just offer a computer graphics and animation tool for the already computer-sophisticated or skilled animator.

As an alternative to interactive specification, a simulation system allows a convenient temporal and spatial parallel "programming language" for behaviors. The Graphics Lab is working with the Natural Language Group to explore the possibility of using natural-language instructions (such as those found in assembly or maintenance manuals) to drive the behavior of our animated human agents. (See the CLiFF note entry for the AnimNL group for details.)

Even though *Jack* is under continual development, it has nonetheless already proved to be a substantial computational tool in analyzing human abilities in physical workplaces. It is being applied to actual problems involving space vehicle inhabitants, helicopter pilots, maintenance technicians, foot soldiers, and tractor drivers. This broad range of applications is precisely the target we intended to reach. The general capabilities embedded in *Jack* attempt to mirror certain aspects of human performance, rather than the specific requirements of the corresponding workplace.

We view the *Jack* system as the basis of a virtual animated agent that can carry out tasks and instructions in a simulated 3D environment. While we have not yet fooled anyone into believing that the *Jack* figure is "real," its behaviors are becoming more reasonable of its repertoire of actions more extensive. When interactive control becomes more labor intensive than natural language instructional control, we will have reached a significant milestone toward an intelligent agent.

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Discourse Processing as Linguistically Constrained Inference

Keywords: Discourse, Anaphora Resolution, Theorem Proving

An immediate problem of understanding discourses of more than one sentence is determining how one sentence is connected to another; one well-known type of connection is made through the reference of pronouns and definite NPs. Such expressions fall into a class called DEPENDENT EXPRESSIONS whose common trait is that they rely on some part of the prior discourse for a part of their meaning. One way these dependencies can be recovered in discourse processing is by constructing a deduction of the discourse presuppositions of dependent expressions from the content of the prior discourse. This approach reduces discourse processing to theorem proving as seen in Hobbs [4]. No less important than the content of the prior discourse in resolving anaphoric dependencies is knowledge about the world. The theorem proving approach is especially compelling because it can naturally integrate the information in the prior discourse with world knowledge while performing inference.

My research involves extending the approach in the following ways:

- Taking advantage of discourse structure to both constrain the inference process and account for saliency effects. I use a theory of local discourse structure based on Centering Theory [2].
- Attending to the uniqueness/non-uniqueness presuppositions of dependent expressions.
- Positing a model of discourse coherence based on inferential effort, following the lead of Joshi and Kuhn [5].
- Capturing salience through a psychological model of the recoverability of entities from descriptions for the hearer. Traditional approaches [3, 1] capture salience absolutely, in terms of properties of the search space for possible discourse referents: more salient ones lie closer in this space than do less salient ones. My goal is to replace this notion of "salience as search" with the idea that salience corresponds to ease of access in the hearer's mind: since this access depends on the key used to retrieve the referent, the salience of an entity on this view is a function not only of the subdomain of the discourse model discourse where the entity is found, but also of the description that picks it out. For example, an entity counts as salient by this definition even if last mentioned much earlier in the discourse, so long as a sufficiently rich definite description is used to pick it out. That same entity would not be salient if a descriptively impoverished pronoun were used.

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Phonetology

Keywords: Phonetics, Phonology, Typology

My work focuses on the use of phonetics and cross-linguistic typologies in constraining phonological representation. For example, major innovations in feature representation are sometimes proposed on the basis of narrow databases or processes which are not unambiguously phonological (as opposed to phonetic). While this is unavoidable in some cases and may be desirable in the short term, phonology must broaden and deepen the database for which its theorizing is accountable. This means we must make serious and responsible scholarly efforts to bring increasing amounts of data from the descriptive domain into the theoretical one, and at the same time devise mechanisms for the adequate evaluation of this data. A phonetic understanding assists in such evaluation, and can contribute towards some measure of the plausibility of phonological representation motivated by such data. The development of phonological typologies is likewise crucial in constraining the power of abstract representation.

To date, my pursuit of this research program has involved acoustic and phonological analysis of data from a number of indigenous languages of the Pacific Northwest, particularly Salish. Developing a cross-linguistic context for the phonological phenomena found in some of these languages requires fairly extensive comparison with the phonetics and phonology of Semitic languages. Upon analysis of Salish, the "standard" characterization of a number of segment-types (pharyngeals and laryngeals in particular) appears unmotivated and some fundamental aspects of feature organization are challenged.

In general terms, the contribution made by pursuing theoretical work in conjunction with detailed empirical investigation is clearly demonstrated by findings of the sort outlined above. However, it is sobering to realize that the opportunities to record data from many (indigenous) languages are rapidly diminishing, and our knowledge of the range of data that our theories must accommodate remains desperately incomplete.

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Automatically Learning Structural Information About Language

Keywords: Automated Language Learning

I have developed a transformation-based error-driven technique for learning structural information about a language from a small corpus of annotated text. This technique has been successfully applied to morphology discovery, word classification, part of speech tagging, prepositional phrase attachment, and parsing (both bracketing text and labeling constituents), and I am currently examining the possibility of applying this technique to a number of other problems. In work done with Eric Haeberli and Tony Kroch, this new technique is currently being used to annotate Old English with a small amount of manually annotated text. I am also examining an information-theoretic approach to parameter setting (work with Shyam Kapur). In particular, we implemented an algorithm for setting word-order parameters of a language based upon easily-computed statistical properties of a sample corpus for the language and have tested this algorithm on a large number of languages.

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Centering Null Arguments in English

Keywords: Discourse, Centering, Conceptual Structures

This work is part of my thesis on the grammatical and discourse properties of null arguments in English.

In English, as in other languages, the particular grammatical representation of a discourse entity in an utterance indicates something about both its saliency and its role in the structure of the discourse at that point. For arguments, grammatical representation refers to such factors as whether an indefinite, definite, or pronominal form is used for overt noun phrases, where an argument occurs in the overall grammatical structure of an utterance, and whether an argument is phonologically overt or non-overt (i.e. null).

Centering theory is an approach to modeling local discourse coherence based, possibly among other things, on the relationship between the grammatical representations of the sets of arguments in two adjacent utterances. Grammatical relations (i.e. subjecthood, objecthood, etc...) have been hypothesized as the most relevant aspects of grammatical structure for determining the discourse center for English, with some success. For languages other than English, other factors have been added to improve the performance of centering models, but grammatical relations were kept as the core list. However, even in English, grammatical relations alone are inadequate for handling a variety of discourse phenomena including event and deictic reference, and null arguments.

Using the evidence from null arguments in English, and particularly from null objects, I am examining the effectiveness of an alternative to grammatical relations in a centering model. Examples of the difference between overt and null objects with the verbs *call* and *eat* are given in (1a)-(1b) and (1c)-(1d) below.

(1) a. Thank you for calling me.

b. Thank you for calling.

c. Have you eaten anything yet?

d. Have you eaten yet?

In particular, I am arguing that lexical conceptual structures and the phrasal conceptual structures built from them provide a better source of information for centering models. Most importantly, they are the only reasonable source of information about the different types of English null objects which play a role in the discourse and yet are not part of the syntactic representation of an utterance. In addition, conceptual structures provide a unified means for incorporating event reference into centering models.

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Understanding Natural Language Instructions: A Computational Approach to Purpose Clauses

Keywords: Instruction Understanding, Discourse Processing, Action Representation

My area of interest is at the interface of Natural Language discourse and the knowledge representation and reasoning that support its understanding. There are two aspects that I am particularly interested in: from a linguistic point of view, the discourse factors that affect the choice of a certain surface expression; from a computational point of view, the kinds of inferences necessary to understand certain surface forms, and the choice of an action representation system that can support such inferences.

In my dissertation [2], I propose a computational model for understanding PURPOSE CLAUSES — infinitival *to* constructions expressing the purpose of the action described in the main clause — in instructional text. The model is based on a pragmatic analysis of the functions for which purpose clauses are used. In addition, my fundamental claim is that action descriptions in instructions should first of all be seen as linguistic objects, that need not match exactly the knowledge about actions stored in a Knowledge Base (KB)— contrary to what has been assumed in most previous research on interpreting instructions. Therefore, the model consists of a flexible action representation formalism, and of inference mechanisms that can deal with action descriptions at different levels of specificity.

The representation of actions I propose exploits the reasoning mechanisms that the terminological component of a hybrid Knowledge Representation system is endowed with [1]. The primitives of the representation are those proposed in [3] for the semantic representation of verbs and actions.

A purpose clause expresses the goal that the action described in the main clause contributes to achieve, and therefore, the interpretation of the main clause is constrained by the interpretation of the purpose clause. The inferences I propose exploit the existence of such constraints to compute the description of the action that the agent should execute. In my thesis, I deal with the following two cases:

1. The action described in the input instruction stands in different relations of specificity to the action to be executed. As an example, suppose that the KB contains knowledge about cutting geometric figures in order to obtain other geometric figures: so for instance we may know that α = *cut a square in half along the diagonal* has as a result β = *create two triangles.* Now suppose that the agent is given instructions such as:

   (a) Cut the square in half to create two triangles.

   (b) Cut the square in half with scissors to create two triangles.

   (c) Cut the square in half along a perpendicular axis to create two triangles.

   In (a), the action description *cut the square in half* is less specific than the action α, which is the known method to achieve *create two triangles;* in (b), the action description *cut the square in half with scissors* is neither more nor less specific than α, and the two action descriptions are consistent; finally, in (c), the action description *cut the square in half along a perpendicular axis* is inconsistent with the stored action description α. My algorithm, by exploiting the classification mechanism of the hybrid Knowledge Representation system to compute subsumption relations between action descriptions, is able to conclude that:

(a) the action that the agent should execute is *cut the square in half along the diagonal*, namely, the stored action;

(b) the action the agent should execute is *cut the square in half along the diagonal with scissors*, namely, the stored action augmented with information coming from the surface form;

(c) the input instruction is incoherent with respect to the stored knowledge.

2. The other kind of inference I have worked on deals with expectations that arise while interpreting instructions. Consider:

   - Go into the kitchen to get me the coffee urn.
   - Go into the kitchen to wash the coffee urn.

   While in the first case the hearer develops the expectation that *the coffee urn* is in the kitchen, no such expectation arises in the second case. The inference mechanisms I propose are able to deal with both cases by exploiting planning knowledge about actions, and the relation between the two actions described in the main clause and in the purpose clause.

The inference mechanisms I propose contribute to building the structure of the intentions that the agent develops while interpreting instructions. My work is taking place in the context of the AnimNL project, a collaboration between the Graphics and the Computational Linguistics laboratories at the University of Pennsylvania, which aims at generating animations of NL instructions [4] — see the CLiFF note entry for the AnimNL group for further information.

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Modeling of Scalar Time Series

Keywords: Hidden Markov Models, Signal Reconstruction

I have recently been working on a twice-removed generalization of Hidden Markov Models, as a Research Assistant to Dr. Andrew Fraser at Portland State University. This work does not have an explicit linguistic component, but I intend to explore ways to apply our techniques to problems in the modeling/recognition of speech, as well as to the modeling of written text.

We initially worked with Hidden Filter Hidden Markov Models (HFHMMs), which were introduced by Poritz [9]. These, like Hidden Markov Models, are models consisting of a finite number of hidden states which form a first-order Markov chain, and an output function are associated with each state (or, in some formulations, each transition). But in a HFHMM, the output is allowed to depend on (i.e., to be a stochastic function of) a fixed number of past outputs.

In [3], we introduced the class of MIXED STATE MARKOV MODELS (MSMMs). These are a generalization of HFHMMs that allow history-dependent state transition probabilities. In such a process, the sequence of hidden states $s(1), \ldots$ does not in general form a Markov chain. However, the output $y(t)$ and the successor state $s(t+1)$ are assumed to be completely determined by the "mixed state" represented by the ordered tuple $\psi(t) \equiv \langle s(t), y_{t-k}^{t-1} \rangle$. It follows that the sequence $\{\psi(t)\}$ *does* form a Markov chain. This allows us to model a time series as the outputs of a first-order Markov process with uncountably many possible states. It can be seen that HMMs and HFHMMs are special cases of this class of model.

The FORWARD-BACKWARD algorithm can be used to iteratively estimate the parameters of a HMM or HFHMM that best fit a corpus of observations. We have not yet adapted it to MSMMs, but even a "seed" MSMM, constructed with the help of a vector quantization algorithm without iterative optimization, dramatically outperforms a HFHMM with double the number of discrete states.

Variable-requiring Environments

Keywords: Semantics, Tripartite Structure, Modality

A number of environments accept phrasal complements in which the combination of a specific subject with an individual level ("property") predicate is unacceptable.

(1) a. It is possible for John to climb a high mountain.

b. # It is common for John to be tall.

c. It is common for a basketball player to be tall.

d. George hates Mary to address him in Russian.

e. # George hates Mary to know Russian.

Adopting Kratzer's proposal that stage level ("event") predicates, but not individual level predicates, have a hidden "Davidsonian" event argument, I analyze such constructions as being quantificational. To avoid violating the VACUOUS QUANTIFICATION PROHIBITION (VQP), the complement must contain an unbound variable, which may be contributed either by a non-specific subject or by an event predicate.

However, events that are "punctual" (i.e., fully specified) and events that cannot be repeated cannot contribute a variable in this way, except in the complement of *possible for*.

(2) a. It is common/unusual for Dr. Jekyll to be drunk.

b. # It is common/unusual for Dr. Jekyll to be drunk tonight.

c. It is common for an office worker to be drunk tonight.

d. It is possible for Dr. Jekyll to be drunk tonight.

(3) a. It is possible for John to destroy this book.

b. # It is common for John to destroy this book.

Note that *possible for* (which should not be confused with the not-really-synonymous *possible that*) is the only one of the above environments that is modal. I argue that quantification over possible worlds satisfies the VQP in that case.

Typically, arguments in a sentence are treated as being of *type* [±variable]. A quantifier binds something of type [+variable], resulting in expression of type [-variable]. I argue that this approach leads to complications for the data that I examine, which can be avoided by a less strongly typed approach that essentially treats everything as a variable type, and replaces the requirement for a variable (the VQP) with a requirement for an argument that is non-trivially restricted, i.e. that is interpreted as ranging over a set that is not explicitly of unit size. This accounts for the behavior of nonrepeatable and punctual events, and even, if one wishes it to, for the interpretation of definite and indefinite NPs.

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Improvements to Propositional Satisfiability Search Algorithms

Keywords: Propositional Satisfiability, Constraint Satisfaction, Search Algorithms

The satisfiability problem for propositional formulas in conjunctive normal form (SAT) was the first problem proven to be NP-complete [2]. Viewed as the conceptually simplest kind of constraint satisfaction problem [8], SAT is ubiquitous, and one of the most important computational problems in classical AI. Many other well known NP-complete problems have a straightforward reduction to SAT [9]. My research objective is to design and implement an exact search algorithm for SAT that is as fast as possible on a wide range of SAT problems.

My implementation is called POSIT, for **PrO**positional **S**at**I**sfiability **T**estbed. POSIT's algorithm is essentially a more complicated version of the widely used Davis-Putnam procedure [4]. POSIT is written in ANSI C. It utilizes only a linear amount of space in the length of the input formula, and spends at most linear time at each node of the search tree—properties that I believe any competitive SAT search algorithm must have.

To illustrate POSIT's current performance, here is the published performance data for James Crawford's Tableau system [3] on Mitchell *et al.*'s hard random 3-SAT problems [7]:

Variables	Clauses	Experiments	Average Number of Nodes
50	218	1000	26
100	430	1000	204
150	635	1000	1532

And here is the corresponding data for the current version of POSIT, rounded to the nearest integer:

Variables	Clauses	Experiments	Average Number of Nodes
50	218	1000	7
100	430	1000	64
150	642	1000	489

For this class of problems, at least, POSIT generates substantially smaller search trees than Tableau.

Developing POSIT required implementing and testing several proposed improvements to SAT algorithms. Many proved ineffective in practice; strangely, the speedup techniques most often cited in the literature, e.g., the pure literal rule [4], were usually less effective than novel techniques and techniques cited less often. This is a disturbing fact, and one which reflects broader methodological problems in the study of algorithms [5].

There are two main problems that I have had to deal with in my research: ensuring the correctness of POSIT's code, and adopting a sensible methodology for evaluating its performance. The first problem, ensuring the correctness of the code, is important but extremely difficult: C is a very unsafe programming language, and SAT search algorithms in particular are hard to implement correctly [1]. I have taken several steps to ensure POSIT's correctness, such as utilizing commercial debugging software, and running shell scripts that check for inconsistencies within a single version of POSIT or between two different versions.

The second problem, namely evaluating POSIT's performance in a sensible way, is also difficult. CPU times are hard to measure accurately [6], and SAT problems that are randomly generated from a fixed set of parameters can yield running times and search tree sizes that vary widely; therefore we must run a lot of experiments. Also, we must try to measure POSIT's performance in a machine- and language-independent manner. I believe that the best way to achieve this latter goal is by determining the asymptotic complexity of POSIT's performance on one or more families of randomly generated hard problems.

Here is a more specific description of the approach I intend to use. Let $P(F)$ be the number of propositions in a CNF formula F, and $L(F)$ be the length of F, i.e., the sum of the lengths of the clauses in F (written as P and L, respectively, when F is understood from context). For a family of related formulas, the number of nodes in the search tree is $O(2^P)$, and the CPU time is $O(L \cdot 2^P)$. In practice, decreasing the number of nodes usually increases the CPU time, and vice-versa, so our goal should be to minimize *both* of these quantities, i.e., to minimize their product, which is also $O(L \cdot 2^P)$. Thus I intend to compare different versions of POSIT by selecting one or more families of randomly generated hard problems, generating an accurate set of ⟨tree size, CPU time⟩ pairs for each family, fitting the product of these numbers to the above function, and then comparing the constant values in the resulting fit.

My hope is that this research will eventually lead to an increase in the number of practical high-level applications built around SAT solvers.

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The Role of Intentions in Means-end Planning

Keywords: Hierarchical Planning, Intentions

Consider the simple blocks-world situation shown in Figure 1 .

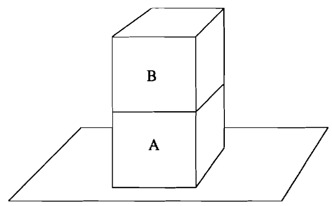

Figure 1: A simple blocks-world situation

In most planning systems, if the system is instructed to pick up block A, it will first move block B to the table. If, on the other hand, a human agent is instructed to pick up block A, there are three possibilities. First, the agent may, like the planner, move block B to the table, then grasp and lift block A. Second, the agent may, by grasping block A, lift both block A and block B, achieving the desired goal. Third, the agent may grasp block A and, by pulling laterally and upward, pull block A from under block B. Notice that only in the first case does the agent actually remove block B before engaging in the desired task.

This behavior is very suggestive. Many planning systems have a precondition on the action *pick up* that the object to be lifted must be clear, and yet, in two of the obvious solutions to this directive, this precondition is not met. The question then is, why should the action *pick up* have a precondition that the block to be lifted be clear? In my research, my claim is that it shouldn't: preconditions as a whole should be eliminated in favor of explicit representation of intentions, situated reasoning about the effect of actions, and robust failure mechanisms.

The strength of two of these mechanisms can be seen in the previous situation. For example, let us assume that the agent's intentions are explicitly encoded. Situated reasoning is sufficient for the agent to determine which methods of lifting the blocks are acceptable and which are not. If the agent has no intentional commitments about the fate of block B, it will not be constrained to "clear" block A before lifting. In this case, the agent might select between any of the methods of picking up the block. If, however, the agent has as one of its intentions that it not break objects, then pulling block A from under block B is not an admissible solution, since block B might fall and break. Of course, the solution of lifting both blocks is still viable, provided the agent takes care to prevent the block on top from sliding off. Finally, if the agent is very concerned about the fragility of block B, there is only one solution that is admissible.

The view being proposed here, namely the use of intentions as a filter on the selection of various solutions to a problem, is not new. As Bratman argues [1]

> My prior intentions and plans, then, pose problems for deliberation, thereby establishing standards of *relevance* for options considered in deliberation. And they constrain solutions to these problems, providing a *filter of admissibility* for options.

It is only by considering the network of those actions that we intend and those that we do not intend that we are able to arrive at correct decisions about methods of achieving our goals and the conditions that should hold before acting. It is through this use of intentions that people are capable of making decisions about actions with the "correct" results in variety of situations presented by the world every day.

In my thesis proposal [2], from which the above example is taken, I argue for two points:

1. Preconditions have been used in existing systems to encode situation-dependent information about actions. Thus, preconditions limit the effective application of intentions to the means-ends reasoning involved in the planning process. In order for a planner to give intentions their correct role in the planning process, preconditions, as previously conceived, must be eliminated from action representations.

2. By explicitly representing positive and negative intentions and using situated intentional reasoning and robust failure mechanisms, preconditions can be replaced without reintroducing the problems associated with them.

To establish and validate these claims, I consider in [2] various definitions for preconditions and show the problems associated with each of them. I then present a planner based on these arguments called the Intentional Planning System (ItPlanS), and outline its operation.

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Deciding What to Say and What Not to Say

Keywords: Critiquing, Discourse, AI in Medicine

As part of my research into using a critiquing interface for communication between the TraumAID system [2, 1] and physicians, I am interested in how the system can decide whether a comment is IMPORTANT to convey to the physician in a given situation. To this end, I am investigating the identification of CRITICAL ACTIONS for trauma management – those actions that can significantly affect the quality of care provided.

Critiquing is a method of communication in which the system evaluates and comments on a proposed solution to the problem at hand rather than simply presenting its own solution. The advantages of this approach over standard expert systems include: (1) the user has greater autonomy in the decision-making process; (2) comments and explanations can be focused on the user's proposed plan; and (3) critiquing systems are more flexible when the user wishes to deviate from the recommended plan.

In an emergency situation, where decisions must be made and carried out quickly and efficiently, it is important to restrict the critique to only those elements of the plan that might affect the outcome of the case. Minor inefficiencies or deviations from protocol need not be mentioned under these circumstances. A current goal of this project is to identify the situations in which it is important to make a comment to the user, as well as those situations in which a comment, while it may be relevant, is not essential. We are pursuing two different methods for obtaining this information: an informal "focus group" of experts, and automatic induction of critical actions from the comments of judges in a validation study.

The first method is a way of generating ideas about the implementation of the critiquing module from experts in trauma care. A group of experts will observe the performance of TraumaTIQ, TraumAID's critiquing module, on various cases and then will participate in a discussion regarding their impressions of the system. As part of this discussion, the group will be asked to point out which types of comments they consider to be important or unimportant for the system to produce. This exercise is not intended to produce a comprehensive list of critical and non-critical actions. Rather, it should provide us with some suggestions of things to look for.

The second method involves the data from a validation study on the performance of TraumAID's reasoning and planning capabilities. Three expert judges were given English transcriptions of 100 cases to evaluate. Each case had three versions: the actual care provided, and the care that would have been recommended by two different versions of TraumAID. For each action reported in the case, the judges were asked to indicate whether they would consider it an error of comission. Next, they were asked to list any errors of omission or temporal ordering of actions. Finally, they were asked to rank the management as to whether it was: (a) acceptable with no errors, (b) acceptable with no errors of major consequence, (c) acceptable with reservations, or (d) unacceptable.

In addition to providing a comparison between the performance of TraumAID and actual trauma surgeons, these evaluations provide us with a great deal of information about what is considered by experts to be "good" care. In particular, the individual comments on errors of omission and comission tell us which actions, according to the judges, are appropriate or inappropriate in each situation. In addition, the acceptability ratings provide some information about the magnitude of the errors involved, even when the outcome of the case was not necessarily influenced by these errors.

I plan to use these data to learn which errors in patient management were important enough for the judges to mention, and which of these errors were associated with unacceptable care. This will provide TraumaTIQ with a decision procedure to determine whether, when the state of the patient is S, where S is a list of clinical findings and test results, doing action α should or should not be considered an error of comission or omission leading to unacceptable quality of care. This decision procedure could then be used by the critiquing system to determine whether or not to comment when the physician indicates that she is planning to do α. Thus, with access to knowledge regarding critical errors in trauma management, the system will be better able to produce an appropriate critique.

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Verb Phrase Ellipsis: Form, Meaning, and Processing

Keywords: Ellipsis, Discourse, Semantics

Elliptical expressions appear to present a major obstacle in the definition of a computable mapping from form to meaning in natural language. In my work, I examine the case of Verb Phrase (VP) ellipsis. I argue that VP ellipsis is really not ellipsis at all; instead, it is an empty proform. This claim has two primary consequences: first, the elliptical VP can have no internal syntactic structure. Second, the interpretation of VP ellipsis must be governed by the same general conditions governing other proforms, such as pronouns. The basic condition governing the interpretation of a proform is that it must be semantically identified with its antecedent. A computational model is described in which this identification is mediated by store and retrieve operations defined with respect to a discourse model. Because VP ellipsis is treated on a par with other proforms, the ambiguity arising from "sloppy identity" becomes epiphenomenal, resulting from the fact that the store and retrieve operations are freely ordered.

A primary argument for the proform theory of VP ellipsis concerns syntactic constraints on variables within the antecedent. I examine many different types of variables, including reflexives, reciprocals, negative polarity items, and wh-traces. In all these cases, syntactic constraints are not respected under ellipsis. This indicates that the relation governing VP ellipsis is semantic rather than syntactic. In further support of the proform theory, I show that there is a striking similarity in the antecedence possibilities for VP ellipsis and those for pronouns.

Two computer programs demonstrate the claims of this theory. One program implements the semantic copying required to resolve VP ellipsis, demonstrating the correct set of possible readings for the examples of interest. The second program selects the antecedent for a VP ellipsis occurrence. This program has been tested on several hundred examples of VP ellipsis, automatically collected from corpora.

I argue that the general computational mechanisms governing the interpretation of proforms adequately account for the full range of facts of VP ellipsis. In a sense, this would mean that the problem of VP ellipsis has been eliminated. In future work, I hope to continue this by showing that the notion of ellipsis can be completely eliminated from the grammar.

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The Dynamic Composition of Phrase Structure

Keywords: Syntactic Theory, X′-Theory, Functional Projections, Clitics, Locality

A theoretical issue is posed by theories of syntax in which functional relationships such as agreement, and functional items such as tense and aspect, are represented in phrase structure as syntactic heads with associated projections, as in [1], [8], and [2]. If a syntactic derivation begins with a representation of the full structure of the clause, these projections must be ordered with respect to lexical projections and one another by relationships of complementation which are not realizations of lexical selection based on semantic argumenthood. One way to obviate this issue is to formulate a framework of syntactic analysis in which phrase structure is composed dynamically in the course of a syntactic derivation from small units, such as local projections of individual heads. One version of such a framework is sketched in [3]. My efforts are directed towards finding empirical concerns pertinent to such a framework, in particular, to finding empirical consequences of deriving structural skeletons based on selectional properties of lexical items, and then interpolating functional projections as required in the course of the syntactic derivation, to satisfy morphological requirements on lexical items already composed into phrase structure. One case study within this project concerns pronominal clitic placement and clitic climbing in Romance languages. The account developed takes crucial advantage of the dynamical composition of functional projections into the phrase structure of a clause, in an effort to improve on the analysis of these phenomena given in [5] and [6]. Another case study concerns the formulation of constraints on A′-locality in terms of the domain of a lexical projection, expanded by the interpolation of functional projections.

Deriving Clausal Phrase Structure in Tree Adjoining Grammar

Keywords: TAG, Syntactic Locality

The elementary trees of Tree Adjoining Grammar are standardly taken to be quite richly articulated, including the full structure of a clause [7, 4]. I am currently formulating a TAG framework for syntactic theory in which elementary trees are projections of individual heads, which are composed by normal TAG operations into larger structure, including clausal structures (in the same way that yet "larger" recursive structure, such as clausal complementation, is generated).

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Description Based Parsing in a Connectionist Network

Keywords: Syntactic Parsing, Connectionism

While connectionist models of computation have been successful in solving many interesting problems, they have had difficulty with natural language parsing. Previously proposed connectionist models of natural language parsing can not parse arbitrarily long sentences and have inadequate grammar representations. The lack of success in this area is mostly due to the difficulty connectionist models have had with symbolic computation; virtually all characterizations of natural language syntax have relied heavily on symbolic representations. A connectionist model of computation recently proposed by Shastri and Ajjanagadde ([3]) largely solves this problem. It stores and dynamically manipulates predications over variables, thus supporting symbolic computation. However, this model of computation has a few limitations which make natural language parsing difficult. In my masters thesis I proposed a formalism for specifying natural language grammars which was motivated by other work in grammar formalisms and by some of the same characteristics imposed by the Shastri and Ajjanagadde (S&A) computational architecture. My dissertation work investigates efficient syntactic parsing in the S&A architecture using this formalism as the grammatical framework. This work shows that all the limitations of the connectionist architecture can be handled within this framework, and suggests that these limitations also make interesting predictions about some natural language phenomena. In addition, the resulting parser has several important computational characteristics. This parser has been and continues to be tested on a variety of natural language phenomena.

In addition to its distinctive support of predications over variables, the S&A connectionist computational architecture provides a neurologically plausible framework that supports the massively parallel use of knowledge, and evidential reasoning. The latter property and recent work showing the importance of statistical information in parsing natural language make this architecture particularly interesting. However, there are a few limitations to this architecture's ability to store and process information. In particular, it has a bounded memory capacity, it can only store a conjunction of predications, and in the general case it is costly to use rules or predicates which involve more than one variable. These problems can be solved by using the particular formulation of partial descriptions of phrase structure trees described below.

In order to allow a parser or a grammar to state all and only what it knows, when and where it knows it, the specification of phrase structure information needs to be a sufficiently partial description. In [1] I propose a grammatical formalism, called Structure Unification Grammar (SUG), which is a formalization of accumulating partial information about the phrase structure of a sentence until a complete description of the sentence's phrase structure tree is constructed. That document demonstrates that SUG is a powerful, flexible, and perspicuous grammatical framework by showing how analyses and insights from a variety of other grammatical investigations can be captured using SUG.

My dissertation work uses Structure Unification Grammar as a grammatical framework in which to investigate efficient syntactic parsing in the S&A connectionist computational architecture. The primary bound on the memory capacity of a computing module in this architecture is its inability to store information about more than a small number of variables at any one time. This limitation is handled by incrementally outputting information about the syntactic structure of the sentence, and using the ability to reason with partial descriptions to abstract away from the existence of phrase structure nodes which will not be further modified. In this way the parser can parse arbitrarily long sentences without running out of memory. The fact that only a conjunction of predicates can be stored by the architecture prevents the general use of disjunction, but the partiality of SUG descriptions allows the parser to state only the information it is sure of (as is done in [2]), rather than stating a disjunction of more completely specified alternatives. This allows the parser to do disambiguation incrementally. The cost of using non–unary predicates is mitigated by the very limited circumstances in which the parser's few binary predicates are needed. Because of certain linguistic constraints, rules which involve more than one variable are never needed. My dissertation argues that these techniques allow a parser which uses SUG as its grammatical framework and the S&A connectionist architecture as its computational architecture to be adequate for recovering the constituent structure of natural language sentences. This argument is given in the form of an existence proof, presenting a specific parsing model and specific grammatical analyses. Arguments are also given that the computational constraints imposed by the S&A architecture make interesting predictions about certain center embedding and wh–movement phenomena.

This model of syntactic parsing is interesting independent of the fact that it is connectionist because of its computational characteristics. Because of its use of massively parallel computation, the parser's speed is independent of the size of its grammar, and it parses in quasi–real time (constant time per word). The parser uses only a bounded amount of memory. The output is incremental, monotonic, and does not include disjunction (i.e. it is a deterministic parser). It can store statistical information and make disambiguation decisions based on that information. Also, the connectionist arbitrator which makes disambiguation decisions provides a simple parallel interface for the influence of higher level language modules. These characteristics and the neurological plausibility of the architecture suggest that this investigation may lead to an explanation of the amazing speed and accuracy with which people understand natural language.

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Categorial Logics for Grammatical Analysis

Keywords: Categorial, Discontinuity, Mixed Substructural

My primary interest is in the development of grammatical systems falling within the area known as Categorial Grammar, particularly systems meeting the rigorous formal standards of the type-logical approaches of Lambek [2, 3]. My current research efforts are focussed largely toward the following two goals, which I believe are crucial to the attainment of a cross-linguistically adequate general categorial framework.

1. There are a number of linguistic phenomena which suggest the existence of discontinuous constituency. Although interesting proposals have been made for definitions (in terms of abstract interpretation) of type-forming operators for use in characterizing discontinuous constituency (esp. Moortgat [4]), an adequate proof system for such operators has so far been elusive. I am currently developing such a proof system, combining ideas from Gabbay's "labelled deduction" framework (Gabbay [1]) with new methods for testing resource usage.

2. Existing logics may be ordered in terms of their resource sensitivity, giving rise to the so-called 'substructural hierarchy of logics'. To deal with various linguistic problems, systems situated at previously unoccupied locations on this hierarchy have been proposed, and further ones remain to be developed. It has become clear, however, that access to more than one substructural level is required even for specifying the grammar of any one language. I am currently developing a general model of mixed substructural systems, under which the range of substructural levels form a single unified descriptive system. Such a unified approach should both facilitate producing grammars for individual languages, and provide a better basis for cross-linguistic generalization.

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Multiple focus in English

Keywords: Focus, Prosody, Semantics, Information Structure

A wide variety of phenomena have been grouped under the term FOCUS, for example, associates of *even* and *only*, prosodic prominence, certain constituents of "syntactic focus constructions", "contrast" and information structure. Cases of multiple foci provide an opportunity to separate the effects of various focus phenomena and evaluate their treatment in the numerous approaches to focus that have been proposed in the literature. For example, in syntactic focus constructions, the syntactic focus and prosodic prominence are assumed to coincide, but this does not have to be the case. Instances in which the two are distinct allow the function and interpretation of foci marked by syntactic and prosodic mechanisms to be considered independently of each other.

My approach to investigating multiple foci includes:

1. a distributional analysis of prosodic and syntactic focus in a corpus of naturally occurring speech
2. production experiments
3. perception experiments

Using the descriptive component of the study as a basis, I am interested in addressing theoretical issues in the form and interpretation of multiple foci.

Feature-Based TAG in place of multi-component adjunction: Computational Implications

Keywords: Feature-based TAG, Multi-component Adjunction

This project is being carried out jointly with Srinivas Bangalore. See the abstract on page 90.

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Linear Logic as an Extension of Phrase Structure Grammar

Keywords: Linear Logic, Logic Programming, Gap Threading, GPSG, Parsing

Generalized Phrase Structure Grammar proposes that it is possible to parse filler-gap constructions using just a simple extension of context free grammars. For example, a relative clause can be viewed as a sentence that is missing a noun phrase, and can be parsed with the rule:

$$\mathsf{rel} \longrightarrow \mathsf{Rel\text{-}Pron}\ \mathsf{S/NP}$$

All that is left is to specify grammar rules for the expansion of the new non-terminal S/NP. So, a simple grammar that includes relative clauses (including the generalized left-branch condition) might be:

S ⟶ NP VP
NP ⟶ PN
NP ⟶ DET N
NP ⟶ DET N REL
VP ⟶ TV NP
REL ⟶ REL-PRON S/NP
S/NP ⟶ NP VP/NP
VP/NP ⟶ TV NP/NP
NP/NP ⟶ ϵ

Because the resulting grammar is potentially much larger than the original grammar, the standard method of implementing GPSG grammars is to forgo the specification of new rules and instead use a series of switches to control how the existing rules are used. So, for instance, a Prolog DCG of the above grammar (with the GPSG rules that each DCG represents) could be:

`s --> s(noslash).`	
`s(Slash) --> np(noslash), vp(Slash).`	S ⟶ NP VP S/NP ⟶ NP VP/NP
`np(slash) --> [].`	NP/NP ⟶ ϵ
`np(noslash) --> pn.`	NP ⟶ PN
`np(noslash) --> det, n.`	NP ⟶ DET N
`np(noslash) --> det, n, rel.`	NP ⟶ DET N REL
`vp(Slash) --> tv, np(Slash).`	VP ⟶ TV NP VP ⟶ TV NP/NP
`rel --> rel-pron, s(slash).`	REL ⟶ REL-PRON S/NP

Unfortunately, constructing such grammars correctly is a tricky business, since parts of the grammar that are unrelated to the filler-gap dependency will require modification in order to ensure that the switches are properly maintained.

It is possible however, to read the meaning of the rule:

```
np(slash) --> [].
```

as saying that there are noun phrases with no overt realization. The purpose of all the switches is to control when this rule can be used. The reason the switches are necessary is that context free grammars, like the horn clauses underlying Prolog DCGs, are flat, with no scope control.

Hodas and Miller have, however, proposed an extension of Prolog, called Lolli, in which implications are allowed in goals. The operational meaning of such a goal is to add the assumption of the implication to the context and then attempt to prove the conclusion. In addition, Lolli uses the operators of linear logic, so that when clauses are added to a program, it is possible to enforce the relevance constraint – that the assumption is actually used – and the affine constraint – that the assumption is, in general, not used more than once.

This operational view of implication can be seen as providing just the type of scope restriction that is needed in this setting. In Lolli, the last grammar is given as:

```
s --> {np}, vp.
s --> (s, [and]) & s.
np --> pn.
np --> det, n.
np --> det, n, rel.
vp --> tv, np.
rel --> rel-pron, (np --> []) -o s.
```

The use of braces in the first rule enforces the generalized left branch condition by barring the use of newly assumed rules during the parse of the subject noun phrase. This corresponds to trying to prove a sequent with a modally marked consequence in linear logic. The alternate form of conjunction in the second rule enforces a restriction that each of its conjuncts use the same set of assumed rules. This is the second form of conjunction in linear logic, and is used to enforce coordination constraints.

This small grammar will correctly accept:

(1) a. John bought the book that Mary sold.

b. John bought the book and Mary sold a book.

c. John bought the book that Mary sold and John bought.

and reject all of the following:

(2) a. *John bought the book that Mary sold the book.

b. *John bought the book that the the story in is long.

c. *John bought the book and Mary sold.

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Word Order Variation in Turkish

Keywords: Turkish, Scrambling, Pragmatics, CCGs

In Turkish and many other "free word order" languages, a rich system of case markings identifies the predicate-argument structure of a sentence; word order in these languages serves a pragmatic function. The most common word order in Turkish is SOV (Subject-Object-Verb) in simple transitive sentences. However, almost any word order can be used in the proper discourse situation. For example, all of the permutations of the transitive sentence seen below are grammatical.

(1) a. Esra gazeteyi okuyor.
Esra newspaper-acc read-present.
Esra is reading the newspaper.

b. Gazeteyi Esra okuyor.

c. Esra okuyor gazeteyi.

d. Gazeteyi okuyor Esra.

e. Okuyor gazeteyi Esra.

f. Okuyor Esra gazeteyi.

Erguvanlı [1] presents a functional approach to word order variation in Turkish. She claims that each position in a Turkish sentence is strongly associated with a specific pragmatic function. Generally, the element in the S-initial position is the *Topic* (i.e. what the sentence is about); the element in the immediately preverbal position carries the primary stress of the sentence and is the *Focus* (i.e. the most information bearing element in the sentence); and the elements in the postverbal positions are *backgrounded* information. An active area of my research is to determine the specific pragmatic functions of word order variations in Turkish.

My current work involves extending Combinatory Categorial Grammars (CCGs) [4] to handle free word order languages. In [2], I developed {}-CCGs in which the subcategorization requirements of the verbs are relaxed such that they require a *set* of arguments without specifying their order. I am also concerned with the formal properties of this grammar, namely its weak generative capacity. In [3], I show that the use of variables in the lexical category assignments can increase the weak generative capacity of CCGs and investigate whether such a grammar can handle free word order languages. In future research, I will compare the treatment of word order variation in {}-CCGs with a CCG using variables and unrestricted composition.

In complex Turkish sentences with clausal arguments, elements of the embedded clauses can occur in matrix clause positions; this has been called long distance scrambling in transformational theories. Long distance scrambling appears to be no different than local scrambling as a syntactic and pragmatic operation. Generally, an element from the embedded clause can occur in the S-initial topic position of the matrix clause (e.g. (2)b) or to the right of the matrix verb as backgrounded information (e.g. (2)c).

(2) a. Fatma [Esra'nın okula gittiğini] biliyor.
Fatma [Esra-GEN school-LOC go-GER-3SG-ACC] know-PROG.
Fatma knows that Esra goes to school.

b. $Okula_i$ Fatma [Esra'nın e_i gittiğini] biliyor.
school-LOC_i Fatma [Esra-GEN e_i go-GER-3SG-ACC] know-PROG.

c. Fatma [Esra'nın e_i gittiğini] biliyor $okula_i$.
Fatma [Esra-GEN e_i go-GER-3SG-ACC] know-PROG school-LOC_i.

My analysis in {}-CCGs handles both local and long distance scrambling uniformly. Although there are not many syntactic restrictions on word order in Turkish, there are semantic and pragmatic restrictions on word order that we must take into account. My future research involves integrating a pragmatic information structure with the CCG syntactic and semantic information in order to interpret all word order variations in Turkish.

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Lexicalized Grammars and Categorially Clothed TAGs

Keywords: Lexicalized Grammars, TAG, Categorial Grammar

A lexicalized grammar consists of elementary structures anchored on lexical items and general rules for composing these elementary structures. Context-free grammars (CFGs), in general, are not lexicalized and cannot be lexicalized with substitution alone. Substitution and adjoining can lexicalize CFGs and the resulting system is the same as Lexicalized TAGs (LTAG). In this sense, TAGs arise naturally in the process of lexicalizing CFGs.

The main goal of this work is to define a TAG-like system ENTIRELY within the framework of categorial systems. In this way, we will be able to combine the key idea in categorial systems, in particular, the tight interface between syntax and semantics, and the key idea in TAGs, namely the extended domain of locality and factoring recursion from the domain of dependencies.

First, I will describe some background and then state some of the key ideas of this new work. There are many interesting relationships between TAGs and Categorial Grammars (CG). For example, Weir (1987) has shown that TAGs are equivalent (with respect to the weak generative capacity) to Combinatory Categorial Grammars (CCG) of Steedman, under certain conditions. Vijay-Shanker and Weir (1990) developed a common parsing architecture for TAGs, CCGs, and Linear Indexed Grammars (LIG), indirectly based on the equivalence of these systems.

We can describe more fine-grained relationships between TAGs, more specifically Lexicalized TAGs (LTAGs) and CCGs, based on the observation that both LTAGs and CCGs are lexicalized grammars. LTAGs (with substitution and adjoining) are similar to CCGs in the sense that, for each lexical item, the elementary tree(s) in an LTAG, which is (are) anchored on that item can be regarded as the STRUCTURED category (categories) associated with that item. One of the elementary trees associated with *likes* is (represented in a labeled bracketed form, anchored on V) S[NP VP[V NP]]. (This is just one of the trees associated with *likes*). In a CCG, the syntactic type associated with *likes* is (S\NP)/NP. The CCG representation and the LTAG tree for *likes* both encode the information that *likes* has two NP arguments. However, the LTAG tree also encodes the structural positions for the two arguments. It also encodes a specific CCG derivation. Further, the LTAG tree makes a commitment to certain constituencies. In a CCG, there is a strict correspondence between types and constituents, i.e., each type is a constituent and each constituent is a type. In fact, this property is exploited by CCG in its novel account of coordination. This is not the case for LTAGs. For each lexical string built by the operations of substitution and adjoining, there is obviously a functional type that can be read from the elementary or derived tree. Thus, for *likes*, it is NP x NP $\rightarrow$ S, for *likes peanuts*, it is NP $\rightarrow$ S, and for, *John likes*, it is NP $\rightarrow$ S. The first two strings are constituents but the last one is not. Hence, in LTAGs the type-constituency correspondence is not strict. It is partial. In LTAGs, constituencies are defined at the level of the elementary trees, no other constituencies are introduced during the derivation. However, every string has a functional type associated with it.

Based on the above considerations Joshi and Schabes (1991) showed how a CCG-like account of coordination can be given in LTAGs. The coordination schemas are defined over the STRUCTURED categories. In particular, Joshi and Schabes showed how an account parallel to Steedman's treatment of coordination and gapping can be given in LTAGs. There are some interesting differences in these two treatments but they are essentially parallel. Although this work clearly shows some close relationships between LTAGs and CCGs, they do not allow a direct comparison of LTAGs and CCGs.

The key idea in constructing a TAG-like system entirely within the categorial framework is to assign elementary PARTIAL proofs (proof trees) of certain kinds as types to lexical items rather than the types associated in a categorial grammar. These partial proofs will include ASSUMPTIONS (assumption nodes) which must be FULFILLED by LINKING the conclusion nodes of partial proofs to assumption nodes. Roughly speaking, these partial proofs are obtained by unfolding the types associated with the lexical items. This allows us to associate an extended domain of locality to the structure associated with a lexical item, analogous to the trees of LTAGs.

Partial proofs are COMPOSED to obtain proofs for strings of lexical items. We need to go further however. Treating a node of a proof tree as a pair of conclusion and assumption nodes, a proof tree can be STRETCHED. Then an appropriate proof tree can be INSERTED by linking conclusion nodes to assumption nodes.

During unfolding the syntactic type associated with a lexical item by a categorial grammar, we will also allow INTERPOLATION. That is, during unfolding, we can interpolate a proof. Interpolation is like stretching except that unlike stretching, the interpolated proof has to uninterpolated by linking it to a non-null proof tree.

CCGs have no fixed constituencies, LTAGs have fixed constituencies defined at the level of elementary trees. To capture this property, we need to consider assumptions that are really TRACES. These trace-assumption nodes are DISCHARGED internally (locally) in the elementary proof trees. Discharging these trace assumptions is exactly like discharging assumptions in a natural deduction system. Only trace assumptions are discharged in this way. The assumptions we talked about earlier are not discharged. They have to be fulfilled by linking them to conclusion nodes of other partial proof trees. The discharge of trace assumptions locally within an elementary tree not only allows us to define fixed constituencies but also to capture long-distance dependencies in a LOCAL manner analogous to their treatment in LTAGs.

In summary, the elementary proof trees associated with a lexical item are constructed by unfolding the syntactic type up to atomic types. While unfolding, we can optionally stop if the conclusion is the same as one of the arguments, i.e., assumptions. If trace assumptions are introduced then they have to be locally discharged, and finally, while unfolding a proof tree can be interpolated. Proof trees are combined with proof trees by linking, by stretching and linking, and by uninterpolating by linking. This system appears to be adequate to describe the range of phenomena covered by the LTAG systems and the corresponding weakly equivalent categorial systems such as the Combinatory Categorial Grammars of Steedman. If we are successful in constructing a system as described above then there is possibility of extending the parsing algorithms for LTAGs to this system, thus achieving polynomial parsability.

Another way of viewing this work is as follows. Starting with CFGs, by extending the domain of locality, we arrive at LTAGs. Starting with Categorial Grammars (the so-called Bar-Hillel–Ajdukiewicz grammars, BA), by extending the domain of locality as described above, we arrive at the system described above.

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Modeling Natural Language Acquisition

Keywords: Formal Learning Theory, Natural Language Acquisition

I am primarily interested in formal and computational modeling of various aspects of natural language. My work so far has focused on modeling natural language acquisition. I have looked at the applications of formal principles, such as the SUBSET PRINCIPLE, in linguistics and natural language acquisition, and pinpointed the inaccuracies in the past applications and suggested alternatives (with Barbara Lust, Wayne Harbert, and Gita Martohardjono) [9, 10]. I have also strengthened formal results (with Gianfranco Bilardi) so as to enable such future applications [6, 7, 8]. We investigated variations of some existing models along the directions suggested by some studies in natural language acquisition and obtained characterizations for families of languages learnable under some commonly assumed constraints. We also incorporated a stochastic element in our model (along the lines of PAC-learning) and obtained positive results.

Based on these results, I proposed a new learning algorithm that uses stochastic input to generate 'indirect' negative evidence [4, 5]. The learning algorithm is uniform, simple and robust. One interesting feature of my proposal is that the relations between the acquisition of grammatical knowledge and the development of parsing strategies are integrated into a single account. In related developments, I have performed successful computational experiments (with Eric Brill) to investigate the possibility of setting parameters based on information-theoretic considerations [1]. I have analyzed (with Robert Frank) the notion of a trigger as it is conceived in the study of setting of linguistic parameters [2]. I have also obtained (partly with Thomas Zeugmann and Steffen Lange) characterizations of families of languages learnable under some new constraints which are also motivated by work in inductive logic [3, 11, 12].

I plan to continue to develop as well as apply some of the ideas I have been working on. Logic-based computer languages will be good candidates for initial development and testing. I also plan to run my learning algorithms on large corpora of parental speech in different languages. My research will involve development of (statistical) natural language processing systems. Besides determining the consistency of my learning model with existing data on natural language acquisition, I intend to initiate psycholinguistic studies in order to verify the predictions my model makes. Simultaneously, I will develop the formal theory, in part to appreciate better the significance of notions such as *triggers* in the context of parameter setting. I also intend to continue formal investigations of learning in other general settings.

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Causal Reasoning in Anatomic Modeling with Physiology for Trauma

Keywords: Causal Reasoning, Spatial Reasoning, Human Anatomy

For the past two years, I have been working with Dr. Bonnie Webber and John Clarke, M.D. on the TraumAID project [8]. Initially, I ported TraumAID from the Symbolics machine to the X-Windows and Macintosh environment, in addition to reworking it for easier transport to any other platform. With a better understanding of TraumAID, I came to recognize deficiencies that were common to other programs in Medical Informatics. My interest in causal modeling as a means for sound explanation led me to my dissertation topic: reasoning about the effects of spatial disruptions from trauma in human anatomy with knowledge about physiologic processes.

I see two principal directions in which medical programs have emerged: analysis of space (anatomy) and of function (physiology and pathophysiology). While many domains involve both, typically a program only focuses on one.

It is not hard to see that these directions ultimately will meet. At the same time, there have been few attempts in medicine to integrate space and function meaningfully [3], in spite of its importance [1]. Researchers in Medical Informatics have recognized the value of designing knowledge for programs to use over a range of applications, rather than on an application-specific basis [4, 6, 5]. I believe that anatomic knowledge has a great potential for reuse because of its central role in medicine.

I am developing a system to integrate spatial (anatomic) and functional (physiologic) knowledge about the human body; the system focuses on how structural change due to trauma (initially penetrating injury such as caused by guns and knives) affects physiology. Using *Jack* [?], I am building a graphical interface to my system to provide an intuitive user interface, an illustration of the system's knowledge about the situation, and a tool to assist medical professionals in visualizing the internal extent of injury they cannot see directly. Based on clinical findings and tests, the system will try to arrive at hypotheses about the potential for injury due to spatial and functional constraints. The results will be accessible on-line to TraumAID, which will be a separate decision-making program that will choose the course of action. When my system receives more information, it will adjust its hypotheses on the basis of the new information.

I expect that implementing such a system will serve as a starting point for linking medical imaging and functional analysis. I envision its direct impact as reinforcing the fundamental interaction of anatomy and physiology, to give the computer a solid framework for representing medical knowledge. This could aid in learning about their relationship, solidifying the medical professional's mental image of the situation, and reusing anatomic knowledge.

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Phonology and Lexical Selection

Keywords: Language processing, Acquisition, Phonology, Lexical structure

When speakers accidentally say one word instead of another, the substitution errors appear to be of two types. In one type of error, the intended word and the error share clear phonological similarities, but no semantic relationship (e.g., saying *apartment* instead of *appointment*). In the other type, the intended word and the error are similar semantically, but not phonologically (e.g., saying *purple* instead of *green*). The strong separation between these two classes of substitution errors has led to strict, two-stage theories of lexical selection. In the first stage, words are distinguished solely by their semantic properties, and have been denoted LEMMAS so that they are not confused with the common usage of "word," which unites semantic and phonological properties in a single entity. At this first stage, the conceptual content of a message is used to select lemmas with the appropriate semantic properties. Errors in lemma selection will eventually lead to semantic substitution errors. However, since phonological information is unavailable at the first stage, phonological relationships will not affect these errors. After lemma selection is completed, the phonological forms associated with each lemma will be accessed. Errors at this stage will create phonological substitutions.

In addition to accounting for word error patterns, the two-stage model has implications for normal, error-free aspects of lexical selection. Consider, for example, the choice between the words *supper* and *dinner*. Although these two words are similar in meaning, they nonetheless have some differences, which follows from the general linguistic assumption that languages do not contain exact synonyms. Thus, *dinner* implies a more formal affair, as evidenced by the awkwardness of *I'm having supper at the White House this evening.* According to the two-stage model of lexical selection, the choice between *supper* and *dinner* is determined solely at the lemma stage. Phonological information makes no contribution to this decision. As Levelt *et al.* [2] put it, there is no "phonological activation of semantic alternatives."

In a recent series of corpora analyses and experiments [1], we have obtained evidence that lexical selection is, in fact, affected by phonological factors. More specifically, both investigations document phonological priming effects in lexical selection. In the text analyses, we have found, for example, that the use of *supper* over *dinner* is associated with a greater incidence of neighboring words beginning with /s/ rather than /d/. Such results suggest that the activation of words with certain phonological properties will spread activation to similar sounding words that possess semantic properties relevant to a particular context, in contrast to the predictions of the two-stage model of lexical selection. The experiments pursue such phonological priming effects in more detail. In these studies, subjects are asked to read a series of words and name a series of pictures as rapidly as possible. The critical pictures can be denoted with alternate words, such as *sofa* or *couch.* Prior to these critical items, the subjects read prime words that are phonologically similar to one of the alternatives. We find that the names subjects choose for these critical objects are affected by the preceding primes. For instance, the probability of using *sofa* increases if the subject has just read a set of disyllabic rather than monosyllabic words. In further studies, we will attempt to determine the strength of the priming effects for different phonological variables and the various ways in which they might interact. Such studies will hopefully provide us with a more detailed understanding of lexical access, lexical selection, and the organization of the mental lexicon.

The results of these studies suggest a model of lexical selection that attributes some aspects of word choice to the ebb and flow of lexical activation in memory. When one considers the demands placed on a person in speech production, this view of lexical selection seems more adaptive than the strict, stage view. Speakers typically maintain conversational speech rates of 150 words per minute. A number of demanding problems must be solved very rapidly in order to achieve such speech rates, including message formulation, preparation of motor commands, and lexical access. In the case of the latter, speakers must retrieve words from memory at the rate of two or more per second, and they must do so by accessing a lexicon containing upwards of 30,000 items. One way of making this task easier would involve forgoing a perfect map between conceptual structure and lexical selection and opting for reasonable approximations. (After all, in most cases, it will not matter whether a speaker says *sofa* or *couch*, *supper* or *dinner*, or *bike* or *bicycle*.) These "reasonable approximations" will be determined, in part, by the relative ease with which words are retrieved from memory, and this retrieval will in turn be affected by the structure of and processing within the mental lexicon.

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Formalizing the Theory of Grammar Using TAG

Keywords: Grammar Formalisms, Theory of Grammar, TAG

Research over the last several years has demonstrated the utility of the TAG formalism in empirical research on natural language syntax. Use of the formalism allows the linguist to capture syntactic generalizations that would be represented as constraints on movement in a transformational grammar rather than as constraints on the well-formedness of elementary structures. Due to the limited generative capacity of TAG, the theory of grammar that results from the change in representation is more highly constrained than standard transformational theory. For example, the principle of subjacency, independent of other principles in a transformational grammar, falls out as a corollary of the TAG formalism. The possibility of successfully translating well-motivated transformational analyses into TAG has been demonstrated for a number of constructions, among which the most important has been wh- movement, including such complex features of the construction as the parasitic gap phenomenon and the phenomenon of long movement. In addition, there has been work on NP movement, on extraposition, and on the complex West Germanic verb-raising construction. Recent research on scrambling has also yielded promising results. Currently, our research on the linguistic application of the TAG formalism centers on specifying in detail the proper representation of elementary TAG structures and evaluating the empirical utility of various extensions to the formalism, with the aim of improving the coverage and conceptual elegance of TAG analyses of core grammatical phenomena.

Patterns of Grammar in Language Use and Change

Keywords: Statistics and Language, Language Change

Work on the history of the English auxiliary system has revealed a surprising statistical pattern in the frequency of use of modern versus Middle English forms. When sentences from the late Middle English corpus are grouped by sentence type into negative interrogatives, affirmative interrogatives, negative declaratives, and affirmative declaratives, the frequency of use of the periphrastic auxiliary *do* differs substantially by type. This difference follows the ordering given; and under assumptions long standard in studies of language change, the ordering of frequencies would be taken to reflect a temporal ordering of contexts. Specifically, the use of *do* would have been supposed to enter the language context by context following the frequency ordering, and the rate of spread would have been differentiated by context in the same way. Statistical analysis, however, reveals that the rate of spread of the *do* form is the same in all contexts. Furthermore, this rate is the same as that of the spread of preverbal positioning of prosodically weak sentential adverbs, which, under a well-motivated and standard syntactic analysis, is a reflex of the same grammatical change as the one that motivates the use of periphrastic *do*. The parallelism across contexts suggests the following "constant rate" hypothesis for language change: When alternations in different surface contexts reflect competition at a single locus in an underlying grammatical system, the rates of change in the frequencies of the alternating forms over time will be the same for all contexts. In other words, change takes place at the level of the grammar, not at the level of the surface contexts where its effects are observed. The first support beyond the original Middle English case found for the constant rate hypothesis was in certain previously described historical changes in Portuguese and French. More recently, the hypothesis has received further support in diachronic studies of Old English and Yiddish phrase structure that were specifically designed to test it.

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Geometric, Functional and Intentional Reasoning

Keywords: Function, Intention, Geometric Reasoning, Natural Language Processing, Lexical Semantics, Graphics

My interests are in investigating and developing a computational model for understanding and acting on instructions. I am specifically interested in how a plan for action can be developed.

Object Specific Reasoner

If I blindfold you, walk you into a new room, and say "When I take off the blindfold, please open the door" you can partially plan the actions you will perform. You must move to the door, grasp the door handle, and then move the door. This partial plan will work for most doors. But there is information missing in the plan – is the door within reach? where is the handle and what type of handle is it? in which direction does the door move? are you blocking its path? Until I remove the blindfold, you can't finalize the plan, but you can, and do, start to act on your partial plan. I am studying the reasoning process that takes you from a partial plan to perform a task with a specific object, to the physical actions you will perform when I take off the blindfold.

I am developing a system, the Object Specific Reasoner (OSR), which will address the issue that realistic agent-object interaction cannot be completely specified from a symbolic task description alone (a TASK-ACTION in our system) [5]. The OSR maps task-action descriptions to a set of physical acts for an agent to perform by making the task-action sensitive to the geometric and functional features of the object as well as the reason – the INTENTION – for carrying out the task. This sensitivity constrains agent-object interaction and is a crucial part of the reasoner.

Working from a skeleton plan for the task-action (e.g., *open, grasp*), the OSR looks to the object of the task-action for information needed to fill in the plan. Examples of object information incorporated in the plan elaboration process are: category and instance information (the door is of TYPE sliding door; this PARTICULAR door has a handle on the right and moves left); the FUNCTION of the object (doors provide access into or out of a room); and the INTENTION of the action (e.g., the reason for opening the door might indicate the extent to open it). The output of the OSR is a sequence of commands directing the actions of an agent. This work is being done in conjunction with the AnimNL Project; the OSR will direct the actions of an animated agent in the *Jack* human figure modeling system [6, 1].

SodaJack

With Chris Geib and Tripp Becket, I have built an interactive system called SodaJack. SodaJack features Jack, an animated human figure in a soda fountain, who can manipulate objects such as bowls, glasses, ice cream scoops, and refrigerator doors. The system links

Geib's ItPlanS [3] to the OSR, and both modules to a Behavioral Simulator [2]. ItPlanS decomposes high-level goals into task-actions, and passes each one together with objects, agents and intention, to the OSR. The OSR passes the list of physical actions for Jack to perform, as well as constraints on his performance, to the Simulator. In addition to animating movement of the human figure, the Simulator provides "sensory" feedback to both ItPlanS and the OSR (e.g., the current location of Jack or an object in the scene); this knowledge is used by both modules for incremental decision making and plan specification.

SodaJack currently accepts instructions of the complexity: **`(grasp(coke),serve)`**, and **`(move(glass,table),puton)`**. (The predicate is the task-action; the last parameter is the intention behind the action; first (and second) parameters are the objects of the task-action.) As the SodaJack system develops, it will accept commands such as **`serve ice cream`**, which requires ItPlanS to decompose the high-level goal **`serve`** into its composite task-actions, and the OSR interpreting and expanding each before sending them on to the Simulator.

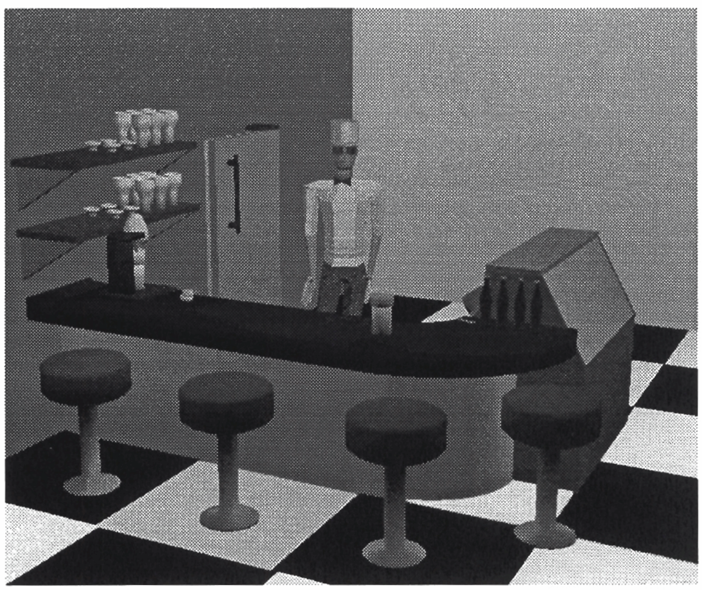

Figure 2: *Tending the SodaJack fountain.*

Lexical semantics of the verb *open*

As part of the previous discussion, the question arises of how to define a task-action. It is extremely tempting to study the lexical token **open** when building a definition for a task-action like *open*. While I take a an imperative verb and a TASK-ACTION to be quite different things, I believe that a study of the lexical semantics of a token like *open* can help in constructing the partial plan which stands as a definition for the task-action *open*.

In a corpus-based study described in [4], I analyzed the nouns which co-occurred with the verb *open*. I argue that there are similarities among the possible physical objects of the verb *open*, based on the objects' underlying geometric structure and their function. This regularity, derived from an analysis of tokens extracted from the Brown corpus, can explain similarities amongst abstract uses of *open*: (*open a meeting*, *open a gulf*), as well as limits in usage: *#open the chair*; *#open the question*. This understanding of the permissible objects of the verb *open* has been used in defining the partial action-plan of the task-action *open*.

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Language Sound Structure

Keywords: Phonetics, Phonology

Phonetic variation sometimes seems to be an annoyance, or even an embarrassment to the elegant structures of phonological description. On the contrary, the infinite variability of phonetic interpretation rescues phonological categories and relations from the problem of their essential finiteness. Phonetic variation provides an inexhaustible body of evidence whose statistical structure reveals the nature of the underlying processes, and thus can help settle questions about phonology that might otherwise depend on evaluating the elegance of alternative accounts of the structure of a finite set of word forms.

At least, this ought to be the case. There are some problems: often, the physical measurements that we would like to have are difficult to get; very large amounts of data are usually required, due to the complexity of the underlying processes; finally, since phonetics deals with what happens when people actually talk, its interpretation requires consideration of many things besides the structure of the linguistic message narrowly conceived.

One way forward involves concentrating on cases where easily-derived acoustic measurements are fairly close to linguistically-motivated dimensions (e.g. vowel formants, F0); constructing experimental designs that maximize variation in dimensions that help choose among alternative models, while minimizing sources of unmodeled variation; and using computer technology to make the collection and interpretation of large data sets as efficient as possible. Since coming to Penn in 1990, I've tried to design Linguistics classes so that students will be able to work on real questions along these lines by the end of their second semester.

Speech and Natural Language Technology

Keywords: Speech Recognition, Speech Synthesis, Text Understanding

While working at AT&T Bell Laboratories (1975–1990), I spent much of my time developing and implementing speech and NLP technology, mainly in the area of speech synthesis, but also to some extent in speech recognition and text analysis. Like most of my colleagues in these fields, I learned that the most efficient way to build the best-performing systems was to rely on models derived from large bodies of speech and text.

One problem that became apparent was the difficulty of acquiring adequate corpora for research and development. Such acquisition (including the necessary "clean up" and annotation efforts) is unglamorous, time consuming and expensive. Nevertheless, the performance of inductive algorithms is directly dependent on the amount of data they are based on. In the mid-80's there was a great deal of duplication of effort; no one had as much data as they wanted; smaller groups, especially in universities, often had a hard time getting started at all; comparison of competing algorithms was difficult because they were usually trained and tested on different bodies of mutually-unavailable material. The experience of the DARPA-sponsored speech recognition effort provided a positive example of how valuable shared data could be in fostering a research community as well as producing concrete results.

For all these reasons, I began working several years ago on efforts to produce and distribute large-scale resources for research in speech and natural language technology. I helped to found and run the ACL Data Collection Initiative, which is now centered here at Penn, funded by grants from GE and NSF; and I serve on the boards of the Center for Lexical Research, which Yorick Wilks directs at New Mexico State, and the Penn Treebank, directed by Mitch Marcus. We are providing four gigabytes of English text for a DARPA-organized project on document retrieval, routing, and understanding. Moreover, Penn has been designated as the host institution for the DARPA-initiated Linguistic Data Consortium. Although a great deal of work remains to be done, we have come a long way in providing the infrastructure for research and development in this area of work. Penn is playing a leading role both in developing the resources for such research, and in exploring the research problems themselves.

Models of Linguistic Inference

Keywords: Language Learning, Linguistic Theory

For entirely practical reasons, the last decade has seen an upsurge of engineering interest in models of speech and language that learn crucial parameters by statistical induction from large bodies of speech or text. Such models are favored simply because they are cheaper to produce and maintain, and work better.

Having participated in this "sea change" through engineering work in speech synthesis, speech recognition, and text analysis, I've been interested in exploring the lessons it offers for linguistic theory. The most obvious one concerns the famous question of "negative evidence," which obviously has a very different status in abstract models of language that induce (or even bound) a probability measure over the infinite set of sentences that they admit. Under appropriate assumptions, access to positive evidence in such cases can provide the same information as access to negative evidence.

A second important issue is the distinction between the number of parameters in a model and the inherent complexity of inducing them from (possibly noisy) evidence. There can obviously be cases where a very large number of parameters are computationally easy to estimate, given adequate data; and also cases where optimal estimation of a relatively small number of parameters is computationally intractable.

In general, it seems to me that linguistic argumentation about language learning over the past few decades has been based on an unwisely narrowed conception of the inductive process and its outcome. Broadening the horizons a bit is likely to lead to quite different conclusions, or at least different boundary conditions on theorizing.

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The Design and Implementation of a Massively Parallel Knowledge Representation and Reasoning System: A Connectionist Approach

Keywords: Knowledge Representation, Reasoning, Connectionism

Systems that model human cognition must use massive parallelism in order to react in real-time. Connectionist models, with their inherent parallelism, seem to be promising architectures for modeling cognition. In exploring such architectures, an understanding of real-time reasoning over a large body of knowledge would offer significant insight into the cognitive as well as practical aspects of knowledge representation and reasoning.

My research investigates mapping structured connectionist models onto existing general purpose massively parallel architectures with the objective of developing and implementing practical, real-time connectionist knowledge base systems. SHRUTI, a connectionist knowledge representation and reasoning system which attempts to model reflexive reasoning, will serve as our representative connectionist model. I am researching efficient and effective ways of mapping SHRUTI onto the CM-2—an SIMD architecture—and the CM-5—an MIMD architecture. In my proposal, I suggest evaluating and testing the resulting system by encoding large, real-world knowledge bases, and achieving real-time performance with knowledge bases consisting of over a hundred thousand rules and facts. Using the resulting system as a simulation tool, psychologically significant aspects of reflexive reasoning will also be explored.

I hope that the proposed research will advance the state of the art in simulating connectionist networks on massively parallel machines and in developing large yet efficient knowledge representation and reasoning systems. I also hope to further our understanding of the nature of reflexive reasoning and evaluate its practical and cognitive significance.

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Deducing Linguistic Structure from Large Corpora

Keywords: Parsing, Stochastic Natural Language Processing, Automatic language acquisition, Annotated databases

Automatic Acquisition of Linguistic Structure

Within the past several years, a widening circle of researchers have begun to investigate a new set of techniques for the use of trainable systems in natural language processing. The early successes of these new techniques, coupled with other advances, have allowed the emergence of a new generation of systems that both extract information from and summarize pre-existing text from real-world domains.

A group of us at Penn have initiated a research program to see how far the paradigm of trainable systems can take us towards the fully automatic syntactic analysis of unconstrained text and towards the automatic acquisition of grammatical structure from both annotated and unannotated text corpora. This research is investigating both statistical and symbolic learning methods using both supervised and unsupervised approaches.

Fundamental to our project is an attempt to unite different linguistic traditions often viewed as mutually exclusive. Thus, this work aims to combine the research program of generative grammar, as set forth originally by Noam Chomsky, and the research paradigm of distributional analysis, as developed by the American structural linguists resulting in the mathematical and computational work of Zellig Harris. For an overview of this point of view, see [3]. Similarly, our approach to language learning rests on the premiss that, in addition to exploiting a core of fundamental linguistic properties shared by every language, learners must also employ the technique of distributional analysis to discover a very wide range of potentially idiosyncratic language-particular linguistic phenomena.

Stochastic Parsing

In an experiment two years ago, we investigated how distributional facts can be used to choose between the multiple grammatically acceptable analyses of a single sentence. The resulting parser, Pearl, [2] differs from previous attempts at stochastic parsers in that it uses a richer form of conditional probabilities based on context to predict likelihood. Tested on a naturally-occurring corpus of sentences requesting directions to vary locations within a city (the MIT Voyager corpus), the parser correctly determined the correct parse (i.e. gave the best parse first) on 37 of 40 sentences. We are now beginning a collaboration with the Continuous Speech Recognition Group at IBM's Thomas Watson Laboratory to develop a new generation of stochastic parsers, based on decision tree technology utilizing a rich set of linguistic predicates, and trained on output from both the Penn Treebank (see below) and the Lancaster Treebank. (A first version of such a parser [1] developed at IBM, with Magerman's participation, can be viewed as an extension of Pearl.)

The Penn Treebank Project

We have been working on the construction of the Penn Treebank, a data base of written and transcribed spoken American English annotated with detailed grammatical structure. This data base, although now only in preliminary form, is serving as a national resource, providing training material for a wide variety of approaches to automatic language acquisition, a reference standard for the rigorous evaluation of some components of natural language understanding systems, and a research tool for the investigation of the grammar and prosodic structure of naturally spoken English.

The Penn Treebank project has just completed its first, three-year phase. During this period, 4.5 million words of text were tagged for part-of-speech, with about two-thirds of this material also annotated with a skeletal syntactic bracketing. All of this material, now available in preliminary form on CD-ROM through the Linguistic Data Consortium (LDC), has been hand-corrected, after processing by automatic tools. The largest component of the corpus consists of materials from the Dow-Jones News Service; over 1.6 million words of this material has been hand parsed, with an additional 1 million words tagged for part of speech. Also included is a skeletally parsed version of the Brown corpus, the classic million word balanced corpus of American English. This corpus has also been hand-retagged using the Penn Treebank tag set. Smaller tagged and parsed subcorpora include 100K words of materials from past ARPA Message Understanding Conference (MUC) and 10K words of sentences from the ARPA-sponsored Air Travel Information System (ATIS) spoken-language system project.

The error rate of the part of speech tagged materials (done several years ago) is estimated at approximately 3%. About 300,000 words of text have been corrected twice (each by a different annotator), and the corrected files were then carefully adjudicated, with a resulting estimated error rate of well under 1%. All the skeletally parsed materials have been corrected once, except for the Brown materials, which were instead quickly proofread an additional time for gross parsing errors.

Earlier material, released through the ACL/Data Collection Initiative, has been used for purposes ranging from serving as a gold-standard for parser testing, to serving as a basis for the induction of stochastic grammars (including work by groups at IBM, and a collaboration between Penn, AT&T Bell Labs and Harvard University), to serving as a basis for quick lexicon induction for the MUC task (in unpublished work at BBN.)

The Penn Treebank Project, now in its second phase, is working towards providing a 3 million word bank of predicate-argument structures. This is being done by first producing a corpus annotated with an appropriately rich syntactic structure, and then automatically extracting predicate-argument structure, at a level of detail which distinguishes logical subjects and objects, as well as distinguishing arguments from adjuncts (for clear cases). This syntactic corpus will be annotated by automatically transforming the current Penn Treebank into a representational structure which approaches that of the intended target, and then completing the conversion by hand. The preliminary version of the corpus is being substantially cleaned up at the same time. The second release of the Penn Treebank should be available through the LDC in late 1993. For more information, see [4].

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Plans for Search Behavior

Keywords: Planning, Knowledge and Action

People often do not know where things are and have to look for them. My research presents a formal model suitable for reasoning about how to find things and acting to find them, which I will call "search behavior". Since not knowing the location of something can prevent an agent from reaching its desired goal, I argue that the ability to plan and conduct a search increases the variety of situations in which an agent can succeed at its chosen task.

Searching for things is a natural problem that arises when the blocks world assumptions (which have been the problem setting for most planning research) are modified by providing the agent only PARTIAL knowledge of its environment. Since the agent does not know the total world state, actions may APPEAR to have nondeterministic effects. The significant aspects of the search problem which differ from previously studied planning problems are the acquisition of information and iteration of similar actions while exploring a search space.

Since introduction of the situation calculus [2], various systems have been proposed for REPRESENTING and REASONING about actions which involve knowledge acquisition and iteration, including Moore's work on the interaction between knowledge and action [3]. My concern with searching has to do with a sense that Moore's knowledge preconditions are overly restrictive. Morgenstern [5] examined ways to weaken knowledge preconditions for an individual agent by relying on the knowledge and abilities of other agents. Lesperance's research [1] on indexical knowledge is another way of weakening the knowledge preconditions. My approach is to reduce the amount of information an agent must know by capitalizing on the agent's ability to search a known space. For example, if you dial the right combination to a safe it will open, whether or not you knew in advance that it WAS the right combination. Search is a way to guarantee you will eventually dial the right combination. So what I am exploring is how to systematically construct a search that will use available knowledge to accomplish something the agent does not currently know enough to do directly. Such systems can be used to infer properties of plans which have already been constructed, but do not themselves CONSTRUCT PLANS for complex actions.

I am presently modifying a system for hierarchical planning to create a system for constructing and executing plans for search behavior.

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A Computational Model of Syntactic Processing: Ambiguity Resolution from Interpretation

Keywords: Garden Path, Parsing CCG, Late Closure

Natural language contains ambiguities on many levels, of which my dissertation addresses two: part of speech selection and syntactic structure assignment. A central question is how are people able to cope so effortlessly with the considerable computational task of language understanding? One intriguing hint about this process of syntactic disambiguation is the existence of grammatical sentences such as Bever's example:

(1) The horse raced past the barn fell.

Ambiguity early in this sentence "tricks" the reader/hearer into committing to the ultimately incorrect analysis. The overall research strategy then is to collect evidence of situations where the process succeeds and fails, and to construct theories in computational terms. While just about all extant theories of sentence processing have recognized the role of meaning, most consider purely structural aspects as well. My thesis is that it is solely meaning which determines which grammatical alternative is chosen. It follows that the processor is a very simple device, consisting of a blind all-paths syntactic-rule-applier, and a meaning-based controller which performs the disambiguation. Here I consider three aspects of my project: a reexamination of a structural disambiguation strategy, formulation of a parser, and my proposed ambiguity resolution scheme.

One of the most successfully exploited structural disambiguation strategies is Right Association [4]. It states that modifiers prefer to attach as low as possible in the phrase structure. While other structural disambiguation strategies have recently been argued to be artifacts,[1] arising only in a limited set of circumstances, I am aware of no such claims about Right Association. Through an investigation of the Penn Treebank corpus of syntactically annotated newspaper reports, I argue that this principle is often violated, especially when the modifier in question is "syntactically heavy". It follows that the data adduced in support of this principle can be explained by the same competence mechanism which is responsible for other heaviness related phenomena such as dative shift and heavy-NP shift. The need for the structural ambiguity resolution criterion in the parser is eliminated.

The structural preference for Late Closure [3] is a generalization of Right Association. It has been used to account for the difficulties in:

(2) When the cannibals ate the missionaries drank.

I argue that the difficulty with this and other sentences, where a noun phrase is temporarily ambiguous between serving as a subject or in some other role, results not from any parsing strategy, but rather from the fact that the ultimately correct analysis requires putting new information in subject position — in violation of well-known principles of the linguistic competence.

[1] Minimal Attachment [2, 5]

Examination of sentences such as the examples above indicates that the meaning of a word is integrated into the meanings of the various syntactically defined possibilities immediately after the word is encountered. This condition of timely semantic analysis, along with the desideratum of simplicity in the parser, places certain requirements upon the form of the competence grammar. I adopt, and follow up on, Steedman's work on Combinatory Categorial Grammar (CCG, [10]) as a formalism which satisfies these constraints. I consider various proposals for coping with the additional nondeterminism which CCG entails. I focus on the formulation of the parsing operation called REVEALING [9]. Deploying the method of term rewrite systems I provide a sound, complete, and efficient parser for CCG. This work is potentially applicable to bottom-up parsers for any grammatical formalism which share CCG's associativity of derivation.

For the central project of my dissertation — a demonstration of how meaning could be used to resolve all syntactic ambiguity, I construct a model of an interpreter which considers certain aspects of meaning: filler-gap relations, reference resolution, thematic relations, and a form of heaviness. The role of reasoning is minimized. Using this model, I explore many specific questions, among them:

- How long is ambiguity maintained before it is resolved?
- How are conflicts in ambiguity resolution preferences resolved?

I test the resulting model on human performance data available from psycholinguistic research and from other naturally occurring and artificially constructed examples.

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Event Description in Causal Explanation

Keywords: Event description, Causation, Explanation, Theories of Action

I have been examining the role of event description in causal explanation. My work can be divided into two areas: (1) providing a semantics for a set of periphrastic causatives commonly used to draw connections between events (e.g., *causes, forces, enables, prevents,* etc.), and (2) examining the pragmatic factors that influence the choice of description for events that stand in causal relations. Previous work in this area has neglected the communicative role that an event description plays in an explanation. For example, in [5], event descriptions are built into the representation of whatever system is being explained.

Although an event can be named in many different ways, no single name exhausts the nature of the event. Further, no single property of an event can always count as the event's intrinsic nature. For example, contrast the statement *Falling from the roof caused him to fracture his leg,* with *Coming down from the roof caused him to fracture his leg.* The first seems to better capture the nature of the event in question, in terms of drawing the desired connection with prototypical falls and fractures. However, given that observation, one could just as well have employed the following description for the same event: *Because of his falling 20 feet, in the earth's gravitational field, through the earth's atmosphere, onto a hard surface,.... he suffered a fracture,* which violates Grice's maxim of quantity by being overly descriptive. In normal conversation, many of the conditions mentioned would be understood by a prevailing context. In contrast, *Because of gravity he suffered a fracture,* though naming a necessary condition of the fall, inappropriately picks out what should be an element of the background context. I claim most causal explanations are framed in terms of some background assumptions; the choice of event description therefore depends strongly on the content of those assumptions.

In order to motivate and test this work, I plan to implement a question answering interface to an arcade-style video game similar to [1] involving a group of agents engaged in simulated tasks. Given a scenario of primitive events, the states of agents (including their beliefs and intentions), and a set of causal rules, my goal is the development of a program to produce event descriptions that best explicate relationships between pairs of events.

On the theoretical side, I have, to date, investigated the semantics of event prevention [4] and the use of negative action descriptions. The notion of event prevention is important for both planning and explanation. In planning tasks an agent may often find himself in a situation demanding that he choose an action that would prevent some unwanted event from occurring. Similarly, in tasks involving the generation of descriptions or explanations of sequences of events, it is often useful, as I have already mentioned, to draw as many informative connections as possible between events in the sequence; often this means explaining why certain events are not possible. In [4] I argue that a naive semantics which equates prevention with the elimination of all future possibility of the event in question is often difficult, if not impossible, to implement. I argue for a more useful semantics which falls out of some reasonable assumptions regarding restrictions on the set of potential actions available to an agent: (1) those actions about which the agent has formed intentions,

(2) those actions consistent with the agent's attitudes (including its other intentions), and (3) the set of actions evoked by the type of situation in which the agent is embedded (for example, in a traffic situation, the set of actions defined by the vehicle code). I present these constraints in a modification of Cohen and Levesque's logic of belief and intention [2].

With respect to negative action descriptions, I have been examining the use of action descriptions involving cases of (1) DISPLACEMENT REFRAINING in which some positive action is performed by an agent as a way of not doing some other action; (2) RESISTINGS in which an agent performs some positive action as a way of obviating some inevitable event from occurring; (3) action FAILURES in which an agent is not aware that the expected circumstances for some intended action do not obtain; (4) simple REFRAINS which cannot be redescribed in terms of some positive action but which do constitute an action by virtue of the agent's mental state: in such cases the agent knows some option is possible but simply refrains from performing it; and (5) OMISSIONS which also do not necessarily involve a positive re-description but which might represent the most appropriate description from the point of view of a hearer's expectation of the positive counterpart. Once again, I am attempting to formalize some of these notions in variants of Cohen and Levesque's logic of belief and intention. Permitting negative events introduces representational difficulties. For example, saying that an agent has not-α-ed is stronger than saying that α did not occur. This would imply, if one were to adopt a Davidsonian approach [3], that the statement would be equivalent to $\neg\exists e.\alpha(e)$. However, this would not capture the above sorts of cases.

Finally, I am examining the pragmatic factors involved in choosing a negative description over a positive one. Consider a video-game scenario [1] in which a character called an Amazon is attempting to get to an object called a scroll within a certain span of time and picking up a potion would give it extra powers needed to get to the scroll more quickly. Then, the statement *Not picking up the potion prevented the Amazon from getting to the scroll on time* seems more appropriate than *#Proceeding to the scroll prevented the Amazon from getting to the scroll on time,* on the grounds that the first names a wider class of events. The choice of description also influences the choice of relation. Consider the case in which stopping would simply be a waste of time. Then: *#Not picking up the potion* **caused** *the Amazon to get to the scroll on time,* seems improper on the grounds that a negative event should not "cause" a change in state; whereas *Not picking up the potion* **enabled** *the Amazon to get to the scroll on time,* seems to correctly pick out the desired relation.

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Quantification and Semantic Interpretation

Keywords: Quantifier scope ambiguity, Scope-neutral representation, Semantic evaluation

Approaches to quantifier scope ambiguity to date can be classified into two broad categories, namely generate-and-see and wait-and-see. As the name implies, generate-and-see approaches produce completely scoped logical expressions right after syntactic analysis is done, but before any semantic interpretation is tried. Further clues from the context before and after the sentence in question as well as an appropriate discourse model are supposed to filter out irrelevant scoped logical expressions to a sufficient degree, DURING semantic interpretation. Most known approaches to quantifier scope ambiguity fall under this category [1, 2, 3, 5, 9, 11, 12, 14, 16]. Wait-and-see approaches start with scope-neutral but well-formed logical expressions and refine them as more evidence is collected during the process of semantic interpretation [7, 6, 10, 13]. There is no logical expression to be filtered out, since irrelevant logical expressions have never been around in the first place.

In this project, I am looking into a third possible approach to quantifier scope ambiguity. In this case, tagged scope-neutral expressions are made available during syntactic analysis, which are then fed directly into a semantic EVALUATION module. It is an assumed but not critical fact that the complexity of a semantic evaluation module is substantially lower than a full-fledged semantic interpretation module. Tagging provides a clue to the semantic evaluation module to discard certain ordering relations among quantified NPs. For example, the sentence *Three Frenchmen visited five Russians* may be assigned one of the following three tagged scope-neutral expressions:

(1) a. **`visited(five(russians),three(frenchmen))`**

b. **`visited(*five(russians),three(frenchmen))`**

c. **`visited(five(russians),*three(frenchmen))`**

The untagged or null-tagged logical form (1a) corresponds to a written form or a monotonous utterance of the sentence, while (1b) and (1c) correspond to utterances of the sentence where *five Russians* and *three Frenchmen* are respectively stressed. Suppose that our discourse model has a situation such that there are three Frenchmen each of whom visited a group of five Russians, but not necessarily the same group. If we have evidence to claim that quantified NPs if stressed always take wide scope over unstressed ones, our semantic evaluation module should respond to the logical forms (1a), (1b) and (1c) by returning the values **`<true,subject>`**,[1] **`<false>`** and **`<true>`**, respectively. A possible tagged scope-neutral expression for another sentence *Every representative of some company saw most samples* is shown below.[2] (The tagging scheme is for illustrative purpose only. A more helpful tagging scheme would reveal the relative stressing between the two quantified NPs, for instance.)

[1] The sentence is true with this model, provided that the subject NP takes wide scope.

[2] As a side note, the reason I have used a non-standard notation for the semantic form of complex quantified NPs is to retain surface word order in the semantics in order to facilitate proper specification of binding theory (cf. Jacobson [8], Chierchia [4] and Steedman [15]). In a way, any notation that reflects the underlying structure, or the obliqueness hierarchy as Steedman [15] calls it, will do.

(2) saw(*most(samples),of(*some(company),every(representative)))

There are a number of advantages of the proposed approach to quantifier scope ambiguity over the other approaches to date. Three of them are discussed.

First, a clean interface between logical form and phonetic form is now established. (Recall that in Government and Binding framework to date, there is no acknowledged interface between LF module and PF module.) It is possible to augment generate-and-see approaches to accommodate intonation information, but the process of choosing the appropriate completely-scoped logical forms that satisfy the constraint provided by intonation is at best ad hoc, mainly due to the redundancy inherent in the two forms, logical and intonational. Wait-and-see approaches can also be augmented, but the resulting logical forms will be very round-about, since scope-neutral BUT WELL-FORMED logical forms are not replaced but just augmented. For example, these approaches would produce a logical form that roughly looks like *visited(five(russians), three(frenchmen)) & |domain(visited)| = 3* for the sentence *Three Frenchmen visited five Russians* where *three Frenchmen* is stressed. One would rather expect to see a completely scoped logical form for an appropriately stressed (thus unambiguous) sentence, with no intervening intermediate scope-neutral logical form. By contrast, the proposed approach would only require to put an additional stress information for the semantic form of a quantified NP e.g. three(frenchmen) in order to accommodate intonation, without affecting any other part of the logical form. Notice also that this interface between logical form and phonetic form is bidirectional, in that one can make use of the output such as <true,subject> to influence phonetic form.

Second, the need to generate all the completely scoped but mostly irrelevant logical forms is gone, yet relevant scoping information can be retrieved in an efficient way. Generate-and-see approaches would require either a serial off-line generation phase for all the available scoped logical forms or a parallel derivation-dependent phase for each of the available scoped logical forms. None of these extra phases is linguistically justifiable. Wait-and-see approaches tie with the proposed approach on this count.

Third, since the proposed approach retains crucial surface word order information in the logical form, it is straightforward to state binding condition on the logical form, without ever consulting other sources. This is an advantage gained by unifying all the information in the single structure, that has not only logical information but also other information, syntactic and phonetic. (Steedman [15] calls this *surface structure*, though his surface structure does not require logical forms to be fully specified as to scope.) For example, there is a constant debate within the GB approach, as to the level(s) of representation binding theory is supposed to work with. Evidence that versions of binding theory work with S-structure, LF, and perhaps PF, makes one wonder if binding theory itself is ubiquitous across levels of representation, or if those levels of representation contain redundant information and are unifiable. (A similar point has been raised by Steedman [15].) For clarification, the proposed approach starts with the logical form shown in (3b) for the sentence in (3a):[3]

(3) a. Some man gave every actress whom he met a book that she appreciated.

b. gave(a(book,appreciated(1,she)),every(actress,met(1,he)),some(man))

A *c*-command relation defined on logical forms can account for how the pronouns in (3b) function as bound variables. Compare this with the following unacceptable sentence (with

[3] 1 signifies the role that is played by an individual constrained by its innermost quantifier. One may for the moment think of this as a kind of variable, bound by the quantifier. This characterization is not quite correct, though.

its logical form):[4]

(4) a. * Some man gave a book that she appreciated to every actress whom he met.

b. `gave(every(actress,met(1,he)),a(book,appreciated(1,she)),some(man))`

Notice the difficulty of specifying this condition for generate-and-see approaches. If it is indeed possible to specify this condition for wait-and-see approaches, the task must require a serious reconstruction of the information that is already present in the original surface word string.

I have developed three theses so as to properly characterize quantifier scope ambiguity: orthogonality, boundedness and correspondence. The core of the algorithm for the semantic evaluation module evaluates tagged scope-neutral expression in a provably optimal way and works for any complex quantified NP, as in (2), of an arbitrary modifying depth. It also has a natural account for coordination. I am working on implementing the idea in a natural language interface to a logical query system.

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Acquisition of Word Meanings

Keywords: Word learning constraints, Syntax-semantics links, Adjectives, Mass-count nouns

My primary area of interest is how children learn the meanings of words. The basic problem in learning the meaning of a word is that the evidence the learner has concerning the meaning of a novel word is consistent with an infinite set of meanings. Researchers interested in word learning have proposed that the hypotheses about word meanings that are considered by the learner are constrained by syntactic, semantic, and pragmatic knowledge. In my research, I have focused on syntax-semantics links and whether they can be used by young children to constrain their hypotheses about the meaning of a novel word.

In particular, I have proposed that the default interpretation of the structural relation between a prenominal adjective and its complement is one of restriction [1]. Thus, in an example such as *John touched the big dog*, the adjective will be interpreted as restrictive. Only if it is not possible to make a restrictive interpretation is an appositive interpretation made. The proposal accounts for certain restrictions on the ordering of adjectives (e.g. why *big red plastic bat* is preferred to *plastic red big bat*) [1]. Furthermore, the proposal can be used to motivate constraints on the meanings of novel adjectives. For example, it predicts that in a sentence like *I want a fep table*, it should be more likely that *fep* is interpreted as naming a value on a dimension on which tables vary (e.g. shape, size), than a dimension on which they do not vary (e.g. flatness, hardness). This heuristic for learning the meaning of a novel adjective was tested and found to be used by children as young as two-and-a-half to three-and-a-half years [1]. Another heuristic that is motivated by the proposal is that a prenominal adjective is more likely to name a non-standard value than a standard value. There is some evidence that three year olds can make use of this heuristic when learning the meanings of novel adjectives. Finally, the proposal suggests that given knowledge of an adjective meaning, one can make certain inferences about the properties of the things named by the noun. I am currently running further experiments to investigate the extent to which syntax-semantics links between adjectives and their complements can be exploited in word learning. Another question being investigated is how the structural relation comes to have this default interpretation: Is it due to properties of the input, or is it due to our knowledge of how this structural relation is to be interpreted?

A second domain in which I am investigating syntax-semantics links in word learning is in the acquisition of count and mass nouns. I am currently working on carefully specifying the semantic relation that underlies this syntactic distinction. Getting a proper characterization of the distinction will be crucial in conducting experiments on the factors that are relevant to how the quantificational properties of determiners and novel nouns are learned. In addition to the role of syntax-semantics links, I am interested in the role that nonlinguistic knowledge may play in the acquisition of word meanings, and have done some work on children's acquisition of names for solid substances and their nonlinguistic knowledge of solid substances [3].

Representation of knowledge of inflectional morphology

Keywords: Rules, Connectionism, Processing

It is common in linguistics and psychology to represent our knowledge of language in terms of symbols and rules that are used to concatenate symbols together. For example, knowledge of how the past tense form of a verb is formed in English is stated as the concatenation of the morpheme /d/ with the stem of the verb. Exceptions to this rule are presumed to be stored in memory, and the rule is said to apply whenever there is no irregular form stored in memory. Recently, however, the notion that our knowledge of language is represented in terms of rules has been challenged [6, 7]. It has been proposed that rules such as the past tense rule in English are epiphenomenal and that the productivity accounted for by rules can be accounted for through generalization on the basis of similarity which arises in parallel distributed processing models. In research done in collaboration with Steven Pinker at M.I.T., I have investigated how we represent knowledge of the past tense in English using studies that use reaction times [4], questionnaires [5, 2], and simulations [2]. The results of these studies strongly suggest that knowledge of the past tense in English requires the notion of a default symbolic rule and that this knowledge cannot be reduced to patterns of association.

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Intonation in Spoken Language Generation

Keywords: Intonation, Speech Synthesis, Generation, Combinatory Categorial Grammar

Text-to-speech systems often produce intonation contours that are improper or unnatural in certain contexts, primarily due to the lack of consideration of syntactic, semantic and discourse level structures. Without such considerations, speech synthesis systems are unable to produce the necessary intonational variations shown in the responses below:

(1) Q: I know the old widget has the slowest processor,
but which widget has the FASTEST processor?
L+H* LH% H* LL%
A: The NEW widget has the FASTEST processor.
H* L L+H* LH%

(2) Q: The old widget has the slowest processor,
but which processor does the NEW widget have?
L+H* LH% H* LL%
A: The NEW widget has the FASTEST processor.
L+H* LH% H* LL%

The intonation contours in these examples (shown in Pierrehumbert-style notation, see [2]), are quite different and cannot be interchanged without sounding strikingly unnatural. The goal of this project is to build a response generator that can produce such prosodic variations with a simple, domain-independent discourse model.

The tunes shown in these examples (*L+H* LH%* and *H* LL%*) associate different discourse functions with the constituents over which they are distributed. In the paradigm of *wh*-queries and responses, the *L+H* LH%* tune seems to represent the THEME of the utterance–what the discourse participants are talking about. The *H* LL%* tune, on the other hand, marks the RHEME–what is being said about the theme. Moreover, the placement of the pitch accent (*L+H** or *H**) within such a tune marks the focus of the interpretation of the theme or rheme.

In the examples shown above, one can easily see that intonational phrase boundaries do not necessary correspond to traditional syntactic boundaries. Steedman, however, has previously argued that under flexible notions of syntactic constituency offered by Combinatory Categorial Grammar (CCG), syntactic and prosodic bracketing can be considered isomorphic [4, 5]. We exploit this work in building a database query system that produces intonationally-natural spoken responses.

Input to the database query system is given textually with intonation represented symbolically using Pierrehumbert's notation. A CCG-parser of the type described in [1] determines a semantic representation for the query as well as interpretations for its thematic and rhematic constituents. The semantic representation for a *wh*-question is represented as an open proposition in the lambda calculus.

The semantic representation of the question is employed by a "strategic" generation module to produce a semantic representation for the response, accomplished by instantiating the variable in the open proposition. The representations for the theme and rheme of the response are determined by mapping the rheme of the question onto the theme of the response. Our current research is aimed at developing a theory for determining the focused elements of the response semantics.

A "tactical" generator works from the output of the strategic generator to produce a string of words for the response along with appropriate intonational annotations. The top-down generation mechanism employs a "functional"-head-driven scheme that utilizes the same CCG rules as the parser. The output string can then be easily converted to input for a text-to-speech system, without modifying the underlying design or algorithms of the speech synthesizer. Currently we use the Bell Laboratories TTS system to produce our spoken results.

Current research is aimed at incorporating a proper theory of focus into the strategic generation mechanism, for the purpose of conveying contrastive distinctions and emphasis licensed by the discourse model.

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Discourse/pragmatics

Keywords: Discourse Functions of Syntax, Reference, Language contact, Yiddish

I am interested in that part of linguistic competence that underlies the use of particular linguistic forms in particular contexts, where the choice is not entailed by sentence-grammar or truth-conditional meaning. In particular, I am interested in the choice of referential expressions and syntactic constructions. I am also interested in the effects of language contact on this domain. The bulk of my research has focused on English and Yiddish.

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The study of reasoning and visual perception

Keywords: Knowledge Representation, Diagnostic Reasoning, Object Recognition, Probabilistic Approaches to AI

My main areas of research interest are Artificial Intelligence (AI) and Computer Vision. The AI research focuses on Knowledge Representation and Reasoning (KR), and the application of KR techniques to diagnostic reasoning. My theoretical KR research involves the design of efficient general-purpose representations and algorithms. The representations studied include both logic-based and uncertainty-based (e.g. probabilistic) approaches. Current research projects include analysing how to create a database to both store knowledge about the world and to update this knowledge when new information arrives. I address this dynamic database consistency maintenance task by using a formal analysis to identify more efficient algorithms.

A second AI research area, model-based diagnosis, aims to extend existing diagnostic reasoning formulations by incorporating crucial aspects of the task, such as treating system abnormalities, planning courses of treatment, and using utility functions to rank treatments and diagnostic hypotheses. On the practical side, these issues are being addressed in the development of probabilistic diagnostic tools for the diagnosis over time of acute abdominal pain and of Graft versus Host Disease, and in the development of qualitative simulation models of the cardiovascular system to aid in trauma management.

My vision research focuses on high level vision, particularly model-based object recognition. This involves storing representations of object models, and using these stored models to speed the identification of unknown objects in a given scene. This is an area in which techniques from statistical artificial intelligence as well as computational vision must be used, both in building the databases of stored models and reasoning about the relationship of models to image data, and in analysing the image data. The use of task-dependence issues, functionality and active perception to facilitate efficient recognition are future research topics.

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Formal and Computational Systems for Natural Language Syntax

Keywords: Mathematics of Language, Natural Language Syntax, Psycholinguistic Modeling

My work is concerned with the adequacy of formal systems for the representation of syntax [7]. The work comprises three parts: a formal study in which the formal properties of linguistic phenomena are investigated and compared to those of formal systems; a linguistic study in which I investigate how current linguistic research can be expressed in different formal systems; and a processing study, in which formal models of computation are investigated with respect to their usability of models of human syntactic processing.

As an example language, I use German. German is interesting from both a linguistic and a formal point of view because it shows two distinct types of word-order variation, topicalization and scrambling. In topicalization, a sentence element moves past the finite verb (in second position) into sentence initial position. Topicalization is found in many European languages, including English. Scrambling refers to word-order variation between the finite verb in second position and the clause-final non-finite verb(s). Scrambling is found in many verb-final languages, including Hindi, Japanese, and Korean. In modeling German syntax, two challenges must be met:

- Topicalization and scrambling have different linguistic [1], formal [8], and processing properties, which must be reflected by the model.
- Scrambling leads to a large number of word orders, many of which are of intermediate grammaticality. This "grey zone" must be accounted for.

The basis for my approach is Tree Adjoining Grammar (TAG). I propose to handle topicalization by adjunction, as has been proposed for English [5]. Scrambling, on the other hand, I propose to handle by multi-component adjunction, as proposed for Korean by Lee [6]. In order to integrate both solutions, a formal variation on the multi-component TAG (MC-TAG) system of Weir [13] is used. In the new system, the requirement for simultaneous adjunction is lifted. Interestingly, this decreases the formal power of the system, making it both semi-linear and polynomially parsable [12]. I propose principles of instantiating natural language grammars in this formalism based on the notion of "predication" as used by Heycock [2]. I present a fragment of a grammar for German, and briefly discuss parametric variation in Bavarian, English and Yiddish. Finally, I present a formal automaton model which is formally equivalent to the proposed MC-TAG variant. Following Joshi [3], I suggest that the formal automaton can serve as a model for human syntactic processing. An automaton that is equivalent to the fragment of German grammar makes interesting and plausible processing predictions; it can thus serve to explain the "grey zone" of grammaticality judgments and the processing differences between scrambling and topicalization [10]. Interestingly, this automaton can be defined in terms of the direct dependency between lexical items, thus providing a dependency-based parser for phrase-structure formalisms [9, 11].

Text Planning and Knowledge

Keywords: Text Generation, Text Planning, Intentions and Discourse Structure

In a separate vein of interest, I have been investigating the types of knowledge needed for planning multi-paragraph texts during the process of text generation. Recent approaches to text planning have stressed the importance of rhetoric. However, it appears that the task of relating rhetorical goals to domain knowledge is difficult and needs a type of knowledge all of its own, DOMAIN COMMUNICATION KNOWLEDGE [4]. The relationship between domain communication knowledge, domain knowledge and communication knowledge (such as rhetoric) remains to be investigated further, from both the theoretical and practical points of view.

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An Information-theoretic Approach to Selectional Preference

Keywords: Statistical methods, Lexical acquisition

"Selectional preference" is a term often used to describe constraints on permissible arguments, independent of syntactic considerations. For example, the phrase *eat a beach* is odd because *beach* violates constraints on what can appear as a direct object of the verb *eat*. In addition to its linguistic interest, this kind of knowledge about word meanings and relationships can be very useful in practical applications: for instance, a speech recognition device might be well advised to consider *eat a peach* as a more likely hypothesis about what was said.

I have been exploring a new, information-theoretic formalization of selectional preference. More generally, I have been pursuing the idea that a very limited conceptual representation (implemented using Miller's WordNet lexical database [1]), when combined with statistical, corpus-based techniques, provides a practical method for acquiring and using conceptual relationships in processing unconstrained text.

Selectional preference for an argument is defined as an information-theoretic relationship involving conceptual classes. Consider selection by verbs for their objects. When the verb is unknown, there is some baseline probability distribution over classes of nouns — for example, it may be that legumes are *a priori* less likely to be direct objects than, say, animate beings. Once the verb is specified, that distribution changes, with some classes becoming more likely and others becoming less likely. (For example, if the verb is *grow*, then legumes are more likely direct objects than animates.) It is the DIVERGENCE between these two distributions that matters — in technical terms, the relative entropy between the prior distribution $\Pr(C)$ and the posterior distribution $\Pr(C|v)$. Since this divergence can be interpreted as the amount of information you gain about C by knowing v, selectional preference is, in a very direct way, the information that the verb carries about the semantic class of its argument.

In computational experiments, I have used this definition to investigate the relationship between selectional preference and implicit objects in English [2, 3]. For some transitive verbs, an omitted direct object is understood either as existentially quantified (e.g. *eat*) or as referring to something previously specified (e.g. *win*); for others (e.g. *find*) the direct object is obligatory. The results support the conclusions that (a) verbs that permit implicit objects select more strongly for (i.e. carry more information about) their argument than verbs that do not, and (b) the actual tendency to use implicit objects is correlated with selectional preference strength.

I have also applied these techniques to the practical problem of resolving syntactic ambiguity in parsing. The particular cases I have looked at concern coordination and noun-noun compounds — specifically, the correct bracketing of a phrase like *business and marketing major* (conjoined modifiers) as compared to a phrase like *policeman and park guard* (conjoined heads). The results demonstrate that "conceptual" information, acquired using class-based statistical techniques, makes a significant contribution in avoiding syntactic misanalyses.

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Prepositional phrases and conjunction in parsing

Keywords: Statistical, Corpus, Prepositional Phrase Attachment, Conjunction

I am interested in two long standing problems in parsing natural language: prepositional phrase attachment and conjunction. Although these two problems are responsible for a large portion of the errors made by many current parsing systems, progress in both has been slow. Using statistical techniques and studying the distributional properties of language using large corpora may yield more complete solutions to these problems.

The portion of the prepositional phrase problem that interests me is determining whether a particular prepositional phrase modifies the preceding noun phrase or verb phrase. By looking at several words from a sentence and applying statistical methods, I hope to attain results on par with human performance on this task. Because people find some attachment decisions ambiguous without the context of the sentence, achieving performance greater than humans is unlikely.

Parsing natural language is greatly complicated by conjunctions. Despite the simplicity of some forms of conjunction, other forms are difficult to handle. For instance, it seems straight-forward to parse two nouns joined by a conjunction. However, the situation is more difficult when two sentences are separated by a conjunction or when ellipsis is involved. Examining the data regarding conjunction from corpora may yield better techniques which can be applied as preprocessing steps before parsing actually begins. For example, having determined that a conjunction separates two complete sentences, the sentences could be parsed individually with greater accuracy and speed than would be achieved by parsing the compound sentence as a whole.

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Reasoning in Exploratory-Corrective Domains

Keywords: Diagnosis, Planning

My thesis work centers on the general problem of reasoning in exploratory-corrective domains. Using the concrete problem of diagnosis-and-repair in multiple trauma management, I developed a reasoning architecture which integrates diagnostic reasoning and planning. This EXPLORATORY-CORRECTIVE MANAGEMENT (ECM) architecture is implemented in TraumAID 2.0, a consultation system for trauma management (Figure 3). The ECM architecture allows INTERLEAVING diagnosis and repair. It uses diagnostic reasoning, best at characterization tasks, to also set and monitor the ACTUAL achievement of diagnostic and therapeutic GOALS. It uses planning to mediate between competing diagnostic and therapeutic needs.

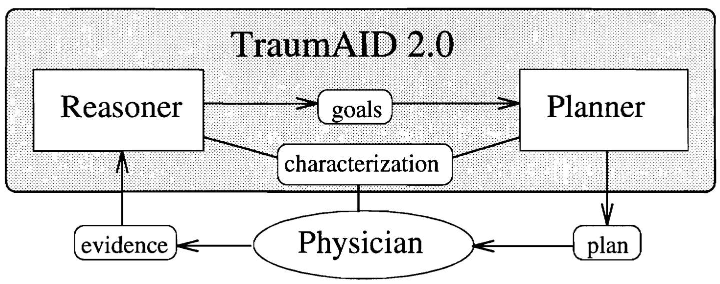

Figure 3: ECM architecture: basic cycle of Reasoning, Planning and Action

Goal-Directed Diagnosis

GOAL-DIRECTED DIAGNOSIS (GDD) [5] is a logical formalization of diagnosis that begins from the principle that DIAGNOSIS IS ONLY WORTHWHILE TO THE EXTENT THAT IT CAN AFFECT SUBSEQUENT REPAIR DECISIONS. Since in diagnosis-and-repair domains, recommendations (diagnostic and therapeutic) are often more important than a complete characterization of the problem, GDD extends the traditional notion of diagnosis as characterization to GOALS. Conflicts between competing goals can often be resolved in the goal-level without considering the alternative ways in which they can be addressed. In particular, goal-level resolution allows INHIBITING diagnostic goals that are not likely to contribute to repair decisions, thereby reducing some of the notorious complexity of planning. In addition, goals also serve as a natural interface with the planner.

Planning

PROGRESSIVE HORIZON PLANNING (PHP) [2] is an incremental planning framework in which the eventual plan being followed (THE PLAN) is shaped while it is executed. Intermediate plans, constructed in each cycle, are partially followed and then adapted based on the response, and on other events. Intermediate plans are also partial in that not all goals are known, and in that they are constructed via a partial optimization of a rough plan SKETCH. In this partial optimization, the computational effort is focused on a plan's initial segment. Intermediate plans are complete, however, in that ALL KNOWN goals are addressed.

We use a SELECTION-AND-ORDERING plan sketching algorithm [3] in which planning is functionally divided into:

1. SELECTION of a set of procedures that parsimoniously (with respect to some predefined measure of preference and cost) address the current combination of goals. This part is formalized as a set-covering problem.

2. ORDERING these procedures into a single overall plan, taking into account their respective urgency, priority, compatibility, etc. This part is formalized as constraint-based scheduling.

TraumAID 2.0's plan sketching algorithm INTERLEAVES greedy selection and ordering.

TraumAID 2.0

TraumAID 2.0 was first validated against 270 hand-crafted trauma cases. More recently, three judges (trauma surgeons) were presented, in a blind test, with 97 management transcripts of actual trauma cases and of the management that would have been recommended by TraumAID 2.0 [1]. Each judge was asked to grade each management on a 4-point scale. The following table summarizes the results:

	Perfectly Acceptable	No Major Errors	Accept. with Reservations	Unacceptable	Grade Average
Actual Care	3	39	41	14	2.39
TraumAID 2.0	17	53	23	4	2.85

In paired comparisons of management plans for all 97 cases, the judges had a significant preference for TraumAID 2.0 plans over actual plans by a ratio of 64 to 17 with 16 ties ($p < 0.001$ by binomial test).

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Complexity of recognition and parsing problems

Keywords: Recognition, Parsing, Computational Complexity

In the area of automatic processing of Natural Language, many researchers study methods for recognition and parsing of formal languages, with the aim of improving already known upper time bounds. Some problems have resisted all these attempts. One can hope to settle the issue by trying to establish some nontrivial lower time bound for these problems; unfortunately, this doesn't seem to be an easier task and these kinds of investigations are considered extremely difficult in the area of computational complexity theory.

Nevertheless, a qualitative evaluation of the complexity of a recognition or parsing problem can be obtained by the reduction of some standard problem which is known to be "tough to improve" to the problem under investigation. If this reduction has almost linear time complexity, the result can be used to show that straightforward methods for improving known upper bounds for the problem of interest are not likely to exist or should be very hard to find. At the same time, these kind of results usually reveal which features of the problem under investigation are responsible for the claimed difficulty, giving us new insight into the problem itself.

Following this line, I have recently reduced the boolean matrix multiplication problem to the Tree Adjoining Grammar (TAG) parsing problem (see [1]). The result can be used to show that any algorithm for TAG parsing that improves the already known $O(|G||w|^6)$ time upper bound, G and w the input grammar and the input string respectively, can be converted into an algorithm for boolean matrix multiplication running in less than $O(m^3)$ time, m the order of the input matrices. As a matter of fact, the design of practical algorithms for boolean matrix multiplication that considerably improve the cubic time upper bound is considered a very difficult enterprise. As a consequence, TAG parsing should also be considered "hard to improve", so there is enough evidence to think that methods for TAG parsing that are asymptotically faster than $O(|G||w|^6)$ are unlikely to be of any practical interest, i.e., will involve very complex computations.

As a second result, I have characterized the Tree Adjoining Grammar recognition problem by means of a context-free recognition problem, using again an almost linear time reduction. This result has revealed a previously unknown computational relation between self-adjunction and self-embedding, which are the two most important elementary operations underlying these rewriting systems. The consequences of the above result still need to be investigated.

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Estimating Syntactic Entropy

Keywords: Entropy, Dependency Grammar

I am interested in grammar induction from large text corpora using statistical methods. The dependency grammar formalism I have been investigating allows one to estimate a lexically based syntactic entropy. The entropy metric is useful because it is a measure of the uncertainty of the syntactic structure of a sentence relative to the grammar. The better a grammar describes syntactic structure the lower entropy. This approach is motivated in part by the part-of-speech tagging task where the entropy of the part-of-speech tag given word is very low, less than 0.3 bits per word. A grammar with a syntactic entropy this low should approach the success of today's part-of-speech taggers.

In a dependency grammar each word of a sentence is dependent on another word. The syntactic structure is described by a graph of links from all words to the part-of-speech of the word they are dependent on. In this way average syntactic entropy can be estimated in the same way that average tag entropy is estimated: Calculate the link entropy of each word in the corpus and average over the lexicon.

In an experiment we chose 40 words from the Brown Corpus for which to calculate the syntactic entropy. For each word we extracted 20 sentences containing the word and labeled the word on which it depended. We then calculated the entropy of the link of each word and averaged the result over the 40 word test sample. The preliminary results are encouraging and indicate that the average syntactic entropy is somewhere below 1.7 bits per word for our dependency grammar.

The biggest problem for further study is a lack of data. I am presently looking into automating the dependency link annotation by using already bracketed text from the Penn Treebank Project.

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Lexical Acquisition

Keywords: Lexical Semantics, Language Acquisition, Constraint Satisfaction

In the process of learning their native language, children must learn the meanings of the words in that language. For some time now, I have been studying the nature of the language acquisition task by investigating a variety of algorithms for solving a particular formal problem that is a simplified variant of the task faced by children. In this task, known as the MAPPING PROBLEM, the learner is presented with a corpus of utterances, each utterance being paired with a set of hypothesized meanings. Without prior access to any language specific knowledge, the learner must infer a lexicon mapping the words in the corpus to representations of their meaning. In previous work ([1, 2, 3]), I presented a number of different algorithms, all of which solve essentially the same formal problem. While those algorithms were successful in solving small language acquisition puzzles in English and Japanese—learning the meanings of a dozen or so words from a dozen or so utterances—they became computationally intractable when applied to larger tasks.

During the past year I have developed several novel algorithms which attempt to solve this same formal language acquisition problem, but which can scale up—in some ways—to tasks of the size faced by actual children. These new algorithms have been implemented and are able to correctly identify the word-to-meaning mappings for randomly generated English-like and Japanese-like corpora containing 20,000 utterances and 10,000 distinct words. This is the same size task (in number of word meanings acquired) as faced by real children, though for admittedly a much simplified task. Furthermore, the new algorithms are several orders of magnitude faster than the old ones and scale in an essentially linear fashion.

Two different algorithms have been developed. The first ([4]) reduces the mapping problem to a constraint satisfaction problem (CSP). This CSP can be solved using a variant of arc consistency. While a straightforward application of arc consistency would require time exponential in the length of an utterance to process each utterance in the corpus, it is possible to reduce the time needed to process each utterance to time cubic in the utterance length using a variant of the CKY algorithm.

The second algorithm ([5]) reduces the mapping problem to a propositional satisfiability problem (SAT) by instantiating a number of axiom schemas over the corpus. The SAT problems generated are then solved using the Davis-Putnam procedure. While the SAT problems that are generated are quite large, in practice they can be solved very quickly with almost no backtracking because the reduction to SAT exploits the redundant nature of the information present in the corpus.

A key difference between these new approaches and those taken in my prior work is that these new approaches learn word-to-meaning mappings primarily from semantic information alone, with only a minute amount of exceedingly general syntactic information. This is in contrast to the strategies advocated in my prior work which required tight integration of syntax and semantics, simultaneously learning word-to-meaning mappings, word-to-syntactic-category mappings, and the language specific components of syntax. By demonstrating that word-to-meaning mappings can be learned effectively by an prior independent process, it may be possible to decouple these different aspects of language acquisition into separate, more computationally tractable, stages.

Nondeterministic Lisp and Constraint Satisfaction

Keywords: Nondeterministic Programming Languages, Constraint Satisfaction

Nondeterministic LISP is a simple extension of LISP which provides four new programming constructs: **`either`**, a choice point operator; **`fail`**, a backtracking operator; **`local setf`**, a backtrackable assignment operator; and **`for-effect`**, a mechanism for controlling the nondeterminism. Together, these constructs allow concise description of many search tasks which form the basis of much of AI research. Adding nondeterminism to LISP is not new. It was first proposed by McCarthy in 1963. Several implementations have been constructed, most notably Chapman's DDL Schemer (Zabih et al.) and that of Haynes. To date, no implementation of nondeterministic LISP has proven even remotely efficient enough to be used as more than a research toy. This is because these systems attempt sophisticated search pruning strategies which incur significant runtime overhead and preclude efficient compilation. Together with David McAllester of M.I.T., I have developed SCREAMER, an efficient implementation of nondeterministic LISP as a fully portable extension of COMMON LISP. Forgoing search pruning in favor of chronological backtracking allows SCREAMER to generate extremely efficient code.

Built on top of the basic nondeterministic primitives, SCREAMER also contains a constraint solving package. This package contains all of the functionality of Van Hentenryck's CHIP system, including the ability to solve constraint satisfaction problems using generalized forward checking, propositional satisfiability problems using the Davis-Putnam procedure, nonlinear equations and inequalities using range propagation, and Herbrand equations and disequations using unification, all in a unified manner. Much of our knowledge about efficient search algorithms has been incorporated into SCREAMER making it an ideal environment for writing AI applications that need to leverage off of such knowledge without reinventing it. We have demonstrated this by using SCREAMER as a vehicle for teaching 6.824 and CIS520, the graduate core AI courses at M.I.T. and the University of Pennsylvania. Problem sets in these courses asked students to use SCREAMER to build small working versions of a number of programs which have been the focus of AI research in the past and present, including solutions to the N Queens problem, crossword puzzle solvers, Waltz line labeling, Allen's temporal logic, hardware fault diagnosis, A^* search, linear and non-linear planners, natural language query processors based on Montague grammar, theorem provers based on semantic tableaux, congruence closure, resolution, and robot path planning.

In [6], Siskind and McAllester present the basic nondeterministic LISP constructs, motivate the utility of the language via numerous short examples, and discuss the compilation techniques. In [7], we present the constraint handling extensions provided with SCREAMER, and motivate the utility of these extensions with numerous examples.

SCREAMER is available by anonymous FTP from:

`ftp.ai.mit.edu:/com/ftp/pub/screamer.tar.Z.`

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Disambiguation of Supertags

Keywords: Part-of-speech Disambiguation, TAG, Parsing

This work is jointly being pursued with Dr. Aravind K. Joshi.

Part-of-speech disambiguation techniques (taggers) are often used to eliminate (or substantially reduce) the part-of-speech ambiguities of words in a sentence. The taggers are all local in the sense that they use only local information in deciding which tag(s) to choose for each word. As is well known, these taggers are quite successful.

In Lexicalized Tree Adjoining Grammar (LTAG), each elementary structure of a grammar is associated with exactly one lexical item. Elementary structures localize dependencies such as long distance dependencies. As a result of this localization, a lexical item may be (and, in general, is almost always) associated with more than one elementary structure. We call the elementary structures associated with each lexical item 'supertags', in order to distinguish them from the usual parts of speech. For each sentence, an LTAG parser may have to to search a large space of supertags because of the many ways to associate elementary structures to the words in it; however, when the parse is complete only one supertag is assigned to each word (assuming there is no global ambiguity).

Since an LTAG is lexicalized, there is an opportunity here to eliminate (or substantially reduce) the supertag assignment ambiguity for a lexical item, even before parsing is attempted. Obviously, this would substantially prune the search space for the parser.

As in the part-of-speech taggers, there are two possibilities for constructing supertaggers—statistical and rule based. The main goal of this work is to present techniques for disambiguating supertags and their performance, and their impact on TAG parsing. Note that in the best case, when the supertagger assigns to each word only one supertag, parsing is trivial. We will also attempt to compare our results with dependency type parsers.

Feature-Based TAG in place of multi-component adjunction: Computational Implications

Keywords: Feature-Based TAG, multi-component adjunction

This work has been jointly carried out with Beth Ann Hockey.

It has been argued that the analysis of certain linguistic constructions requires an extension of the basic tree adjoining grammar (TAG) formalism to include multi-component adjunction. The restricted version of multi-component adjunction suggested for these constructions does not change the weak or strong generative capacity of the formalism with respect to derivation trees. However, while multi-component adjunction does not alter the power of the formalism it does complicate the problem of parsing since the parsing algorithm will have to handle sets of trees rather than single trees. This work demonstrates how these constructions can be handled with feature based TAG, thereby avoiding the implementation problems associated with multicomponent adjunction. This would enable the parsing of such constructions with the current implementation of the feature-based TAG parser [4].

Our analysis first develops the alternative suggested by Kroch and Joshi [3] of handling extraposition with features and then extends the approach to the other cases in English that appear to require multi-component adjunction such as extraposition, extraction from PP adjuncts and extraction from the indirect questions. The feature based TAG analyses for these cases are as linguistically well motivated as analyses that require multi-component adjunction (e.g. [3]). Our feature based TAG analysis for extraction from recursively embedded NP's is superior to the analysis using multi-component adjunction proposed by Kroch [2].

Thus feature based TAG analyses show that the implementation difficulties associated with multi-component adjunction can be avoided without sacrificing linguistic coverage.

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Combinators and Grammars for Natural Language Understanding

Keywords: Computational Linguistics, Syntax and Semantics, Speech, Combinatory Logic, Cognitive Science

My research interests cover a range of issues in the areas of computational linguistics, artificial intelligence, computer science and cognitive science, including syntax and semantics of natural languages and programming languages, parsing and comprehension of natural language discourse by humans and by machine, natural language generation, and intonation in spoken discourse. I also work on formal models of musical comprehension.

Most of my research since completing my graduate work has been on two problems in computational linguistics. The first concerns a theory of natural language syntax and its relation to "incremental" syntactic and semantic processing of spoken and written language. The research demonstrates a direct relation between certain problematic natural language constructions and certain purely local, variable-free, combinatory operations on functions, such as functional composition. The constructions in question involve unbounded dependencies between syntactic elements, such as those found in relative clauses and in coordinate constructions. The combinatory operations are related to some of the simplest combinators which have been used to provide a foundation for applicative systems such as the lambda calculus and the related programming languages. The research addresses a number of questions of practical importance. The weaknesses of most current theories of grammar in the face of the full range of coordination phenomena means that existing computational grammars have the characteristics of unstructured programs – that is, they are non-modular and hard to modify, placing practical limitations on the size and portability of the systems that include them. The standard theories show a similarly bad fit to a number of other phenomena of practical importance, notably phrasal prosody and intonation. Most of my current work is in this latter area, in particular in the problem of synthesising contextually appropriate intonation in limited conversational domains.

My second principal research interest concerns a computationally-based semantics for tense and temporal reference, and exploits the advantages of computational models for capturing phenomena which are presupposition-laden and involve interactions with non-sentence-internal knowledge. The work shows that the primitives involved in this domain are not solely (or even primarily) temporal, but rather are concerned with "contingent" relations between events, such as causation. This project also addresses a practical concern, for any database that is to be interrogated or updated in natural language making use of tense and related categories is certain to require structuring in the same way. A number of domains are under investigation, including certain problems in the graphical animation of action sequences.

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Semantic Representation and Information Structure

Keywords: Anaphora, Plurals, Focus

Recent work in formal semantics has emphasized the role of pragmatics in determining the truth-conditions of quantificational sentences. These sentences can be given a uniform semantic characterization as tripartite structures involving a relational operator and two sets of cases, one the restrictor, and the other the nuclear scope [12]; however, the semantics cannot completely specify on its own how a sentence realizes such a structure. Pragmatic notions such as salience of entities in discourse, presuppositions of utterances, and the articulation of sentence into theme and rheme are needed to resolve anaphora, to individuate quantificational cases, and to determine which candidate cases are relevant [1, ?].

The construction of a semantic theory to accommodate this interaction naturally is as difficult as it is necessary. It is not enough for semantic representations simply to capture the complete range of meanings for a sentence across contexts: they must also present the range of variability concisely, in terms to which the pragmatics is sensitive, so that pragmatic disambiguations can be incorporated smoothly and elegantly.

I've been looking at three domains in which the interface between semantics and pragmatics reveals itself, which might provide insight into what kind of structure such a successful semantics might have. The domains are distinguished by the apparatus their interpretation requires: modeling of anaphoric processes, of plural noun phrases, and of the division of sentences according to information structure.

Anaphora

Given the semantically possible values that might be assigned to an anaphor, pragmatic processes must determine the correct one, according to criteria of salience [4] and plausibility [7]. However, the determination of the space of values from which the pragmatics can pick is problematic. In work started at Brown University [14], I explore the contrast between the E-Type characterization of these values presented by Heim [6] and that of Discourse Representation Theory [8, ?]. I argue that the E-Type characterization more naturally captures the range of meanings in complex examples of quantification involving the word *or*. In such examples as (1), as suggested by the E-Type approach, anaphors pick out individuals on the basis of described similarities rather than explicit common introduction:

(1) If John catches a fish or Mary traps a rabbit, Bill will cook it.

Further, it is likely that the function of descriptions in providing explanation also makes descriptions a more natural input for pragmatic processes. This is something I hope to look at in the future.

Plurals

After a survey of literature on the semantics of plurals (see the Plurals Working Group summary), I have come to the conclusion that the collective and distributive readings of sentences with plural NPs represent two endpoints on a scale of division of cases according to pragmatic principles: sentences with plurals are just like quantificational sentences in this respect. I propose that this interaction is mediated by a pragmatically specified anaphoric variable R associated with the meaning of each verb phrase, that partitions the set of individuals in the denotation of the NP on the basis of some salient property those individuals have. Different resolutions of R give different meanings, so this idea shares the advantage of Gillon's proposal [2] that sentences with plurals have distinct readings; nevertheless, because the resolution of R is pragmatic and not semantic, it retains from Verkuyl and van der Does's proposal [15] a uniformity of semantic composition and representation. Moreover, the anaphoric status of the variable R accounts for the absence of unusual readings for plurals in the absence of the appropriate context (cf. [11, 3]) and the effect of phrasing on the readings available [10], while its association with the verb phrase avoids the need for the complex typelifting invoked by Landman to handle conjunction [9].

Focus

I've been working with Mark Steedman in specifying the semantics of sentences whose information structure is explicitly articulated by intonation into foci and focus-frames, themes and rhemes. The work is slow and rather frustrating, because the complexities involved in constructions with multiple focus and multiple focusing operators are poorly understood: even determining what meaning ideally should be assigned to such sentences requires sensitivity to a wide range of subtle and independent informational factors.

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The acquisition of English stress accent by native Japanese Speakers

Keywords: English stress accent, Acquisition

My research consists of a study of the interlanguage English prosody of native Japanese speakers (NJSs). It is well documented that learners of a second language have features of their native language in the language they are learning. At the same time, these learners are constructing an interlanguage grammar that is often unlike both the source language and the target language. This process of transfer and creation has been well documented for segmental aspects of the phonology, however, the mechanisms of transfer and interlanguage prosodic development are poorly understood. The case where the prosodies are typologically different as in the case of Japanese pitch accent and English stress accent provides an interesting case for study and poses problems that are quite different than those encountered between English and Dutch or German which are all stress accent languages. This study looks at natural data elicited in an activity designed to control for the position of the intonational phrase (IP) nucleus based on contrastive context. Target forms included adjective-focused sentences like *I have a BIG cat* vs. the default, or noun-focused sentence, *I have a big CAT.* Native and interlanguage speech were considered in terms of the way that speakers changed the placement of the sentence nucleus depending on contrastive context. After determining nucleus placement based on the judgements of native speakers, pitch and duration were measured in order to determine how NJSs achieve nucleus placement in interlanguage forms. This approach was chosen because it captures the important aspects of constructing prosodically appropriate utterances in English.

This cross-sectional study divided the NJSs into three groups based on spoken proficiency. It was found that NJSs usually failed to produce appropriate contrastive focus in the placement of the IP nucleus. I hypothesize that although Japanese also uses phonological means to differentiate contrastive context, the differences in the prosodic systems do not allow for the straightforward transfer of Japanese parameters. Only some of the more advanced speakers showed emerging abilities in native-like manipulation of the IP nucleus. Duration is considered to be important in the marking of accent in English, however Japanese uses only pitch. Therefore, it seems likely that Japanese speakers will have difficulty in manipulating duration to mark the position of the IP nucleus. This was found to be true; however, some learners who showed abilities to vary the placement of the IP nucleus were beginning to use duration in ways that were more like that of native speakers. An analysis of the pitch contours showed that speakers tended to stress long phrases like *yellow banana* on the noun and phrases like *big cat* on the adjective. The implication of this is that Japanese, which favors the placement of pitch change on the left-most element, is more apparent in some forms than others.

There are two problems in interlanguage development that need to be solved. Firstly, NJSs must learn to move the IP nucleus from the adjective to the noun in normally-stressed short noun phrases. Secondly, learners must learn to move the IP nucleus based on contrastive context. The continuing analysis of the speech data collected will attempt to document if and how the grammar is restructured as interlanguage speakers approach a prosody more like the target in their second language.

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A Model of Informational Redundancy in Dialogue

Keywords: Discourse, Resource-bounded Reasoning, Belief Revision, Information Structure

Contrary to the assumptions of the Gricean program, it appears that some entailments are reinforcable without anomalous redundancy. My dissertation is based on an analysis of the communicative function of INFORMATIONALLY REDUNDANT UTTERANCES (IRUs) in dialogue [5]. An IRU is an utterance whose propositional content was already added to dialogue representation by the IRU's ANTECEDENT, a previous utterance that realizes the same propositional content as the IRU. The communicative functions of IRUs can be broadly classified as relating to (1) ATTITUDE: IRUs that indicate whether the hearer accepts or rejects an assertion; (2) CONSEQUENCE: IRUs that make it easier for the hearer to make an inference or that demonstrate that an inference was made; and (3) ATTENTION: IRUs that manipulate the locus of attention of the discourse participants.

Each of these classes is motivated by a non-controversial cognitive property of human speakers. Attitude IRUs are motivated by the fact that conversants are autonomous and will not necessarily understand or believe everything they are told [3]. Consequence IRUs are motivated by the fact that conversants are not logically omniscient and won't necessarily derive all the relevant inferences [4, 1]. Attention IRUs are motivated by the fact that conversants have limited attentional capacity.

Empirical support for this thesis comes from two sources. The first is a distributional analysis of IRUs in a large corpus of naturally occurring problem-solving dialogues. Here I correlated the functions of IRU's with (1) the way in which an IRU is performed, i.e. whether it is realized with narrow or broad focus and whether its boundary tone is a final high, mid or low [7]; (2) the location of the IRU with respect to its antecedent; (3) whether the antecedent was uttered by another speaker or by the speaker of the IRU; and (4) whether the IRU includes the information focus of its antecedent. This analysis provides support for the hypothesized communicative functions and provides insights on the process of incrementing context in dialogue. The theory developed includes a formal model of dialogue context incrementation that is supported by the results of the distributional analysis [6, 3].

The second source of support is derived from a new methodology I developed to address the relationship between IRUs and limited inferential and attentional capacity, which is difficult to support by a distributional analysis alone. This is a simulation environment, Design World, in which I have carried out a series of computational modeling experiments, showing that communication strategies that incorporate IRUs improve performance when: (1) conversants have limited attention or limited inferential capacity; (2) task complexity is high; or (3) retrieval from memory is unreliable or costly [1].

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Understanding Instructions

Keywords: Understanding Instructions, Human Figure Animation

For many years, the focus of my research was on how we use language to get information from each other, and how we accommodate for the fact that we are not particularly good at it. I felt that the results of this research would help us to design information systems that could accommodate the real behavior of information seekers and providers. The work done with colleagues (Joshi, Finin, Weischedel) and students (Mays, McCoy, Pollack, Hirschberg, Cheikes) on topics related to "Cooperative Responses" and "Expert Questions" had this as their primary goal.

More recently, with developments in model-based human figure animation (see CLiFF Note entry for Badler), I have become interested in the complementary problems of how we use language to get each other to behave in particular ways and what this may tell us about language understanding in general. The work I am doing with my colleague, Norman Badler, and student members of the AnimNL project (for "Animation and Natural Language") has this as its primary goal. (See CLiFF Note entries for **AnimMNL**, Badler, Di Eugenio, Geib, Levison, Moore.)

In AnimNL, we take the view that instructions are TEXTS intended to be understood IN CONTEXT, produced by an instructor with MORE EXPERIENCE than the instructee. (1) That instructions are texts means they rely on an interaction of language, world knowledge and reasoning to get their message across, and do not of themselves suffice to inform an agent of what to do or what to expect. (2) That instructions are meant to be understood in context means that an agent's understanding of a text evolves over time: that while some degree of understanding is needed to make their content available at the right point, full explication only comes through situated execution. (3) That instructors have more experience means that their words are worth trusting to some extent, even if the world initially provides no corroborating evidence.

There are many topics I have wanted to pursue in the context of AnimNL, all of which reflect the above view of instructions. One such topic is how agents who know how to perform an action when it involves a single object (e.g., carrying a box, washing a dish, etc.) use that knowledge and their awareness of the current situation to understand and respond to instructions to perform the action on multiple objects. It is clear that they don't merely iterate the same action on each object: rather, they may multiplex in a variety of different ways. Another topic is how agents figure out what perceptual activity is needed, to carry out the actions specified in instructions. For example, when an agent is told to *wait until the paint has dried*, the agent is going to be in a sorry state if he doesn't think to interleave his waiting with one or more types of perceptual tests: He can't rely on the paint itself to tell him when it's dry. These are just two of many issues that come up when one is trying to understand how language conveys information about behavior. There are many more.

Decision Support for Multiple Trauma Management

Keywords: Clinical Decision Support Systems, Diagnosis, Planning, Critiquing, Physiological Modelling, Anatomical Reasoning

For the past eight years, I have been working with John R. Clarke, M.D. (Dept. Surgery, Medical College of Pennsylvania) and students here at Penn on developing a clinically-viable computer-based system that can provide valuable support for physicians dealing with trauma patients. Our original intention was that the system, now called TraumAID, would serve to provide on-line advice, telling the physician what clinical procedures were currently called for and why they were needed. A subsequent experiment with putting an earlier version of TraumAID in the MCP Emergency Room, changed our opinion, and our current concept is better characterized under the title "Real-Time Quality Assurance"(RTQA). For RTQA, TraumAID's role is to evaluate the physician's orders and verify that they are compatible with TraumAID's understanding of the case. If they diverge too greatly from the standards of cost-effective care embodied in TraumAID, then TraumAID must deliver a critique of those orders.

TraumAID and its evolution remain of great interest to me, not only because of the potential good it can provide but also because of the parallels between reasoning, planning and acting in clinical management, and the same activities carried out in Natural Language interaction. Work on each informs the other, to the greater enrichment of both.

(See CLiFF Note entries for TraumAID, Gertner, Kaye and Rymon for further information on this work.)

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A Sortal Approach to Aspectual Composition

Keywords: Aspect, Event Semantics

Central to previous approaches to the problem of ASPECTUAL COMPOSITION (cf. Dowty [1], Verkuyl [6]) have been attempts to explain the puzzling parallels between count noun phrases and telic sentences on the one hand, which have inherently "delimited" extents, and mass nouns, bare plurals, and atelic sentences on the other, which do not. In connection with this intuitive notion of delimitedness, it has often been observed that mass terms (e.g. *beer*) and bare plurals (e.g. *margaritas*) are similar to atelic expressions (e.g. *John drink beer / margaritas*), insofar as they share the property of REFERENTIAL HOMOGENEITY. This sets them apart from count noun phrases (eg. *a pint of beer*) and telic expressions (e.g. *John drink a pint of beer*), which do not generally do so.

Observations such as these led Dowty [1], Hinrichs [2] and Krifka [4, 5] to incorporate various tests for referential homogeneity into their logical forms in an attempt to explain the problem of aspectual composition. I have argued against this move in White [7] by showing that it engenders the ACCIDENTAL REFERENTIAL HOMOGENEITY PROBLEM. Briefly, the problem is that some expressions, such as *for John to drink some quantity of beer*, only "happen" to refer homogeneously – that is, some expressions behave syntactically like count expressions despite their referential homogeneity. As an alternative to the above theories, I have begun developing a novel, sortally-based approach to aspectual composition, which I argue to be superior not only on empirical grounds, insofar as it dissolves this particular problem, but also on computational grounds, insofar as it justifies employing a feature-based approach to aspectual composition. So far I have applied this theory to reasoning about descriptions of sequences of simple motion events, using a constraint optimization technique. In future work, I plan to investigate the integration of the theory with the Interpretation as Abduction framework advocated by Hobbs et al. [3].

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Part III
Projects and Working Groups

The AnimNL Project

Department of Computer and Information Science

Norman Badler, Bonnie Lynn Webber, Mark Steedman, Brett Achorn, Welton Becket, Barbara Di Eugenio, Christopher Geib, Libby Levison, Dan Melamed, Michael Moore, Joseph Rosenzweig, Michael White, Xinmin Zhao

Keywords: Instruction Understanding, Human Figure Animation.

The AnimNL project (for "Animation and Natural Language") aims to enable people to use Natural Language instructions to tell animated human figures what to do. Potential applications include not only human factors analysis (creating animated task simulations from instructions) but also small group training (enabling people to collaborate through language with virtual human agents in virtual environments).

Our work has focussed on procedural instructions and warnings, such as those found packaged in with appliances and equipment and in the pages of "how to" books—for example,

- Depress door release button to open door and expose paper bag.
- Unplug the vacuum cleaner if you leave the room.

(both from the *Royal* CAN VAC^{TM} Owner's Manual). Such instructions assume that agents may be new to the tasks specified, but that they have both the experience and world knowledge needed to understand the instructions, and the skills needed to carry them out.

Besides its potential applications, AnimNL provides a rich framework in which to analyse the semantics and pragmatics of instructions, and to characterize how understanding evolves through activity. The latter has not been studied systematically before, but is especially important for linking language with behavior. The link requires that language understanding no longer be viewed merely as "front-end processing". What an agent takes an instruction to mean must be able to evolve as the agent acts. Two examples should suffice:

- When an agent is told to *Go into the kitchen to get the coffee urn*, he does not need to ground the definite expression *the coffee urn* before he begins to act. All that is required is that he be able to establish a referent once he gets to the kitchen. The understanding process must be able to allow for this delay.
- When an agent is told *Vacuum against the direction of the pile to leave it raised*, the agent can find out through vacuuming what direction of sweep leaves the carpet pile raised. Again, he does not need to know the referent before starting to act, but he must be able to use the instruction to guide what it is he needs to know.

AnimNL builds upon the *Jack*^{TM} animation system developed at the University of Pennsylvania's Computer Graphics Research Laboratory. Animation follows from model-based simulation. *Jack* provides biomechanically reasonable and anthropometrically-scaled human models and a growing repertoire of behaviors such as walking, stepping, looking, reaching, turning, grasping, strength-based lifting, and collision-avoidance posture planning [1]. Each of these behaviors is environmentally reactive in the sense that incremental computations during simulation are able to adjust an agent's performance to the situation WITHOUT FURTHER INVOLVEMENT OF THE HIGHER LEVEL PROCESSES [2] unless an exceptional failure condition is signaled. Different spatial environments can easily be constructed and modified, to enable designers to vary the situations in which the figures are acting.

Trying to make a human figure move in ways that people EXPECT a human to move in carrying out a task is a formidable problem: human models in *Jack* are highly articulated, with over 100 degrees of freedom [1]. While the environment through which a *Jack* agent moves influences its low-level responses, we have found that a great many behavioral constraints can be derived through instruction understanding and planning. Further descriptions of work being done in the context of AnimNL can be found in CLiFF Note entries for Badler, Di Eugenio, Geib, Levison, Moore, Webber and White.

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The FOCUS group

Linguistics, CIS

Participants include: Mark Liberman, Mark Steedman, Irene Vogel, Ann Bies, Dan Hardt, Beth Ann Hockey, Beryl Hoffman, Scott Prevost, Matthew Stone, Lyn Walker, and others too numerous to name.

Keywords: Focus, Prosody, Semantics, Discourse, Pragmatics, Syntax

The FOCUS group is an ongoing discussion group interested in issues related to focus, accent, phrasing, form and interpretation. Meetings consist of presentations of participants' research or discussion of papers on focus related topics. We have had presentations by Mark Steedman of his current work on relating syntax, information structure and intonation in a categorial grammar framework. Two formal semantics papers on focus, by Rooth [1] and Kratzer [2], have been discussed. In addition, a presentation by Istvan Kenesei (UDEL) is scheduled.

The group is beginning a project of applying approaches that have been discussed to a collection of examples from a corpus of natural speech and comparing the results. For further information about the FOCUS group contact Beth Ann Hockey at the e-mail address *beth@linc.cis.upenn.edu.*

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NLstat: Statistical Methods working group

Department of Computer and Information Science

Keywords: Statistical methods, text corpora

The NLstat group includes faculty and students primarily from Computer and Information Science and from Linguistics, although all members of the research community are welcome to attend. The group meets periodically to examine papers of interest, to discuss work in progress, and to hear talks by visiting speakers.

A mailing list — *nlstat@unagi.cis.upenn.edu* — carries announcements and discussion to members; currently the list has about 60 members. To be added to the list, send mail to *nlstat-request@unagi.cis.upenn.edu*.

Semantics of Plurals Reading Group

Department of Computer and Information Science

Breck Baldwin, Christine Doran, Dan Hardt, Matthew Stone, Mike White

English sentences containing plural noun phrases display a dizzying array of construals. So subtle and complicated is the data that, in trying to extend classic but simple treatments of plurality, such as that given by Link [9], researchers can inevitably consider only part of it. What results is a diverse and seemingly incompatible series of proposals, each tuned to account for particular examples in a particular way, so that to sort through them and compare them is – at best – a difficult task.

Nevertheless, that's what this group tried to do. In five meetings we reviewed papers from as many or more perspectives. Here's a quick summary of the readings:

- Gillon [1] and Verkuyl and van der Does [12] start with sentences like:

  (1) Rogers, Hammerstein and Hart wrote musicals.

  These fall outside Link's account because they involve neither collective nor distributive predication yet are intuitively true. These authors call for a continuum of segmentations of a plural noun phrases into a set of sets—of which the collective, the set of all entities denoted by the plural NP, and the distributive, the set of all singleton sets whose elements are denoted by the plural NP, are two extremes. Thus (1) is true on the basis of a structuring of Rogers, Hammerstein and Hart into the pairs, Rogers and Hammerstein, and Rogers and Hart, who actually did collectively write musicals. Gillon differs from Verkuyl and van der Does in claiming the alternative partitioning induces different readings of the sentence rather than inducing vagueness.

- Landman [4] focuses his attention instead on examples like:

  (2) The cards below seven and the cards from seven up were separated.

  His claim is that predicates such as *separated* are true of collections of collections only, and that the noun phrase above denotes a group whose members are two groups of cards. This requires an augmentation of Link's ontology to give the lattice of individuals recursive structure: In fact, Landman argues that all of set theory is required to interpret noun phrases.

- Van Eijck [11] and Roberts [10] tack is to look at the appearance of plurals in discourse. While they keep Link's collective/distributive alternation, they extend Discourse Representation Theory to include groups as well as singular individuals. Roberts argues that this kind of extension—orthogonal to the extensions of the first two approaches—is needed to account for all ambiguities in sentences like:

  (3) John and Mary invited their parents to their apartment for dinner.

- The final approach, exemplified by Latecki [8], is motivated more by computational than linguistic concerns. His scope and reading neutral representations for sentences with plural noun phrases, although they lack the refined accuracy of the other proposals we looked at, constitute a provocative first step toward a computationally realizable theory of the interpretation of plurals.

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The TraumAID Project

Department of Computer and Information Science

Bonnie Lynn Webber, John Clarke, Gregory Provan, Abigail Gertner, Jonathan Kaye, Stefanie Neumann, Ron Rymon

Keywords: Trauma Management, Diagnostic Reasoning, Critiquing, Planning, Anatomic/Physiological Modelling

Injury is a major health problem in the United States, resulting in more years of human life lost than any other disease. Believing that the morbidity and mortality due to injury can be reduced through rapid delivery of expert care, the American College of Surgeons developed an Advanced Trauma Life Support (ATLS) course that educates physicians in the FIRST PHASE of trauma management: the initial evaluation, resuscitation, and stabilization of severely injured patients. For this same reason, we have been developing TRAUMAID to assist physicians in the SECOND PHASE: the initial definitive management of those patients in Emergency Centers and Trauma Centers.

During this second phase, a medical team led by the attending physician acts to identify the patient's injuries, providing initial therapy and preparing for further diagnosis and therapy in the X-Ray Department, Operating Room (OR) or Intensive Care Unit (ICU). This phase, which can last up to two hours, is often characterized by the need for urgent actions and definitive decisions that pre-empt further diagnostic (i.e., information-gathering) activity: e.g., the patient must be taken to the OR immediately and pending goals satisfied through surgical procedures. Decision support during this second phase of trauma management must therefore balance systematic diagnostic activity with the demands of quick and definitive therapeutic action.

TraumAID has been under development for the past eight years, a joint effort of a team at the Medical College of Pennsylvania (MCP) led by Dr. John Clarke (Professor of Surgery), and a team at the University of Pennsylvania, led by Professors Bonnie Webber and Greg Provan. The current system, TraumAID 2.0, comprises (1) a RULE-BASED REASONER that addresses the question: given the current situation (i.e., what is known about the patient), what CONCLUSIONS can be drawn and therefore what GOALS are most appropriate for the physician to adopt; and (2) a PLANNER that addresses the question: given the entire set of currently relevant goals, what ACTIONS should the physician and medical team best perform now.

This division into local reasoner and global planner reflects the demands noted above: first, it supports GOAL-DIRECTED DIAGNOSIS, in the sense that its attempt to characterize a patient's injuries is not pursued beyond the point that it would make a difference to the therapeutic goals that one would adopt under the circumstances. Second, it engenders flexibility in patient management. As more is learned about the patient's condition through diagnostic activity, TraumAID's advice on what to do next will constantly reflect the entire set of current management goals. The physician can thus be directed to actions that can be used to satisfy multiple goals and to actions that are of greatest urgency.

TraumAID 2.0 currently runs on SUN workstations and high-end versions of the MAC. On the SUN, it runs with a menu-based interface. For clinical use in Emergency Centers and Trauma Centers, a broad-coverage HyperCard interface is being developed in cooperation with Emergency Center nurses at MCP. This latter interface has been designed to serve not only the information needs of TraumAID, but also the data-recording needs of the Emergency Center, replacing current paper-based methods. Work is currently being done on completing the interface and linking it to TraumAID's reasoner and planner. The complete system will be delivered to the Emergency Center at MCP in August 1993 for on-site testing.

TraumAID's HyperCard interface is designed to allow the system to fit in with standard Emergency Center practices and thereby to ensure its acceptance at the DATA ENTRY end. We are developing what we hope will be a clinically acceptable form of INFORMATION DELIVERY in the form of REACTIVE CRITIQUING in non-urgent situations with PROACTIVE ADVISING in urgent situations. (See CLiFF Note entry for Abigail Gertner.) We are also experimenting with the use of AUTOMATIC SPEECH GENERATION to deliver both critique and advice, augmenting the textual record that appears on the computer screen. (See CLiFF Note for Scott Prevost.)

Other current development work on TraumAID is proceeding in three directions. The first involves development of a computer model of acute cardio-vascular response that can be used to interpret changes in a patient's vital signs in response to blood loss and fluid replacement and thus further aid in diagnosis. Since we are constructing a general model, when complete, it should be of use in other systems than TraumAID—e.g., for modeling gastro-intestinal or interoperative bleeding. This work is being done by Stefanie Neumann, a PhD student in Bioengineering.

Secondly, we are beginning to address the problem of how the knowledge needed to support sophisticated diagnostic-planning systems such as TraumAID and to enlarge TraumAID's coverage can be acquired. To date, this has been done completely by hand. We are exploring a new machine learning techniques called SE-TREE LEARNING to automate and thereby overcome some of the knowledge acquisition hurdles. (See CLiFF Note abstract for Ron Rymon.)

Finally, we are exploring the use of 3-D human figure modeling techniques pioneered by Penn's Computer Graphics Laboratory, both to augment a physician's own anatomical visualization abilities and to improve TraumAID's ability to reason about the relationship between anatomical structure and physiological function and thus about the anatomical and physiological disturbances caused by injury. (See CLiFF Note for Jonathan Kaye.)

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The XTAG Project

Department of Computer and Information Science

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Keywords: Tree Adjoining Grammar (TAG), Parsing, Syntax, Morphology

Introduction

XTAG is a grammar development system based on the lexicalized tree adjoining grammar formalism. It consists of a predictive left-to-right parser, an X window interface, a morphological analyzer, a part of speech tagger and an English grammar. The figure below illustrates the interactions between these components.

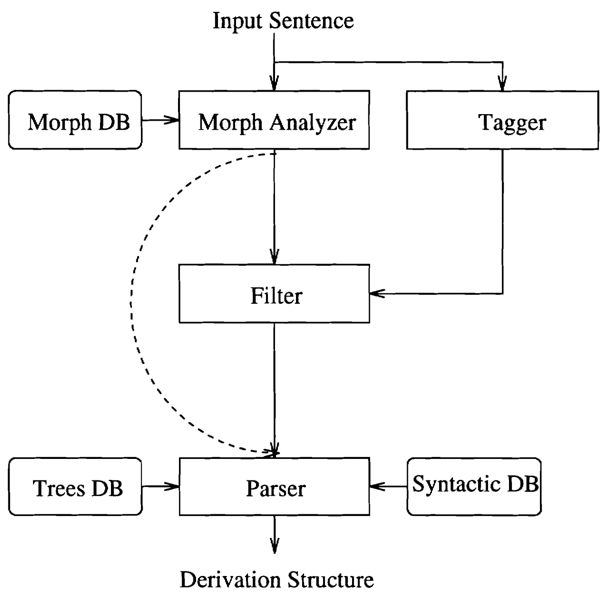

Figure 4: **Overview of XTAG system**

XTAG Interface

XTAG provides an editing tool to create and manipulate tree data structures, that offers these facilities:

- Easy manipulation of the tree data structure with the mouse.
- Automatic and easily readable display of tree and feature data structures.

- The production of postscript files for trees.
- Storage and retrieval facilities for tree files.
- Scrollable display of tree files.
- Easy combination of trees by adjoining or substitution and easy bookkeeping of the derivation.

Morphology

The morphology data has been extracted from the 1979 edition of the Collins English Dictionary and Oxford Advanced Learner's Dictionary of Current English. There are approximately 316,000 inflected forms derived from 78,000 root forms in the morphological database. Each inflected form is associated with its root and has tag information that specifies its part of speech and other relevant morphological information (such as case and number). The database requires approximately 10M of space and has a very low access time of approximately 0.6 msec.

Tagger

Two kinds of part of speech taggers, stochastic-based and rule-based have been interfaced to the XTAG system to reduce the number of specious parses for a sentence. The tagger decreases the parse time of a sentence by an average of 40-50%.

English Grammar

A Lexicalized TAG (LTAG) is organized around a lexicon, which associates sets of elementary trees with the lexical items. The lexical item that is associated with a tree is called the ANCHOR of the tree. The anchor provides values for syntactic features associated with the tree. The set of lexical items and their associations to elementary trees constitutes the syntactic database while the tree structures constitute the tree database.

The syntactic database entries have been extracted from the Oxford Advanced Learner's Dictionary and Oxford Dictionary for Contemporary Idiomatic English. There are a total of 37,000 syntactic database entries.

A tree family in the English LTAG grammar represents a single subcategorization. The collection of trees in a tree family would be related to each other transformationally in a movement-based approach. There are 30 tree families and 250 trees in the tree database.

A range of syntactic phenomena have been handled including: auxiliaries, copula, raising and small clause constructions, topicalization, relative clauses, infinitives, gerunds, adjuncts, it-clefts, wh-clefts, PRO constructions, noun-noun modifications, genitives, constructions with negatives, noun-verb contractions and imperatives.

Parser

The system uses an Earley-style parser that has been extended to handle feature structures associated with trees [2, 1]. The parser uses a general two-pass parsing strategy for 'lexicalized' grammars [4]. In the first pass, the parser selects a set of elementary structures associated with the lexical items in the input sentence, and in the second stage the sentence is parsed with respect to this set. [3] discusses the relevance of lexicalization to parsing in more detail.

Additional methods that take advantage of lexicalized TAGs have been implemented to improve performance. Specifically, the span of the tree and the position of the anchor in the tree are used to filter the selection of trees in the first pass of the parser. These methods speed the runtime of the parser by approximately 50%.

The morphological component is available separately from the XTAG system. It can be obtained by sending requests to lex-request@linc.cis.upenn.edu. Requests for the XTAG system can be sent to xtag-request@linc.cis.upenn.edu.

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Part IV

Appendix

CLiFF Talks

Spring 1992

Jan 15, 1992 Mike White UPenn – CIS
The Nature of Reference Time

Jan 29, 1992 Jan Van Kuppevelt UPenn – CIS
Discourse Structure and Topicality

Feb 5, 1992 Shin-ichiro Kamei NEC Corporation, Japan
A Discrete Model of Degree Expression Understanding

Feb 12, 1992 Michael Hegarty UPenn – IRCS
Factive Complementizers and Antecedent Government Domains

Feb 18, 1992 Helmut Horacek University of Bielefeld
Cooperation by Communication

Feb 19, 1992 David Yarowsky AT&T Bell Labs
A Class-Based Statistical Approach to Word Sense Disambiguation

Feb 28, 1992 David Magerman Stanford University
Probabilistic Prediction and Picky Chart Parsing

Feb 28, 1992 David Magerman Stanford University
Towards History-based Grammars: Using Richer Models for Probabilistic Parsing

Mar 4, 1992 Dan Hardt UPenn – CIS
VP Ellipsis and Discourse

Mar 18, 1992 Mike Moore UPenn – CIS
Modal Logic for Knowledge Representation

Mar 25, 1992 Robert Rubinoff UPenn – CIS
Integrating Text Planning and Linguistic Choice by Annotating Linguistic Structures

Apr 8, 1992 Paolo Terenziani Universitá di Torino, Italy
Integrating Linguistic and Pragmatic Temporal Information

Apr 15, 1992 Shyam Kapur Upenn – IRCS
Some applications of formal learning theory results to natural language acquisition

Apr 22, 1992 Philip Resnik UPenn – CIS
Implicit-object Verbs and the Predictability of Argument Classes

Apr 29, 1992 Jeff Siskind UPenn – IRCS
Recent Work on Computational Models of Child Language Acquisition

Summer 1992

May 13, 1992 Uzzi Ornan Haifa University
Problems in Processing Hebrew

May 22, 1992 Christine Nakatani UPenn – CIS
Notions of Phrase in Japanese

June 3, 1992 Barbara Di Eugenio UPenn – CIS
Plan Recognition in Understanding Instructions

June 10, 1992 Mike White UPenn – CIS
Conceptual Structures and CCG

June 17, 1992 Michael Niv UPenn – CIS
Right-Association Revisited

June 17, 1992 Jong Park UPenn – CIS
A unification-bsd sem interpr for coord conjunction

June 18, 1992 Beryl Hoffman UPenn – CIS
A CCG Approach to Free Word Order Language

June 18, 1992 Owen Rambow UPenn – CIS
A Linguistic and Computational Analysis of the German "Third Construction"

June 18, 1992 Philip Resnik UPenn – CIS
A Class-Based Approach to Lexical Discovery

June 22, 1992 Dan Hardt UPenn – CIS
Some Problematic Cases of VP Ellipsis

June 22, 1992 Dan Hardt UPenn – CIS
An Algorithm for VP Ellipsis

June 23, 1992 Giorgio Satta UPenn – CIS
Recognition of LCFRS

June 23, 1992 Barbara Di Eugenio UPenn – CIS
Understanding Natural Language Instructions: the case of Purpose Clauses

July 9, 1992 Philip Resnik UPenn – CIS
Probabilistic Tree-Adjoining Grammar as a Framework for Statistical Natural Language Processing

July 9, 1992 Philip Resnik UPenn – CIS
Left-corner Parsing and Psychological Plausibility

July 17, 1992 Daniel Hardt UPenn – CIS
VP Ellipsis and Contextual Interpretation

Fall 1992

Sep 23, 1992 Atro Voutilainen University of Helsinki
A Grammar-based Disambibiguator for English

Sep 30, 1992 Michael Hegarty UPenn – IRCS
A Look at A′-Dependencies in a Minimalist Framework

Oct 7, 1992 Michael Hegarty UPenn – IRCS
A Look at A′-Dependencies in a Minimalist Framework (2)

Oct 14, 1992 Dan Hardt UPenn – CIS
A Semantic Theory of Verb Phrase Ellipsis

Oct 28, 1992 Jeff Siskind UPenn – IRCS
NonDeterministic Lisp

Nov 4, 1992 Josh Hodas UPenn – CIS
Specifying Filler-Gap Dependency Parsers in a Linear Logic Programming Language

Nov 11, 1992 Mark Hepple UPenn – IRCS
Hello Mr Lambek: a Short Introduction to the Lambek Calculus

Nov 18, 1992 Toby Mintz URochester
Why I Can't Yet Talk About Prosodic Bootstrapping

Nov 25, 1992 David Milward U. Edinburgh
Dynamics, Dependency Grammar and Incremental Interpretation

Dec 2, 1992 Owen Rambow UPenn – CIS
Functional Categories as Features

Dec 9, 1992 Lyn Walker UPenn – CIS
The Role of Informational Redundancy in Managing Limited Attention and Inference in Dialogue

Dec 16, 1992 Jamie Henderson UPenn – CIS
A Tale of Two Stacks

Spring 1993

Jan 27, 1993	Young-Suk Lee	UPenn – Linguistics

Scrambling as Case-driven Obligatory Movement

Feb 3, 1993	Mike White	UPenn – CIS

The Imperfective Paradox and Trajectory of Motion Events

Feb 16, 1993	Chris Mellish	U. Edinburgh

Using Classification to Generate Text

Feb 25, 1993	Barbara Partee	UMass Amherst – Linguistics

Topic, Focus and Quantification

Mar 24, 1993	Breck Baldwin	UPenn – CIS

Anaphora Resolution as Structure Constrained Inference

Mar 31, 1993	Shyam Kapur & Eric Brill	UPenn – CIS

How Much of What?: Is This What Underlies Parameter Setting?

Apr 7, 1993	B. Srinivas & Beth Ann Hockey	UPenn – CIS & Linguistics

The XTAG Project

Apr 14, 1993	Scott Prevost	UPenn – CIS

Generating Contextually Appropriate Intonation

Apr 15, 1993	Shalom Lappin	IBM Watson Research

E-Type Pronouns as Functions to I-Sums

Apr 28,1993	Michael Hegarty	UPenn – IRCS

Deriving Clausal Phrase Structure in Tree Adjoining Grammar

Recent LINC Lab Technical Reports

Multiple Instantiation Of Predicates In A Connectionist Rule-Based Reasoner
D.R. Mani,
Lokendra Shastri
MS-CIS-92-05
LINC LAB 212

Goals and Actions In Natural Language Instructions (Dissertation Proposal)
Barbara Di Eugenio
MS-CIS-92-07
LINC LAB 213

Planning Responses From High-Level Goals: Adopting The Respondent's Perspective In Cooperative Response Generation (Dissertation)
Brant A. Cheikes
MS-CIS-92-14
LINC LAB 215

Ellipsis and Discourse (Dissertation Proposal)
Daniel Hardt
MS-CIS-92-21
LINC LAB 216

CLiFF Notes: Research In Natural Natural Processing at the University of Pennsylvania
Facutly & Graduate Students
MS-CIS-92-22
LINC LAB 217

Progressive Horizon Planning–Planning Exploratory-Corrective Behavior
Ron Rymon,
Bonnie L. Webber,
John R. Clarke
MS-CIS-92-23
LINC LAB 218

Japanese Discourse and the Process of Centering
Marilyn Walker
(University of Pennsylvania),
Masayo Iida
(Hewlett Packard Laboratories),
Sharon Cote
(University of Pennsylvania)
MS-CIS-92-32
LINC LAB 220

Logic Programming In A Fragment Of Intuitionistic Linear Logic
Joshua S. Hodas,
Dale Miller
MS-CIS-92-33
LINC LAB 221

Conceptual Structures and CCG: Linking Theory and Incorporated Argument Adjuncts
Michael White
MS-CIS-92-34
LINC LAB 222

Pronominal Reference To Events and Actions: Computational Foundations (Dissertation)
Ethel Schuster
MS-CIS-92-43
LINC LAB 224

A Structural Interpretation of Combinatory Combinatory Categorial Grammar
James Henderson
MS-CIS-92-49
LINC LAB 227

A Reconsideration of Preconditions
Christopher W. Geib
MS-CIS-92-50
LINC LAB 228

Surface Structure
Mark Steedman
MS-CIS-92-51
LINC LAB 229

Categorial Grammar
Mark Steedman
MS-CIS-92-52
LINC LAB 230

Grammars and Processors
Mark Steedman
MS-CIS-92-53
LINC LAB 231

Specifying Filler-Gap Dependency Parsers In A Linear-Logic Programming Language
Joshua S. Hodas
MS-CIS-92-62
LINC LAB 233

Search Through Systematic Set Enumeration
Ron Rymon
MS-CIS-92-66
LINC LAB 234

Intentions In Means-End Planning (Dissertation Proposal)
Christopher W. Geib
MS-CIS-92-73
LINC LAB 235

Doing What You're Told: Following Task Instruction In Changing, but Hospitable Environments
Bonnie Webber, Norman Badler, F. Breckenridge Baldwin, Welton Becket, Barbara Di Eugenio, Christopher Geib, Moon Jung, Libby Levison, Michael Moore, Michael White
MS-CIS-92-74
LINC LAB 236

Acquisition Of Verb Categories
Mark Steedman
MS-CIS-92-76
LINC LAB 237

More On Goal-Directed Diagnosis
Ron Rymon
MS-CIS-92-81
LINC LAB 239

Generalized Quantifiers and Logical Reducibilities
Anuj Dawar
MS-CIS-92-85
LINC LAB 240

Syntactic Locality and Tree Adjoining Grammar: Grammatical, Acquisition and Processing Perspectives (Dissertation)
Robert Evan Frank
MS-CIS-92-89
LINC LAB 241

Negotiation, Feedback, and Perspective Within Natural Language Generation (Dissertation)
Robert Rubinoff
MS-CIS-92-91
LINC LAB 242

VP Ellipsis and Semantic Identity
Daniel Hardt
MS-CIS-93-04
LINC LAB 243

An Algorithm for VP Ellipsis
Daniel Hardt
MS-CIS-93-05
LINC 244

VP Ellipsis and Contextual Interpretation
Daniel Hardt
MS-CIS-93-06
LINC LAB 245

Generating Contextually Appropriate Intonation
Scott Prevost,
Mark Steedman
MS-CIS-93-39
LINC LAB 247

An SE-tree based Characterization of the Induction Problem
Ron Rymon
MS-CIS-93-42
LINC LAB 248