

## 1994 IRCS TECHNICAL REPORT ABSTRACTS

### **Instructions, Intentions and Expectations**

**Bonnie L. Webber**  
**Norman I. Badler**  
**Barbara Di Eugenio**  
**Chris Geib**  
**Libby Levison**  
**Michael Moore**  
**IRCS-94-01**  
**MS-CIS-93-61**

Based on an ongoing attempt to integrate Natural Language instructions with human figure animation, we demonstrate that agents' understanding and use of instructions can complement what they can derive from the environment in which they act. We focus on two attitudes that contribute to agents' behavior - their intentions and their expectations - and show how Natural Language instructions contribute to such attitudes in ways that complement the environment. We also show that instructions can require more than one context of interpretation and thus that agents' understanding of instructions can evolve as their activity progresses. A significant consequence is that Natural Language understanding in the context of behavior cannot simply be treated as "front end" processing, but rather must be integrated more deeply into the processes that guide an agent's behavior and respond to its perceptions.

### **A Two-Dimensional Hierarchy for Parallel Rewriting Systems**

**Owen Rambow**  
**Giorgio Satta**  
**IRCS-94-02**

The class of parallel rewriting systems is considered in this work, and the interaction between two complexity measures, that in the literature have been called synchronous parallelism and independent parallelism, is investigated. It is shown that, when the degree of synchronous parallelism is bounded by some constant greater than one, the degree of independent parallelism induces an infinite non-collapsing hierarchy within the generated languages. The result is obtained using an original characterization of parallel rewriting systems.

Our result combines with other well-known properties of synchronous parallelism to reveal the existence of a two-dimensional hierarchy for the family of languages generated by so called finite copying parallel rewriting systems. This gives a new picture of many formalisms in this class. Other language-theoretic properties of parallel rewriting systems are proved in this work, that together with our main result provide an answer to some questions that were left open in the literature.

### **Spherical Retinal Flow for a Fixating Observer**

**J. Inigo Thomas**  
**Eero Simoncelli**  
**Ruzena Bajcsy**  
**IRCS-94-03**  
**MS-CIS-94-06**

When a human observer moves, the eye continually fixates on targets in the world. Although fixation is a common process in human vision, its role has not yet been established for computational purposes. The main contribution of this paper is to formalize the retinal flow for a fixating observer. A further contribution - a potentially more practical one - is to explore the role of the periphery in predicting collision. Utilizing fixation is expected to turn out to be especially fruitful in light of recent advances in computer vision for constructing active head/eye systems.

In this work we make the following assumptions: (i) the observer moves with respect to the world and fixates on a target; (ii) the world is rigid, with no independent moving elements; and (iii) the possible rotation axes of the eye lie on a plane (comparable to Listing's Plane). Assumptions (ii) and (iii) make the problem of determining retinal flow tractable.

We first define retinal flow for a 2D universe and then extend it to the full 3D case; the flow in 2D turns out to form a component of the flow in 3D. The retinal flow in 3D will be decomposed into longitudinal and latitudinal flow; the behavior of longitudinal flow along the retinal periphery will be further analyzed for interesting properties. Finally the results of a simulated experiment on retinal flow at the periphery will be presented.

### **English Main Verbs Move Never** **Bernhard Rohrbacher** **IRCS-94-04**

The traditional view holds that English main verbs do not move to any of the inflectional heads AgrS, Tns or AgrO. Recently, it has been claimed that while English main verbs cannot move to the highest inflectional head (i.e. AgrS), they may move to an intermediate inflectional head such as AgrO or Tns (cf. section 2). In earlier work, I have argued that all verb movement to inflectional heads is triggered by the overt morphology of the latter (cf. Rohrbacher (1993)). This approach is not compatible with movement of English main verbs to AgrO or Tns since the language does not have overt object agreement and its overt tense morphology is not significantly 'richer' than that of the Mainland Scandinavian V in situ languages. The current paper presents new evidence from Quantifier Floating against (short) main verb movement in English. If English main verbs could move out of VP and leftwards to an intermediate inflectional head, they should be able to precede a floating subject quantifier in the specifier of VP. The resulting word order is however ungrammatical, a fact which strongly suggests that English main verbs stay in situ (cf. section 3). This conclusion is confirmed by the inability of adverbs that do not adjoin to the right of VP to surface after main verbs. The paper closes with a reëxamination of the arguments adduced in support of short verb main verb movement in English and finds that most if not all of them are less than convincing (cf. sections 4 and 5).

**Notes on the Antisymmetry of Syntax**  
**Bernhard Rohrbacher**  
**IRCS-94-05**

In what proved to be probably the most influential Principles-and-Parameters manuscript of the last year, Kayne (1993) has proposed 1) a Linear Correspondence Axiom which together with particular definition of (asymmetric) c-command is supposed to allow only SVO and OVS as underlying word orders and 2) an abstract beginning node asymmetrically c-commanding all other nodes which is supposed to further exclude OVS so that one arrives at the conclusion that SVO constitutes the universal underlying word order. Below, I argue against this conclusion on both theoretical and empirical grounds. While the Linear Correspondence Axiom has desirable effects on clause structure (cf. section 3), neither it nor the assumption of an abstract beginning node has any effects on word order. In particular, Kayne's system actually allows not only SVO and OVS, but also SOV and VOS (cf. section 4). Moreover, it will not do to simply stipulate SVO as the universal underlying word order since word order in German, a language traditionally analyzed as being underlyingly SOV, cannot be adequately treated in the universal SVO approach, especially when it is compared with word order in Yiddish, a closely related SVO language (cf. section 5). The next section introduces the theoretical machinery of Kayne (1993). It should be read even by those who are already familiar with Kayne's paper, since the exposition of the linear ordering concept given in section 2 will help the reader to understand the central theoretical arguments in section 4.

**Process Algebra, CCS, and Bisimulation Decidability**  
**Seth Kulick**  
**IRCS-94-06**

Over the past 15 years, there has been intensive study of formal systems that can model concurrency and communication. Two such systems are the Calculus of Communicating Systems, and the Algebra of Communicating Processes. The objective of this paper has two aspects: (1) to study the characteristics and features of these two systems, and (2) to investigate two interesting formal proofs concerning issues of decidability of bisimulation equivalence in these systems. An examination of the processes that generate context-free languages as a trace set shows that their bisimulation equivalence is decidable, in contrast to the undecidability of their trace set equivalence. Recent results have also shown that the bisimulation equivalence problem for processes with a limited amount of concurrency is decidable.

**Psychology as a Natural Science in the Eighteenth Century**  
**Gary Hatfield**  
**IRCS-94-07**

Psychology considered as a natural science began as Aristotelian "physics" or "natural philosophy" of the soul. C. Wolff placed psychology under metaphysics, coordinate with

cosmology. Scottish thinkers placed it within moral philosophy, but distinguished its "physical" laws from properly moral laws (for guiding conduct). Several Germans sought to establish an autonomous empirical psychology as a branch of natural science. British and French visual theorists developed mathematically precise theories of size and distance perception; they created instruments to test these theories and to measure visual phenomena such as the duration of visual impressions. These investigators typically were dualists who included mental phenomena within nature.

**Formal and Computational Aspects of Natural Language Syntax (Ph.D. Dissertation)**  
**Owen Rambow**  
**IRCS-94-08**

This thesis explores issues related to using a restricted mathematical formalism as the formal basis for the representation of syntactic competence and the modeling of performance. The specific contribution of this thesis is to examine a language with considerably freer word-order than English, namely German, and to investigate the formal requirements that this syntactic freedom imposes. Free word order (or free constituent order) languages can be seen as a test case for linguistic theories, since presumably the stricter word order can be subsumed by an apparatus that accounts for freer word order.

The formal systems investigated in this thesis are based on the tree adjoining grammar (TAG) formalism of Joshi et al. (1975). TAG is an appealing formalism for the representation of natural language syntax because its elementary structures are phrase structure trees, which allows the linguist to localize linguistic dependencies such as agreement, subcategorization, and filler-gap relations, and to develop a theory of grammar based on the lexicon.

The main results of the thesis are an argument that simple TAGs are formally inadequate, and the definition of an extension to TAG that is. Every aspect of the definition of this extension to TAG, called V-TAG, is specifically motivated by linguistic facts, not by formal considerations. A formal investigation of V-TAG reveals that (when lexicalized) it has restricted generative capacity, that it is polynomial parsable, and that it forms an abstract family of languages. This means that it has desirable formal properties for representing natural language syntax. Both a formal automaton and a parser for V-TAG are presented.

As a consequence of the new system, a reformulation of the linguistic theory that has been proposed for TAG suggests itself. Instead of including a transformational step in the theory of grammar, all derivations are performed within mathematically defined formalisms, thus limiting the degrees of freedom in the linguistic theory, and making the theory more appealing from a computational point of view. This has several interesting linguistic consequences; for instance, functional categories are expressed by feature content (not

node labels), and head movement is replaced by the adjunction of heads. The thesis sketches a fragment of a grammar of German, which covers phenomena such as scrambling, extraposition, topicalization, and the V2 effect.

Finally, the formal automaton for V-TAG is used as a model of human syntactic processing. It is shown that this model makes several interesting predictions related to free word order in German.

### **Querying Nested Collections (Ph.D. Dissertation)**

**Limsoon Wong  
IRCS-94-09**

This dissertation investigates a new approach to query languages inspired by structural recursion and by the categorical notion of a monad.

A language based on these principles has been designed and studied. It is found to have the strength of several widely known relational languages but without their weaknesses. This language and its various extensions are shown to exhibit a conservative extension property, which indicates that the depth of nesting of collections in intermediate data has no effect on their expressive power. These languages also exhibit the finite-cofiniteness property on many classes of queries. These two properties provide easy answers to several hitherto unresolved conjectures on query languages that are more realistic than the flat relational algebra.

A useful rewrite system has been derived from the equational theory of monads. It forms the core of a source-to-source optimizer capable of performing filter promotion, code motion, and loop fusion. Scanning routines and printing routines are considered as part of optimization process. An operational semantics that is a blending of eager evaluation and lazy evaluation is suggested in conjunction with these input-output routines. This strategy leads to a reduction in space consumption and a faster response time while preserving good total time performance. Additional optimization rules have been systematically introduced to cache and index small relations, to map monad operations to several classical join operators, to cache large intermediate relations, and to push monad operations to external servers.

A query system Kleisli and a high-level query language CPL for it have been built on top of the functional language ML. Many of my theoretical and practical contributions have been physically realized in Kleisli and CPL. In addition, I have explored the idea of open system in my implementation. Dynamic extension of the system with new primitives, cost functions, optimization rules, scanners, and writers are fully supported. As a consequence, my system can be easily connected to external data sources. In particular, it has been successfully applied to integrate several genetic data sources which include relational databases, structured files, as well as data generated by several application programs.

### **Aspects of Partial Information in Databases (Ph.D. Dissertation)**

**Leonid Libkin  
IRCS-94-10**

Information stored in databases is usually incomplete. Typical sources of partiality are missing information, conflicts that occur when databases are merged, and asking queries against several databases simultaneously. The field of partial information in databases has not received the attention that it deserves. Most work on partial information in databases asks which operations of standard languages, like relational algebra, can still be performed correctly in the presence of simple forms of partial information. We believe that the problem should be looked at from another point of view: the semantics of partiality must be clearly understood and it should give us new design principles for languages for databases with partial information.

The main goals of this thesis are to develop new analytical tools for studying partial information and its semantics, and to use the semantics of partiality as the basis for design of query languages. Unlike typical research in artificial intelligence, we concentrate on general purpose solutions that are effectively implementable in the context of database query languages and provide a flexible basis for future modeling challenges.

We present a common semantic framework for various kinds of partial information which can be applied in a context more general than the flat relational model. This semantics is based on the idea of ordering objects in terms of being more informative. Such ordered semantics cleanly integrates all kinds of partial information and serves as a tool to establish connections between them. By analyzing mathematical properties of partial data, it is possible to find operations naturally associated with it. Such operations, arising from characterization of semantic domains of types as free algebras, can be turned into programming language constructs.

We discuss languages for databases with partial information that are given rise to by the semantics. A language for sets and or-sets is introduced and normalization theorem is proved. It allows to incorporate semantics into the language and to distinguish two levels of querying: structural and conceptual. This language has been implemented on top of Standard ML, and shown to be useful in problems of querying independent and incomplete databases.

### **A Computational Approach to Aspectual Composition (Ph.D. Dissertation)**

**Michael White  
IRCS-94-11**

In recent years, it has become common in the linguistics and philosophy literature to assume that events and processes are ontologically distinct entities, on a par with objects and substances. At the same time, the idea that time-based (episodic) knowledge should be represented as a collection of

interrelated eventualities has gained increasing acceptance in the computational linguistics and artificial intelligence literature.

Contrary to what one might expect, a search through the prior literature in linguistics and philosophy reveals no account in which these sortal distinctions play a direct role in adequately explaining the problem of aspectual composition and the closely related imperfective paradox. In the computational linguistics and artificial intelligence literature, moreover, relatively little attention has been paid to either problem.

In the first part of the dissertation, I investigate the hypothesis that the parallel ontological distinctions introduced above may be directly employed in an explanatory formal account of the problem of aspectual composition and the imperfective paradox. In so doing, I develop a synthesis of proposals by Hinrichs (1985), Krifka (1989; 1992) and Jackendoff (1991) which makes correct predictions in many cases not considered by these authors. In particular, the account is the first to adequately explain the syntactic and semantic behavior of non-individuating accomplishment expressions, such as Jack pour some amount of wort into the carboy, which are too vague to individuate a single event but nevertheless behave like other Vendlerian accomplishments.

In the second part of the dissertation, I explore the potential computational applications of the linguistic account, by way of two case studies. In the first one, I follow Moens (1987) in showing how a calculus of eventualities can facilitate the implementation of a simple statement verifier which allows for a much greater range of natural language queries than is usually the case with temporal databases. In the second, more preliminary study, I examine the relevance of the model-theoretic analysis to discourse interpretation, within the context of devising a program which produces simple microworld animations using short narrative descriptions as input specifications.

### **Description Based Parsing in a Connectionist Network (Ph.D. Dissertation)**

**James Henderson**  
**IRCS-94-12**

Recent developments in connectionist architectures for symbolic computation have made it possible to investigate parsing in a connectionist network while still taking advantage of the large body of work on parsing in symbolic frameworks. This dissertation investigates syntactic parsing in the temporal synchrony variable binding model of symbolic computation in a connectionist network. This computational architecture solves the basic problem with previous connectionist architectures, while keeping their advantages. However, the architecture does have some limitations, which impose computational constraints on parsing in this architecture. This dissertation argues that, despite these constraints, the architecture is computationally adequate for syntactic parsing, and that these constraints make significant linguistic pre-

dictions. To make these arguments, the nature of the architecture's limitations are first characterized as a set of constraints on symbolic computation. This allows the investigation of the feasibility and implications of parsing in the architecture to be investigated at the same level of abstraction as virtually all other investigations of syntactic parsing. Then a specific parsing model is developed and implemented in the architecture. The extensive use of partial descriptions of phrase structure trees is crucial to the ability of this model to recover the syntactic structure of sentences within the constraints. Finally, this parsing model is tested on those phenomena which are of particular concern given the constraints, and on an approximately unbiased sample of sentences to check for unforeseen difficulties. The results show that this connectionist architecture is powerful enough for syntactic parsing. They also show that some linguistic phenomena are predicted by the limitations of this architecture. In particular, explanations are given for many cases of unacceptable center embedding, and for several significant constraints on long distance dependencies. These results give evidence for the cognitive significance of this computational architecture and parsing model. This work also shows how the advantages of both connectionist and symbolic techniques can be unified in natural language processing applications. By analyzing how low level biological and computational considerations influence higher level processing, this work has furthered our understanding of the nature of language and how it can be efficiently and effectively processed.

### **Remaking the Science of Mind: Psychology as Natural Science**

**Gary Hatfield**  
**IRCS-94-13**

Psychology considered as a natural science began as Aristotelian "physics" or "natural philosophy" of the soul. C. Wolff placed psychology under metaphysics, coordinate with cosmology. Near the middle of the eighteenth century, Krueger, Godart, and Bonnet proposed approaching the mind with the techniques of the new natural science. At nearly the same time, Scottish thinkers placed psychology within moral philosophy, but distinguished its "physical" laws from properly moral laws (for guiding conduct). British and French visual theorists developed mathematically precise theories of size and distance perception; they created instruments to test these theories and to measure visual phenomena such as the duration of visual impressions. By the end of the century there was a flourishing discipline of empirical psychology in Germany, with professorships, textbooks, and journals. The practitioners of empirical psychology at this time typically were dualists who included mental phenomena within nature.

## **A General Framework for Hybrid Substructural Categorial Logics**

**Mark Hepple**  
**IRCS-94-14**

Some recent categorial proposals have employed structural modalities, modal operators which allow explicit management of resource sensitivity in linguistic derivation. Various theoretical, computational and practical problems arise for the use of such operators. I propose an alternative general model of hybrid substructural systems, in which different substructural logics (i.e. logics differing in their resource usage characteristics) are brought together into a single system, and which eliminates the need of structural modalities by exploiting natural relations between different substructural levels in terms of the relative informativeness of their characterizations. Under this model, the range of substructural levels form a single unified descriptive system, which should facilitate writing grammars for individual languages, and provide a better basis for cross-linguistic generalization.

## **Binding and Control in CCG and its Relatives**

**Mark Steedman**  
**IRCS-94-15**

The CCG account of the unbounded constructions - in particular, relativisation and coordination - generalizes the notion of surface structure in a way that disrupts traditional notions of dominance and command. This has led researchers in other frameworks to suggest that the theory is fundamentally incompatible with a coherent theory of binding and control - the bounded constructions. The present paper offers a theory of binding in CCG which preserves the original account of the unbounded dependencies, and which renders it immediately compatible with other theories, TAG in particular. The theory requires the abandonment of one assumption that has been traditional (though not essential) in other categorial approaches. The significance of the move is discussed.

## **Null Subjects in Early Child English and the Theory of Economy of Projection**

**Tom Roeper**  
**Bernhard Rohrbacher**  
**IRCS-94-16**

In this paper, we present new evidence showing that some of the empty subjects produced by young children acquiring English cannot be subsumed under the performance limitation analysis of Bloom (1990) or the Topic-drop analysis of Rizzi (1994). We argue contra Sano & Hyams (1994) that these missing subjects are instances of pro, not PRO, and demonstrate that the economy-based pro-drop theory of Speas (1994) handles our data in an elegant fashion. The analysis we propose links the acquisition of subjects to the acquisition of functional morphology, in accordance with the minimalist program developed since Chomsky (1989). One desirable consequence of the approach taken here is that no recourse to

a pro-drop parameter is necessary.

## **Kolmogorov Complexity and the Information Content of Parameters**

**Robin Clark**  
**IRCS-94-17**

A key goal of linguistic theory is to account for the logical problem of language acquisition. In particular, linguistic constraints can be taken as constraining the learner's hypothesis space and, so, reducing its computational burden. In this paper, I will motivate an information theoretic approach to explaining some linguistic constraints. In particular, the theory attempts to relate ease of acquisition with the simplicity of linguistic representations and their frequency in the learner's input text. To this end, the paper reviews some results in information theory and Kolmogorov complexity and relates them to a theory of parameters.

## **Active Part-Decomposition, Shape and Motion Estimation of Articulated Objects: A Physics-based**

**Approach**  
**Ioannis A. Kakadiaris**  
**Dimitri Metaxas**  
**Ruzena Bajcsy**  
**IRCS-94-18**

We present a novel, robust, integrated approach to segmentation shape and motion estimation of articulated objects. Initially, we assume the object consists of a single part, and we fit a deformable model to the given data using our physics-based framework. As the object attains new postures, we decide based on certain criteria if and when to replace the initial model with two new models. These criteria are based on the model's state and the given data. We then fit the models to the data using a novel algorithm for assigning forces from the data to the two models, which allows partial overlap between them and determination of joint location. This approach is applied iteratively until all the object's moving parts are identified. Furthermore, we define new global deformations and we demonstrate our technique in a series of experiments, where Kalman filtering is employed to account for noise and occlusion.

## **Active Motion-Based Segmentation of Human Body Outlines**

**Ioannis A. Kakadiaris**  
**Dimitri Metaxas**  
**Ruzena Bajcsy**  
**IRCS-94-19**

We present an integrated approach towards the segmentation and shape estimation of human body outlines. Initially, we assume that the human body consists of a single part, and we fit a deformable model to the given data using our physics-based shape and motion estimation framework. As an actor attains different postures, new protrusions emerge in the outline. We model these changes in the shape using a new

representation scheme consisting of a parametric composition of deformable models. This representation allows us to identify the underlying human parts that gradually become visible, by monitoring the evolution of shape and motion parameters of the composed models. Our algorithm is applied iteratively over subsequent frames until all moving parts are identified. We demonstrate our technique in a series of experiments with very encouraging results.

### **The Well-tempered Computer**

**Mark Steedman**  
**IRCS-94-20**

The psychological mechanism by which even musically untutored people can comprehend novel melodies resembles that by which they comprehend sentences of their native language. The paper identifies a syntax, a semantics, and a domain or "model." These elements are examined in application to the task of harmonic comprehension and analysis of unaccompanied melody, and a computational theory is argued for.

### **Final Report to NSF of the Standards for Facial Animation Workshop**

**Catherine Pelachaud**  
**Norman I. Badler**  
**Marie-Luce Viaud**  
**IRCS-94-21**

Report to the National Science Foundation based on the Standards for Facial Animation Workshop, November 11-12, 1993, sponsored by NSF's Division of Information, Robotics, and Intelligent Systems, and the Institute for Research in Cognitive Science.

### **Physics-Based Tracking of 3D Objects in 2D Image Sequences**

**Michael Chan**  
**Dimitri Metaxas**  
**Sven Dickinson**  
**IRCS-94-22**

We present a new technique for tracking 3D objects in 2D image sequences. We assume that objects are constructed from a class of volumetric part primitives. The models are initially recovered using a qualitative shape recovery process. We subsequently track the objects using local forces computed from image potentials. Therefore we avoid the expensive computation of image features. By integrating measurements from stereo images, 3D positions (as well as other model parameters) of the objects can be continuously updated using an extended Kalman filter. Our model-based approach can handle occlusions in scenes with multiple moving objects by predicting their occurrences. To handle severe or unexpected occlusion we use a feedback mechanism between the quantitative and qualitative shape estimation systems. We demonstrate our technique in experiments involving image sequences from complex motions of objects.

### **Physics-Based Object Pose and Shape Estimation from Multiple Views**

**Michael Chan**  
**Dimitri Metaxas**  
**IRCS-94-23**

This paper presents a new algorithm for object pose and shape estimation from multiple views. Using a qualitative shape recovery scheme we first segment the image into parts which belong to a vocabulary of primitives. Based on the additional constraints provided by the qualitative shapes we extend our physics-based framework to allow object pose and shape estimation from stereo images where the two cameras have arbitrary relative orientations. We then generalize our algorithm to integrate measurements from multiple views. To recover more complex objects we generalize the definition for the global bending deformation. We also present an algorithm for model discretization which evenly tessellates the model surface. We demonstrate the usefulness of our technique in experiments involving real images from a variety of object shapes which may be partially occluded.

### **On German Verb Syntax under Age 2**

**Bernhard Rohrbacher**  
**Anne Vainikka**  
**IRCS-94-24**

Previous research on early child German suggests that verb placement is mastered early on, at least around the age of two; this finding has provided support for the idea that the full syntactic tree is present from the earliest stage of syntactic development. We show that two German children around a year and a half of age already exhibit a clear distinction between finite and non-finite utterances in terms of verb placement and the distribution of empty subjects. Although their verbal paradigms are impoverished, these children clearly already have an inflectional projection (IP) in finite clauses. However, we argue against the idea that a full syntactic tree is available at this point; rather, the data support a reduced representation without a complementizer projection (CP). Furthermore, non-finite matrix clauses, common at this early stage, lack even the inflectional projection.

### **Issues on Modern Greek Sentential Complementation (Ph.D. Dissertation)**

**Spyridoula Varlokosta**  
**IRCS-94-25**

This dissertation is concerned with a range of syntactic phenomena related to sentential complementation in Modern Greek and the consequences they have for the Theory of Grammar. Two types of complements are examined: (i) factive complements and their pattern of wh-extraction, and (ii) subjunctive complements and their implications for the theory of control and the licensing of case.

In particular, evidence from the syntax of Modern Greek - more specifically, from the distribution of an A'-bound

pronoun- is drawn against an operator approach of factive complements. It is argued that the strong islandhood observed in Modern Greek factive complements is due to the fact that they are not real complements of the subcategorizing verb but independent clauses standing in a paratactic relation to an empty nominal complement of the matrix predicate. The crosslinguistic variation attested with respect to extraction, is attributed to the ability of languages such as English to form certain types of A'-chains which evidently are impossible in Modern Greek.

Furthermore, upon investigation of the so called subjunctive complements in Modern Greek it is shown that the position of their understood subject may be occupied sometimes by a pronominal pro and sometimes by an anaphoric PRO. The licensing of the two empty categories is derived through the aspectual and tense properties of these constructions. It is claimed that the presence of PRO in these configurations and the set of anaphoric properties it displays provides evidence that the distribution of this empty category can be derived on a case theoretic account, along the lines of Bouchard (1984), or Chomsky and Lasnik (1991), and does not depend on the notion of government as in Chomsky (1981).

### **Linear Structure From Motion**

**Inigo Thomas**  
**Eero Simoncelli**  
**IRCS-94-26**

Determining the structure of the world and the motion of the observer from image changes has been a central problem in computer vision for over fifteen years. Since the early work on Structure from Motion (SFM) by Longuet-Higgins and Pradny, several techniques have been developed to compute the motion of the camera, the shape of moving objects, or distances to points in the world. However, the image changes are non-linearly related to camera motion and distances to points in the world. Thus, solving the problem typically requires non-linear optimization techniques that can be unstable or computationally inefficient. Linear algorithms are preferable since they are computationally advantageous, and since linear estimation is much better understood than non-linear estimation. Our paper describes an unbiased, completely linear algorithm for Structure-from-Motion. This work is similar to that of Jepson & Heeger, except that we employ spherical projection. The use of a spherical imaging geometry allows a simpler and more intuitive derivation of the algorithm, and produces an unbiased estimator. Experimental results are provided that demonstrate the performance of the algorithm.

### **A Shared-Memory Multiprocessor Implementation of Data-Parallel Operators for ML**

**Dan Suci**  
**Lorenz Huelsbergen**  
**IRCS-94-27**

We have designed and implemented an asynchronous data-parallel scheduler for the SML/NJ ML compiler. Using this general scheduler we built a data-parallel module that provides new operators to manipulate sequences (i.e. arrays, vectors) in parallel. Parallelization concerns such as thread creation and synchronization are hidden from the application programmer by ML's module abstraction. We find that languages with modules, higher-order functions and automatic parallel storage management can, in this manner, seamlessly support data-parallel operators. An implementation of applications using the new sequence module on an eight-processor shared-memory machine indicates that in some cases useful speedup is possible with our approach.

### **Korean Grammars Using Tags**

**Hyun Seok Park**  
**IRCS-94-28**  
**MS-CIS-94-64**

This paper addresses various issues related to representing the Korean language using Tree Adjoining Grammars. Topics covered include Korean grammar using TAGs, Machine Translation between Korean and English using Synchronous Tree Adjoining Grammars (STAGs), handling scrambling using Multi Component TAGs (MC-TAGs), and recovering empty arguments. The data for the parsing is from US military communication messages.

### **Pronominal Clitics in Quebec Colloquial French: A Morphological Analysis**

**(Ph.D. Dissertation)**  
**Julie Auger**  
**IRCS-94-29**

The grammatical status of Romance pronominal clitics has long been the object of intense debate. Are they syntactically-independent arguments or are they affixal agreement markers? This dissertation addresses this question with respect to Quebec Colloquial French (QCF). It treats the morphophonological and morphosyntactic dimensions as two independent dimensions, thus allowing either for affixes to have argument status and prohibiting them from co-occurring with an overt, lexical argument, or for non-affixal elements to behave like agreement markers and not count as syntactic arguments. The analysis reveals that all the clitics of QCF are affixes at the morphological level, since they demonstrate numerous patterns which are too idiosyncratic to be handled by syntactic rules. Only subject clitics, however, function as agreement markers, since they occur in all the environments where we would expect agreement markers; object markers, conversely, are excluded from those environments.

I shall present a morphological analysis following the approach taken by Roberge and his colleagues and work within the Minimalist framework of Chomsky (1993). I assume that fully-inflected lexical items are inserted in the syntax, and I adopt Cummins & Roberge's (1994a,b) suggestion that an additional interface, the Lexicon-Syntax

Interface, handles all inflectional morphology.

Chapter 1 introduces the main problem and summarizes a number of recent studies on Romance and French clitics. Chapter 2 presents the facts in QCF and applies morphophonological and morphosyntactic criteria in order to determine the grammatical status of these argument markers. Chapter 3 develops a morphological approach that allows fully inflected verbs to be inserted in the syntax. Finally, chapter 4 discusses one element which has traditionally been excluded from the paradigm of subject markers: *ca*. The chapter is divided into two parts; the first one discusses the semantic aspects concerning the generic use of *ca*, while the second one develops an approach to grammatical agreement which allows agreement targets to introduce their own features, as well as certain types of feature conflicts.

### **A Multiple-Conclusion Meta-Logic**

**Dale Miller**

**IRCS-94-30**

**MS-CIS-94-51**

The theory of cut-free sequent proofs has been used to motivate and justify the design of a number of logic programming languages. Two such languages, lambda-Prolog and its linear logic refinement, Lolli, provide for various forms of abstraction (modules, abstract data types, higher-order programming) but lack primitives for concurrency. The logic programming language, LO (Linear Objects) provides for concurrency but lacks abstraction mechanisms. In this paper we present Forum, a logic programming presentation of all of linear logic that modularly extends the languages lambda-Prolog, Lolli, and LO. Forum, therefore, allows specifications to incorporate both abstractions and concurrency. As a meta-language, Forum greatly extends the expressiveness of these other logic programming languages. To illustrate its expressive strength, we specify in Forum a sequent calculus proof system and the operational semantics of a functional programming language that incorporates such non-functional features as counters and references.

### **SodaJack: An Architecture for Agents that Search for and Manipulate Objects**

**Christopher Geib**

**Libby Levison**

**Michael B. Moore**

**IRCS-94-31**

**MS-CIS-94-16**

This paper presents an architecture for agents that search for and manipulate objects. It is demonstrated in the SodaJack system, a system that animates a human working at a soda fountain. The system is constructed as a set of three interacting planners. Two of these planners are special-purpose modules which contribute context-specific plans for the tasks of searching for and manipulating objects. The search planner is used to convert knowledge acquisition goals into goals of searching locations. An object specific reasoner is used to

build object sensitive plans for manipulating specific objects. Finally, an incremental hierarchical planner is used to integrate these two special purpose planners into a complete system which interleaves planning and acting.

### **Domain-Independent Queries on Databases with External Functions**

**Dan Suciu**

**IRCS-94-32**

**MS-CIS-94-48**

We investigate queries in the presence of external functions with arbitrary inputs and outputs (atomic values, sets, nested sets etc). We propose a new notion of domain independence for queries with external functions which, in contrast to previous work, can also be applied to query languages with fixpoints or other kinds of iterators. Next, we define two new notions of computable queries with external functions, and prove that they are equivalent, under the assumption that the external functions are total. Thus, our definition of computable queries with external functions is robust. Finally, based on the equivalence result, we give examples of complete query languages with external functions. A byproduct of the equivalence result is the fact that Relational Machines are complete for complex objects: it was known that they are not complete over flat relations.

### **Subsumption Architecture and Discrete Event Systems: A Comparison**

**Luca Bogoni**

**IRCS-94-33**

**MS-CIS-94-09**

In this paper we review Subsumption Architecture and Discrete Event Systems. These approaches present diverse methodologies for dealing with control of interactions. They often take diametrically opposite directions in addressing specific issues. Subsumption architecture expects limited knowledge of the environment, no explicit representation, limited reasoning capabilities and no centralized control. At the other extreme lies Discrete Event Systems, which require, at least in manufacturing and communication: a well-structured environment; explicit representations and models; and have limited reasoning capabilities and centralized control. Both offer benefits and limitations which should really be evaluated and traded off when attempting to build a system. However, combining aspects from these two approaches will not address and resolve all issues. We conclude that while both approaches are powerful there is more to intelligence than just behavior and control, and discuss the limitations and benefits entailed by both.

## **Review of the Literature on Time-Optimal Control of Robotic Manipulators**

**Milos Zefran**

**IRCS-94-34**

**MS-CIS-94-30**

A task that robotic manipulators most frequently perform is motion between specified points in the working space. It is therefore important that these motions are efficient. The presence of the obstacles and other requirements of the task often require that the path is specified in advance. Robot actuators cannot generate unlimited forces/torques so it is reasonable to ask how to traverse the prespecified path in minimum time so that the limits on the actuator torques are not violated.

It can be shown that the motion which requires least time to traverse a path requires at least one actuator to operate on the boundary (maximum or minimum). Furthermore, if the path is parameterized, the equations describing the robot dynamics can be rewritten as functions of the path parameter and its first and second derivatives. In general, the actuator bounds will be transformed into the bounds on the acceleration along the path. These bounds will be functions of the velocity and position. It is possible to demonstrate that the optimal motion will be almost always bang-bang in acceleration. The task of finding the optimal torques thus reduces to finding the instants at which the acceleration will switch between the boundaries.

An algorithm for finding the time-optimal motion along prespecified paths that explores this idea will be presented. It will be shown that so called singular arcs exist on which the algorithm will fail. Modification of the algorithm for such situations will be presented. Also, some properties of the solutions of the more general problem when the path is not known will be discussed. Lie-algebraic techniques will be shown to be a convenient tool for the study of such problems.