Resource Logics and Minimalist Grammars

Christian Retoré **Edward Stabler**

IRISA
Campus de Beaulieu
F-35042 Rennes cedex
retore@irisa.fr

UCLA Linguistics Dept.
3125 Campbell Hall
Los Angeles CA 90095-1543
stabler@ucla.edu

Abstract

This ESSLLI workshop is devoted to connecting the linguistic use of resource logics and categorial grammar to minimalist grammars and related generative grammars. Minimalist grammars are relatively recent, and although they stem from a long tradition of work in transformational grammar, they are largely informal apart from a few research papers. The study of resource logics, on the other hand, is formal and stems naturally from a long logical tradition. So although there appear to be promising connections between these traditions, there is at this point a rather thin intersection between them. The papers in this workshop are consequently rather diverse, some addressing general similarities between the two traditions, and others concentrating on a thorough study of a particular point. Nevertheless they succeed in convincing us of the continuing interest of studying and developing the relationship between the minimalist program and resource logics. This introduction reviews some of the basic issues and prior literature.

1 The interest of a convergence

What would be the interest of a convergence between resource logical investigations of language and the minimalist tradition of transformational grammar? On the one hand, we might expect that the formal nature of the resource logic tradition might prompt a better formal understanding of minimalist grammar, and with this better understanding we might obtain insight into computational questions and models of human language processing. The computation of a parse may be regarded as the demonstration of a theorem, in a context where we can study a broad range of results relating to syntactic analysis (parsing), semantics, learning and generation. Theorem proving techniques, type unification and other algorithms studied in resource logic may apply here.

The generative grammar tradition may also benefit from the resource logic setting by obtaining a good, formal connection with formal semantic proposals that quite directly relate to the Montague tradition. In the resource logic description of syntax, this so-called Montague semantics is really close to syntactic structure (this "semantics" is nothing but a reference calculus and therefore according to the generative approach is

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more syntax than semantics). This enables in resource logics fairly simple computation of semantic representations (or reference structure) of an utterance, which up to now is not that clear in the generative tradition.

A connection with minimalist grammar might bring to the resource-logical tradition a host of new linguistic ideas and possibly also formal problems. In resource-logical grammars, it would be interesting to explore, for example, what the principles and notions of universal grammar correspond to, and whether there are better explanations of cross-linguistic variations.

2 Some basic points of convergence

Lambek noticed that if we add hypothetical reasoning to the classical categorial grammar of Ajdukiewicz and Bar-Hillel, we obtain a kind of propositional calculus with a directionally sensitive implication, where the structural rules (permutation, contraction, thinning) are suspended [50].

$$\frac{\Gamma[B,A]\vdash\Delta}{\Gamma[A,B]\vdash\Delta}\,permute \qquad \frac{\Gamma\vdash\Delta}{\Gamma,A\vdash\Delta}\,thin \qquad \frac{\Gamma[A,A]\vdash\Delta}{\Gamma[A]\vdash\Delta}\,contract$$

And in *linear logic* [30, 31], substructural logics lacking the structural rules have received systematic study. In these logics, the constituents of an expression act like resources: they may be consumed and produced in the course of a proof.

This is easy to explain by analogy with automata or Petri nets, as explained in [93]. In the presence of contraction or thinning (a.k.a. weakening), an implication $A \Rightarrow B$ cannot be viewed as a transition changing the state, since from A and $A \Rightarrow B$ one can deduce B but also A and B: A still holds, i.e. has not been consumed: classical and intuitionistic logic handle eternal truths which are sempiternally reusable. Thinning is less problematic: it simply says that some resources may vanish: if a state change $A \Rightarrow Y$ requires A to yield Y, it may also apply when other resources, say B, are present, but may lead to Y only, and not to B and Y. The rejection of the exchange rule turns our resources into a linearly ordered set, instead of a plain set. Although this might not be adequate for various resource sensitive systems, it is clearly a good idea for linguistic resources which follow the utterances consisting of linearly ordered elements.[1]

Rewrite grammars also consume and produce categories in the course of a derivation, but these systems are even further from logic than classical categorial grammar is, in that the resources of rewrite grammars (i.e. the categories) are simple atoms. Context free grammars and simpler systems are inappropriate for the description of human languages [13], and rather than simply ascending the Chomsky hierarchy to more expressive rewrite grammars, linguists proposed special formalisms: *transformational grammars*, *tree adjoining grammars*, and later, *unification-based constraint grammars*, and other systems. All of these systems adopt the categorial insight that the categories, and even the categories of the simplest lexical items, have structure. This allows a simplification in the generative rules: different categories which are "structurally similar" in some sense can be treated similarly by the generative mechanisms.

[1] A total order may be too strong, e.g. for handling relatively free word orders, or for modeling simultaneous modifier/modified phrase in sign languages

The simplification of the generative mechanisms is taken to an extreme in theories of "government and binding," and even more so in certain recent "minimalist" proposals of the transformational tradition in syntax [14]. In these recent minimalist proposals, two other assumptions of the categorial tradition are adopted: *first,* the generative mechanisms are assumed to be simple and universal (i.e. all language variation is lexical), and *second,* the languages are generated from lexical resources. In sum, we have these four points of convergence:

1. **complex expressions:** The structures over which generative rules are defined are complex (structured categories, or trees labeled with features).

2. **generative:** Languages are generated from lexical resources by rather simple, perhaps universal, generative rules (the axioms of resource logics, the structure building rules of grammar).

3. **resource driven:** Generative rules are triggered by some feature of the structure to which they applies; the trigger is "checked" or "deleted" from the result.

4. **lexical resources:** The resources of the grammar are fundamentally lexical, and language variation is either included in a set of postulate or purely lexical

It is perhaps worth mentioning that in derivational, resource-based perspectives, proofs and derivations are naturally represented by graphs. Graph-theoretic perspectives have played an important practical and theoretical role in the development of these formalisms. (The action of a constraint or filter does not lend itself so easily to simple graph representations.)

The minimalist grammars have many other properties that are not prominent in the resource logic/categorial tradition: heavy use of phonetically empty structures; trans-derivational filters on the generated set of expressions; semantic values specified in a post-hoc, often non-compositional fashion (if at all); and perhaps most notably, no hypothetical reasoning. Without hypothetical reasoning, minimalist grammars are unlike Lambek grammars and other logics for which deduction and completeness theorems can be established.[2] Lambek's proposal that introducing hypothetical reasoning allows grammars that are not only mathematically more natural – "complete" in a certain sense – but also formally simpler and semantically natural, has been advocated by [63, 62, 65] and others, and continues to receive serious attention.

[2]In a logic with an implication $\rightarrow$, a deduction theorem has the form: $\Gamma[A] \vdash B$ iff $\Gamma \vdash A \rightarrow B$.

3 Background: some brief remarks

3.1 Resource logics

The non-associative and associative Lambek calculi respectively introduced in 1958 [50] and 1961 [51] by Joachim Lambek can be given in the following forms:

Non-associative Lambek calculus, NL

$$\frac{}{A \vdash A}\,axiom \qquad\qquad \frac{\Delta \vdash A \quad \Gamma[A] \vdash C}{\Gamma[\Delta] \vdash C}\,cut$$

$$\frac{\Gamma[A] \vdash C \quad \Delta \vdash B}{\Gamma[(A/B, \Delta)] \vdash C}\,/L \qquad\qquad \frac{(\Gamma, B) \vdash A}{\Gamma \vdash A/B}\,/R \qquad \Gamma \neq \epsilon$$

$$\frac{\Delta \vdash B \quad \Gamma[A] \vdash C}{\Gamma[(\Delta, B\backslash A)] \vdash C}\,\backslash L \qquad\qquad \frac{(B, \Gamma) \vdash A}{\Gamma \vdash B\backslash A}\,\backslash R \qquad \Gamma \neq \epsilon$$

$$\frac{\Gamma[A, B] \vdash C}{\Gamma[(A \bullet B)] \vdash C}\,\bullet L \qquad\qquad \frac{\Gamma \vdash A \quad \Delta \vdash B}{(\Gamma, \Delta) \vdash A \bullet B}\,\bullet R$$

$\Gamma[]$ denotes a context with a hole.

Associative Lambek calculus, L

is obtained from NL above by forgetting the $(,)$ i.e. the binary-tree structure on hypotheses; consequently it handles sequences of hypotheses.

These calculi may be used as a grammar as follows. The lexicon provides each word m with several types $T(m)$ built form a finite number of atomic categories, one being a distinguished category S, the start symbol (as in classical categorial grammars); a sequence of words $m_1, \ldots, m_n$ is a sentence whenever $\forall i\ \exists t_i \in T(m_i)$ such that $t_1, \ldots, t_n \vdash S$ for L — or such that for some bracketing $BinTree(t_1, \ldots, t_n)$ of the formula $t_1, \ldots, t_n$ one has $BinTree(t_1, \ldots, t_n) \vdash S$ for NL.

From a logical point of view, these calculi are "perfect," i.e. they enjoy numerous good properties: the cut-elimination and sub-formula property (which make parsing decidable) complete truth value semantics, and denotational semantics (bi-modules) for L. Furthermore the relation to rewrite grammar is by now rather clear [69, 92, 91]. (For more details on mathematical aspects the reader is referred to Buszkowski survey [10].) Nevertheless these calculi remained far from other logics until the 1980's, mainly because they are resource sensitive (lacking contraction and weakening) and also non-commutative. They are also intuitionistic, but this is more standard, especially in computational logic.

The revival of interest in these calculi is mainly due to advances in logic. First van Benthem and Moortgat enriched them with modalities and used techniques from modal logic [94, 96, 63] and also [65] with a slightly different approach. Nevertheless the relation to other logics, in particular with intuitionistic logic and classical logic has only been clarified with the invention of linear logic by Girard [30]: the full power of intuitionistic logic is recovered by modalities which restore (and control) the so called structural rules of weakening and contraction. The embedding into intuitionistic logic is especially important since that is the very reason for the simple interface with Montague semantics where semantic recipes are proofs in intuitionistic logic [26]. Furthermore linear logic enables the consideration of various extensions which can be used for syntactic analysis: systems mixing commutative and non-commutative connectives, and the proof net syntax which is discussed below.

The general setting in *Multi-Modal Categorial Grammar* pursues the idea of Lambek that word behavior is encoded by logical formulas. Since there is now a survey [63] by Moortgat as well as a book by Morrill [65], we shall not give much detail. The base logic is non-associative Lambek calculus NL of [51] in which hypotheses are even more structured than a total order: they are provided with a binary tree. This calculus enjoys the same properties as the Lambek calculus and is even decidable in polynomial time — [1] showed it for product free NL, and recently de Groote [25] extended the result to full NL. As the associative calculus is already too restrictive for linguistic purposes, this "base logic" is extended in two related directions. One extension consists in allowing several similar modes of compositions at the same time, for example $\bullet_l, \backslash_l, /_l$ and $\bullet_r, \backslash_r, /_r$ where the subscript l or r indicates where the head lies. The other consists in enriching the logic by modalities, or unary connectives, used in pairs; one forms a compound which can only be open by the other. An important ingredient of multimodal categorial grammars is the use of postulates which rule the behavior of each modality with respect to binary connectives and to other modalities. Such postulates enable a controlled used of structural properties (like associativity), and there exist faithful embeddings between this family of systems [48]. A pleasant linguistic property of MMCG is that the base logic can be viewed as the universal way for assembling constituents while the use of modalities in lexical entries and above all the postulates ruling structural interactions express some language specific properties.

Linear logic was a priori not designed for linguistic purposes, but for proof theoretical and computational reasons as explained in Girard's original paper [30] and subsequent ones [32, 31]. In a sense, it is a way to combine the "constructive" behavior of intuitionistic logic and the symmetry of classical logic. The constructive aspect of intuitionistic logic can be seen for instance in the Curry-Howard isomorphism between functional programs and intuitionistic proofs; on the other hand the symmetry of classical logic is reflected the de Morgan laws and the involutive negation. But formally, the restriction is quite simple: one obtains the intuitionistic subcalculus of a given classical calculus by requiring that there is always, in the course of a derivation, exactly one conclusion, i.e. one formula on the right of $\vdash$. For more details on the proof theoretical relations between classical and intuitionistic logic, the reader is referred to e.g. [33]. We can say informally that intuitionistic logic is intimately related to the asymmetric relation between function and argument (trees, terms), while classical logic is more concerned with symmetric relations, or graphs.

The computational study of intuitionistic logic led to linear logic via the discovery, in the framework of denotational semantics, that intuitionistic implication corresponds to two operations: one unary connective, an exponential modality, which makes the resource A used unbounded $!A$, and the other is an implication which consumes it

$A \multimap B$ — which denotes both B/A and $A\backslash B$ of the Lambek notation. A major outcome of this embedding of intuitionistic logic into linear logic is for instance the local and optimal implementation of β-reduction — which can be used for e.g. computing semantic recipes.

The absence of structural rules enables the consideration of non-commutative restrictions of linear logic, first introduced by Abrusci and Yetter [2, 100]. For instance one can rediscover the Lambek calculus as being exactly intuitionistic multiplicative linear logic [2, 82, 49, 76]. Non-commutative linear logic proofs, i.e. parse structures, can be viewed as linear logic proofs, even when the proof is lifted to the corresponding semantical types. And using the embedding of intuitionistic logic into linear logic, semantical λ-terms which by Curry-Howard isomorphism are intuitionistic proofs, can also be viewed as linear logic proofs. Thus, both the semantic homomorphic image of the syntactic analysis and the semantic recipes are linear logic proofs, and using cut elimination between the semantics of the words and the "lifted" syntactic analysis one can compute the semantic recipe of an utterance. [26].

The flexibility of linear logic, where logical operations are reduced to very basic ones, also enables variations which may be useful for linguistic description. For instance one can have at the same time commutative and non-commutative connectives. The first way was to introduce a single non-commutative connective which is self-dual [75, 77]. The second way introduced by de Groote and subsequently enriched by Ruet, Abrusci, Demaille resembles the multimodal approach: one has at the same time the Lambek connectives and the commutative linear connectives, with structural rules linking the two — nevertheless it is less powerful, because it is still decidable, and does not involve structural modalities or postulates [24, 83, 6, 23]. There also exists a classical calculus with a left and a right negation [2], with ways to introduce modalities enabling displacement [3], or more sophisticated behaviors. Although these systems have not been used in linguistic applications, they may well be, since one often requires additional mechanisms.

A great outcome of the linear logic already used in linguistics is its natural syntax, the so-called proof nets [30, 31, 93, 5, 49, 76, 80]. A proof-net represents a proof as a graph, which consists of two parts: the subformula tree of the formula it proves, plus some edges linking dual atoms called axioms. These axioms are the representation of resource consumption at the level of elementary resources. Of course not all such graphs can be proofs, otherwise as soon as a formula would have as many positive atoms a as negative ones $\overline{a}$ it would be provable! So one has a correctness criterion, usually a graph theoretical property to define the subclass of these graphs which are proof-nets. And out of this, proof-normalization, semantics, . . . are incredibly easy to establish. Above all, proof-nets are closer to proofs than ordinary sequent calculus proofs or natural deduction: commutations of rule applications are equated.

If the categorial paradigm of and proof net *parsing-as-deduction* brings us closer to the intuitive notion of proof, one might expect some new linguistic perspectives to be revealed, and this is already happening. One of the first uses was the use of the calculus of Pomset logic (linear logic plus a non-commutative self-dual connectives): Lecomte and Retoré [56, 57] defined a grammar which associates a partial proof-net (and not just a formula) with each lexical item. This way they are able to describe some phenomena which hitherto fell out of the scope of categorial grammars (relatively free word order, clitics,. . .) and to encode Tree-Adjoining Grammars [72]. The proof nets may also reveal linguistically and psychologically significant properties of constructions. For example, using proof nets Johnson [40] obtained measures of the instantaneous complexity of center-embedded constructions, and this work has been pursued by Morrill [66] to catch other phenomena.

It is a pity that linear logic enjoys the perfect symmetries of classical linear logic, an involutive negation and de Morgan laws, while all that has been done for linguistic purposes relies on the intuitionistic fragment of linear logic. There is nevertheless an exception to this, namely the Pomset calculus which needs a classical setting, [77, 56] but still reveals, inside the particular proof nets which are used, a privileged conclusion. So the part of the logic used for the grammar is in some sense intuitionistic as well, and in the subsequent papers authors reduced the logic to this intuitionistic-like calculus [57]. There may be good reason for doing so. One is sociological: intuitionistic calculi basically correspond to functions leading from several arguments to a single result, or put differently, they handle tree structures, which are the standard way to depict parse structure. But it may as well be a property of linguistic interaction to never be symmetric. For instance Kayne [47] suggests such properties.

Nevertheless, as is usually the case, richer structures enable the proof of results that would be ignored otherwise, as for example, in proving properties of natural numbers using real numbers. The use of proof-nets (naturally classical) for establishing properties of an intuitionistic calculus (for instance the Lambek calculus) is for us totally similar. For instance, although they use a natural deduction presentation for simplicity[3], the account of Stabler's minimalist grammars [86] (introduced in the next section) in the plain Lambek calculus given by Lecomte and Retoré in [58] is clearly a by product of the study of proof-nets and their paths. Similarly the work of Joshi, Kulick, and Kurtonina [41, 42] on Partial Proof-Trees as building blocks of a categorial grammar, using TAG-like operations, resemble construction in proof nets of [72, 57], although they also use natural deduction.

3.2 Minimalist grammar

The "minimalist" grammar introduced by Chomsky [14] differs from the prior tradition in transformational grammar in a number of respects. We will very roughly indicate just some of these here. Deep structure is eliminated; rather than applying movement operations to a fully constructed "deep structure," *move* and *merge* both apply in the course of building the initial clause structure. This structure is built from a "numeration" or multiset of lexical items, where each lexical item is a set of features, and the derivation is required to meet various "economy conditions." Lexical features may be strong or weak, and they may be interpretable or non-interpretable, with different consequences for the configurations in which they are "checked." In the recent work [15], Chomsky attempts to locate the strong/weak distinction in PF/LF interface requirements, and he assumes that "covert" and "overt" movement operations apply in the same cycle.

In a series of papers Stabler, Cornell and others have formalized a simplified version of some of these proposals in a way that brings us close to the connection with resource logic. In this system, the language is the closure of a finite lexicon under the

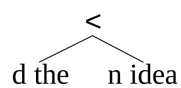
[3] In the intuitionistic case natural deduction is very similar to proof-net syntax; but as soon as the product is used, still a single proof-net correspond to several natural deductions.

structure building rules, where each element of the lexicon is just a sequence of features, and the structure building operations are *merge* and *move* defined as follows:[4]

features		examples
`f, F`	properties	(D,N,V,A,...,case,agr,..., some,every,student,...)
$\circ$`f`, $\circ$`F`	X0 movement triggers	($\circ$v, $\circ$V,...)
`+f, +F`	XP movement triggers	(+case, +CASE,...)
θ`f`	theta requirements	(θd, θc,...)

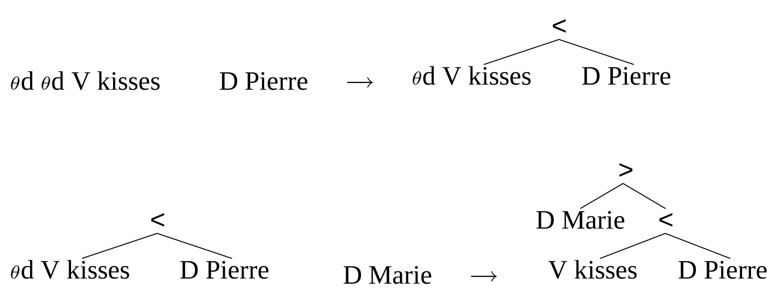
The lexicon is a finite set of finite sequences of these features. Here, the upper case $+$ features are "strong," triggering the overt movement of phonetic material, while lower case features trigger movements that leave all phonetic material behind. The unmarked upper case features, the "properties," are "interpretable," and will not be deleted in the course of the derivation.

Linguistic expressions are ordered trees, and so we regard the lexical items as 1-node trees labeled by these sequences of features. In complex trees, the leaves are labeled by (possibly empty) features sequences, and internal nodes are decorated by an order symbol $<$ or $>$ which "points" toward the head of the phrase. For example, a determiner phrase might have a structure like this:



A "maximal projection" is a maximal subtree with a given head. The set of expressions exp is the set of trees of this kind, and then the structure building rules are maps from tuples of this set into this set. We will present examples to illustrate the two rules; formal definitions are already in other papers in this workshop and in the prior literature.

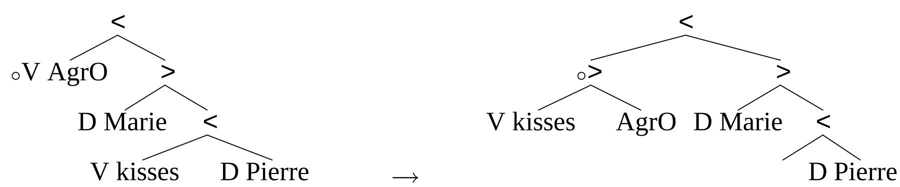
The structure building rule: $merge \subset (exp \times exp \times exp)$ has two cases: (i) A simple head attaches its first constituent on the right, in *complement* position (perhaps deleting matching θfeatures, if any); (ii) A complex expression can merge with other trees, attaching them in *specifier* position (perhaps deleting matching θfeatures, if any).

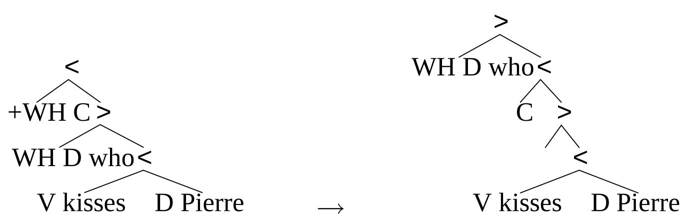


[4]The literature considers a number of variations of this framework. For example, the particular account of feature-checking offered here differs slightly from the ones proposed in earlier work – this adjustment is made to bring the formal framework slightly closer to informal proposals in the field.

This rule $merge$ applies freely (perhaps checking θ features, when possible).

The structure building rule: $move \subset (exp \times exp)$, on the other hand. is triggered by a **+** or $\circ$ feature, and checks all matching features. Unlike $merge$ which applies freely, $move$ only applies when triggered by **+** or $\circ$ feature on the head of the root of the tree, and it checks all matching features. This rule has four cases: overt head movement, covert head movement, overt phrasal movement, and covert phrasal movement – which case applies depends on the triggering feature. The cases of overt head movement and overt phrasal movement, respectively, are illustrated below. The covert operations are identical, except that the phonetic material is left behind (as we will see in the example derivation below).





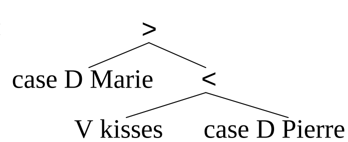
The domain of $move$ is restricted by various constraints: the "shortest move condition" (SMC) and others which will be discussed below.

For an example derivation, consider the following lexicon:

case D Pierre	∘v +case AgrO
case D Marie	∘agrO T
θd θd V kisses	∘v T
θc θd V believes	∘t +CASE agrS
	∘agrS C

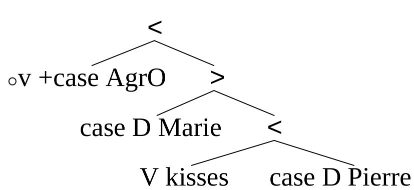
From this lexicon, with 12 rule applications, we can derive a structure in which all features except **c** are checked, as follows:

1. after the 2 merges shown above:

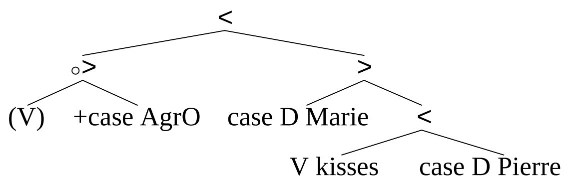


2. lexical: ∘v +case AgrO

3. merge(2,1):

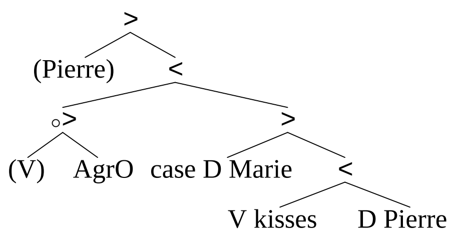


4. move(3):



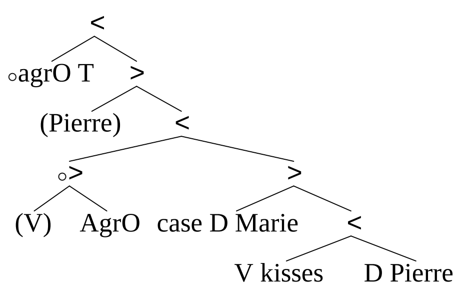
(SMC1) Assuming that a (c)overt head with adjoined elements can (c)overtly attract across a specifier position.

5. move(4):



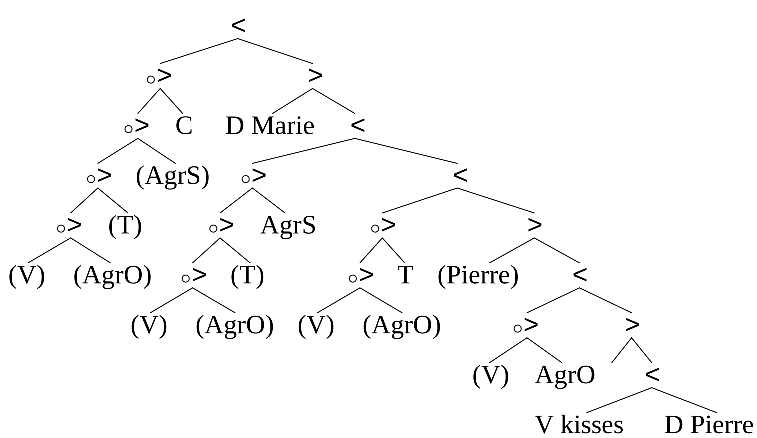
6. lexical: ◦agrO T

7. merge(6,5):

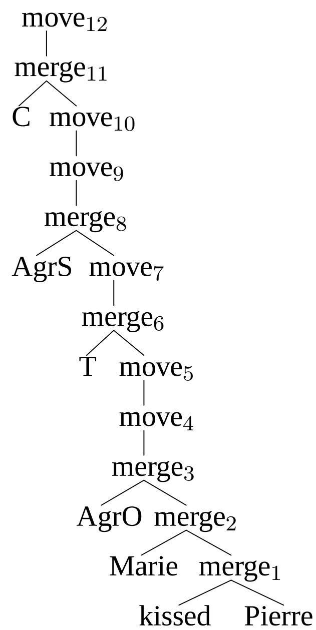


...

15. move:



"Sentences" are the derived structures with root C and no outstanding requirements, so this is a derivation of the sentence *Marie kisses Pierre.* The structure of the whole derivation of *Marie kisses Pierre* can be depicted by a tree that just shows the rule applications, as follows:



Notice that the feature checking done by the merge and move steps to leave only C in this kind of grammar looks quite a lot like the use of “application” steps in categorial grammar to leave only S. In the Gentzen formulation of the Lambek calculus presented above, effects of the application steps of categorial grammar are obtained with the $[/L]$ and $[\backslash L]$ rules.

4 Syntax in resource logics and minimalism

4.1 Universals

One distinction that recent minimalist proposals inherit from the past four decades of work in the transformational tradition is the programmatic assumption that human languages have special properties; that some of these properties are distinctively linguistic, the “linguistic universals”; and that some of these linguistic universals are distinctively syntactic. With this assumption, one expects that human languages are definable in a formalism with limited expressive power, that human language processing mechanisms are specialized for these grammars, and that human language acquisition is keyed to the patterns definable by these grammars.

If generative linguistics is concerned with language universals, one can also say that resource logic is intended to discover logical and computational universals, viewed as elementary logical operations. This can be viewed in the highly computational perspective in which these logics are situated, and also in the atomistic fragmentation of ordinary logic — which captures the traditional deductive operations as compounds. For instance, as we have seen, linear logic restores the options of contraction and weakening of intuitionistic or classical logic by means of modalities. Furthermore, if resource logic lives up to its claim of providing a canonical description of elementary computational processes, one might expect a logical account of whatever computations enter into human language processing. In this respect, though, the traditional tools of formal language theory are still the more useful.

For example, Michaelis [60] has shown that the languages definable in Stabler's minimalist grammars MGs are included in the class of languages defined by context free rewrite systems [99] and by multiple context free grammars MCFGs [84].[5] These languages are known to be efficiently recognizable. Seki et al. provide a simple chart-based parsing algorithm, and a method with improved worst-case performance is provided by [67].

We do not expect efficient decision methods for the whole class of MMCGs.[6] It could be that the decision problem for the languages define by real MMCG grammars for human languages is efficiently solved, but then the linguists' interest is aroused: what explains the fact that real examples have reasonable complexity? It could be that human language processing uses general principles that would extend to any definable set, but a more Chomskian assumption would be that the good average-case complexity of real examples from human languages is due, at least in part, to special properties of human languages (universals), so that we do not need the full power of MMCGs parsing to handle human languages.

This Chomskian expectation can be realized in resource-logical settings as well as any other. The axioms proposed by Cornell [20] to realize movement implement the asymmetries of the transformational account, as do the axioms considered by Vermaat [97], and we see similar asymmetries even in the less traditional proposals of Lecomte [55] and [57]. In these works, categorial grammar is a framework in which universals can be expressed, and it is natural to expect that at least some of the special properties that human languages actually correspond to special properties of human language acquisition and processing.

A more extreme nativism is often assumed. It could be that, not only do human languages have special properties, but the range of real grammatical variation is finitely bounded. The classic results of Gold [36] guarantee learnability in the limit from examples ("positive texts") in this idealized situation, but getting to a more realistic learner is surprisingly interesting even here. The finiteness assumption is difficult to defend empirically given our current state of understanding about what is possible in human languages, but the study the acquisition problem for finite sets of languages has led to some insights.

The acquisition models of Kanazawa [45], Tellier [90], Fulop [29] and others in the categorial tradition yield learnability results without the finiteness assumption, but they are idealized in other respects. Kanazawa establishes learnability of k-rigid grammars from strings. Tellier and Fulop notice that the k-rigidity assumption can be relaxed if the data available to the learner includes not only strings but also "meaning recipes," using the correspondence between semantic representations and syntactic derivations that is so transparent in the resource logical framework. These assumptions about the data available to the learner are still unrealistic, but this work moves in the right direction in abandoning the assumption of a finite range of linguistic variation and in using semantic cues — a restricted implementation of principles advocated in [71, 35]. All of these learning models rely on the categorial unification strategy of [11]; unification appears to be quite a general tool for grammatical inference [68].

[5]The claim that human languages are definable by these grammars is challenged by Michaelis and Kracht 1996, on the basis of an argument that Old Georgian is not semilinear.

[6]See [44] and [39].

Reflecting again on the previous section, one troubling aspect of the four points of convergence listed on page 3 is that they are purely "metatheoretical" in the sense that, even if we grant that all four points are correct, they apparently tell us nothing significant about human languages. That is, any definable set can be defined in a way that conforms to these four points. As linguists, our interest really needs to be claims about human languages that might be false, claims that are not merely expressions of our preferences about formalisms. So for linguists, the interest of the convergence needs to be that it gets us to interesting, possibly false claims about the languages we actually speak: the claim that human languages are defined by asymmetric mechanisms like those described by Cornell [20], Lecomte [55], Vermaat [97], or the claim that all human languages are definable by minimalist grammars.

5 Semantics in resource logics and minimalism

Semantics is sometimes left out of consideration in transformational syntax (but see, e.g. Larson [53], Heim and Kratzer [37], Szabolcsi [89]). Semantic proposals in the categorial tradition are explicit and natural, since they can be based on a Curry-Howard correspondence between derivations and semantic values. The implications of this idea for treatments of movement are rather carefully considered by Cornell [21] and Vermaat [97]. Vermaat argues that while movement can be handled syntactically in MMCG with structural postulates, we can get a natural semantic treatment by treating movement as involving the abstraction step of hypothetical reasoning. Cornell argues that we can get appropriate treatments either way.

Theoretical proposals inspired by comparisons and syntheses from the traditions of resource logic and minimalist grammar are a welcome result of the convergence on some fundamental assumptions. A number of these are presented in this workshop.

6 Problems for resource logics and minimalism

6.1 Functional categories

The proposals of Chomsky [14] and the literature that closely follows it involve a number of "inelegant" complexities. One is that certain functional categories serve only to hold triggers for movement, such as the Agr nodes. This prompts Chomsky [14] to consider how these functional categories could be eliminated. Lecomte [55] considers the more radical idea that all functional categories can be eliminated, including Neg, C, T. This idea is also mentioned in [97]. These resource-logical approaches provide a different and perhaps more natural perspective on how movements can be triggered at positions there is no pronounced form.

6.2 Asymmetries, chains and islands

In most minimalist proposals, feature checking is asymmetric in the sense that the checking feature and the checked feature are not both deleted [14, 17]. Cornell [22] takes some first steps toward implementing analyses like these in a resource logical framework, but the need for these asymmetries and for the visibility of deleted elements might also signal that we do not found the right framework.

A careful consideration of any of the prominent chain-based accounts of restrictions on movements will make this worry serious. For example, Kayne [46] proposes that the licensing of wh-elements in multiple-wh constructions has certain special properties: one dependency is involved in licensing another. In rather different sorts of proposals, Brody [9, §2] and Richards [81] agree with Kayne's basic idea. Consider the following examples:

1. * what$_j$ do you wonder who bought t_j?

2. who$_i$ t_i wonders who bought what$_j$?

3. (a) who$_i$ t_i wonders who bought what$_j$?

   (b) (what$_j$) who$_i$ t_i wonders who bought t_j?

4. (a) * Koja kniga$_i$ razprostranjavaše žurnalistât [mâlvata če senatorât
   which book spread the-journalist the-rumor that the-senator
   iska da zabrani t_i]?
   wanted to ban

   (b) Koj žurnalist$_j$ koja kniga$_i$ t_j razprostranjavaše [mâlvata če senatorât
   which journalist which book spread the-rumor that the-senator
   iska da zabrani t_i]?
   wanted to ban

The first two examples show that the long overt movement of *what* out of an embedded wh-clause is not possible in English. How is this to be blocked? If the WH feature is not deleted from the complementizer of the embedded clause, then an elaborated version of the SMC might suffice. However, the example in (3a) seems to allow a reading in which *what* has wide scope. If this wide scope reading is due to moving the *what* covertly to a higher position, then this means that long covert extraction is possible where long overt extraction is not. Richards [81] notices, though, that in the Bulgarian examples (4), the same effect shows up in overt syntax: it is possible to move the embedded WH element to the matrix position, but only if there is another WH element there too. To account for this, Richards defends a "minimal compliance" principle which says, roughly, that the long movement of the embedded WH element is possible if the landing site has "already respected" once in its relation with another WH element.

The interesting thing about this proposal is that the proposed constraint on movement depends on other movement relations in a way that is not going to be detectable by examining the features of the (heads of the) related positions, even in rather complex grammars with asymmetric feature checking of the sort sketched above. This kind of complexity plagues many of the proposals in the minimalist tradition, and it could signal that a resource logical treatment may not be the most revealing one.

If we think of the derivation as a graph in which the movement relations are represented by arcs connecting the related nodes, then we have something like what linguist's call "chains" – a representation of the history of the derivational steps, and rather rich graph-theoretic constraints on movements can be stated on these structures, constraints which are sometimes impossible to define on the simpler tree structures in which derivational history is not always determinable. These structures with "chains" are also reminiscent of the “proof nets” used in resource logic. Basically a proof net consists of the subformula tree of the proved formula together with arcs matching one propositional variable to its dual. Not all such objects are proofs, but only the ones satisfying a global criterion [76, 80].

6.3 Trans-derivational economy

The global constraints on proof nets are also reminiscent of the constraints on syntactic derivations which require that a derivation be the “shortest” or most “economical” in some specific sense. It is these constraints, rather than a general attention to resources, which motivate linguists to think of a derivation as beginning with a “numeration” or multiset of lexical items. One looks for the most economical derivation of structures from each particular numeration. This requirement differs from the usual constraints on proof nets, but analogs of this requirement could perfectly well be imposed.

The use of graph-theoretic constraints of these kinds will sometimes be compatible with resource logical treatments of the familiar kinds, but it could also happen that the acceptable graphs do not correspond to any finitely axiomatizable resource logic [76].

6.4 Interfaces with phonetic and morphological forms

Notice that while resource-sensitivity is entirely natural in syntax because the most basic dependencies are unique binary relations, things seem to be rather different in phonology and morphology where “spreading” and “blocking” phenomena are familiar. For example, in some languages, affixes are pronounced at the ends of words, but some languages have principles that block this placement with the result that the affix appears near the edge of the word. Prince and Smolensky [74] use the example of the Tagalog prefix *um-* which appears as a prefix except where its consonant would be syllabified as a coda:

um+iyák ⇒ u.mi.yák	‘cry’
um+káin ⇒ ku.má.in	‘eat’
um+gradwet ⇒ gru.mad.wed	‘graduate’

To account for such phenomena, “optimality theory” (OT) assumes that the “rules” or “constraints” of phonology and morphology are violable. In this framework, it will often be impossible to satisfy all constraints, but the structures that do the best, the “optimal” structures, are the grammatical ones. This kind of account has been extended to templatic morphology [59, 16, 7], and the computation of optimal structures is elegantly formalized as a finite sequence of operations on finite automata (intersections of weighted automata and pruning of sub-optimal paths) [28, 27, 8]. For grammatical formalisms that allow intersection with finite automata, this kind of reasoning could be integrated with syntax by intersecting a finite transducer with the syntax[7] In this workshop, we will see a different account of templatic morphology that is interesting since it extends minimality-theory-like mechanisms to a domain where it is far from clear that the basic elements of resource logical approaches are up to the task.

[7] Cf. [52, 70]. Adapting results from [98, 99], [84] shows that multiple context free grammars are closed under intersection with finite automata, and the construction is really quite simple.

7 Conclusion

Several discussions took place during the workshop. We briefly mention some of the topics that came up.

One of the questions that was addressed concerns the logical view of categorial grammars, that is, resource logics. It seems to presuppose that linguistic processing relies on a deductive mechanism. Even if these logics are quite far from classical or intuitionistic logic, which concern truth and deduction, it is not clear whether this assumption is sound. It is well-known that reasoning and language processing are quite separate processes: one person can be very good at one task and disabled at the other. It could be similarly that a general reasoning system for language is quite different from task-specific devices that compute special linguistic functions. Under this assumption, a logical model relying on formal deduction would simply be unrealistic from a psycholinguistic viewpoint – although it still may still be useful for understanding linguistic claims, assessing the complexity of structures, etc.

More precise, related questions were also discussed. For instance, is hypothetical reasoning really needed? Although it is desirable from a logical viewpoint, and used in the Lambek tradition, there is no evidence for it real necessity if one wants to be as economical as possible: the hypotheses introduced and then discharged are, perhaps, not very appealing from a psycholinguistic viewpoint. And it is clear that a lot can be achieved without it, as in combinatory categorial grammar.

Still more precise, the interest of classical systems has been questioned, and although there is no clear evidence of its need, symmetric interaction is appealing for some linguistic constructions, and the possibility to have two negations may be useful to express, for instance, which of the two merged phrases is the head of the compound.

Another general question that was addressed is the status of functional categories and the features that trigger movement. Should empty functional categories be allowed? They are unnatural with respect to the standard string semantics interpretation of non-commutative logics, but cross linguistic variation suggests that they are categories as others, since what can be expressed "overtly" in one language may be achieved in other languages without any pronounced counterpart. It is possible to represent covert categories by modes of composition in a multimodal framework, but then it is less clear how to express the universal properties of human languages: the logic depends on these unpronounced features, and it is difficult to delimit the part of the logic/computational system which is needed for language processing.

Finally, the choice of the logical formalism has importance. The structure of sequent calculus proofs does not make syntactic structure perspicuous. Many linguists seem to prefer natural deduction, which explicitly captures the tree-like constituent structure. Proof-nets should be also considered; indeed they are which are more or less the same as natural deduction proofs for intuitionistic calculi that are commonly used, but they are a bit more canonical, making tighter the connection between the proof and the syntactic analysis.

References

[1] E. Aarts and K. Trautwein. Non-associative Lambek categorial grammar in polynomial time. *Mathematical Logic Quarterly*, 41:476–484, 1995.

[2] V. Michele Abrusci. Phase semantics and sequent calculus for pure non-commutative classical linear logic. *Journal of Symbolic Logic*, 56(4):1403–1451, December 1991.

[3] V. Michele Abrusci. Exchange connectives for non-commutative intuitionistic propositional calculus. In M. Abrusci, C. Casadio, and M. Moortgat, editors, *Linear logic and Lambek calculus*, Roma, 1994. DYANA.

[4] V. Michele Abrusci and Claudia Casadio, editors. *Third Roma Workshop: Proofs and Linguistics Categories – Applications of Logic to the analysis and implementation of Natural Language*. Bologna:CLUEB, 1996.

[5] V. Michele Abrusci and Elena Maringelli. A new correctness criterion for cyclic multiplicative proof-nets. In Retoré [79], pages 449–459.

[6] V. Michele Abrusci and Paul Ruet. Non-commutative logic I: the multiplicative fragment. *Annals of Pure and Applied Logic*, 1999. http://www.uniroma3.it/reseaux9798.ps.

[7] Daniel M. Albro. Evaluation, implementation, and extension of primitive optimality theory. M.A. thesis, UCLA, 1997.

[8] Daniel M. Albro. Three formal extensions to primitive optimality theory. 1998 ACL Meeting, 1998.

[9] Michael Brody. *Lexico-Logical Form: A Radically Minimalist Theory*. MIT Press, Cambridge, Massachusetts, 1995.

[10] W. Buszkowski. Mathematical linguistics and proof theory. In van Benthem and ter Meulen [95], chapter 12, pages 683–736.

[11] Wojciech Buszkowski and Gerald Penn. Categorial grammars determined from linguistic data by unification. *Studia Logica*, 49: 431–454, 1990.

[12] Bob Carpenter. The Turing-completeness of multimodal categorial grammars. Carnegie-Mellon University, 1996.

[13] Noam Chomsky. Three models for the description of language. *IRE Transactions on Information Theory*, IT-2:113–124, 1956.

[14] Noam Chomsky. *The Minimalist Program*. MIT Press, Cambridge, Massachusetts, 1995.

[15] Noam Chomsky. Minimalist inquiries: the framework. MIT. Forthcoming, 1998.

[16] G.N. Clements. Berber syllabification: derivations or constraints? In Iggy Roca, editor, *Derivations and Constraints in Phonology*, pages 289–330. Clarendon, Oxford, 1997.

[17] Chris Collins. *Local Economy*. MIT Press, Cambridge, Massachusetts, 1997.

[18] Thomas L. Cornell. A minimalist grammar for the copy language. Technical report, SFB 340 Technical Report #79, University of Tübingen, 1996.

[19] Thomas L. Cornell. Representational minimalism. SFB 340 Technical Report #83, University of Tübingen. Revised version forthcoming in U. Mönnich and H.-P. Kolb, eds, 1997.

[20] Thomas L. Cornell. A type logical perspective on minimalist derivations. In *Proceedings, Formal Grammar'97*, Aix-en-Provence, 1997.

[21] Thomas L. Cornell. Derivational and representational views of minimalist transformational grammar. In Moortgat [64].

[22] Thomas L. Cornell. Island effects in type logical approaches to the minimalist program. In *Proceedings of the Joint Conference on Formal Grammar, Head-Driven Phrase Structure Grammar, and Categorial Grammar, FHCG-98*, pages 279–288, Saarbrücken, 1998.

[23] Akim Demaille. *Logiques linaires hybrides et leurs modalités*. Thse de doctorat, spécialité informatique, Ecole Nationale Suprieure des Tlcommunications de Paris, juin 1999.

[24] Philippe de Groote. Partially commutative linear logic: sequent calculus and phase semantics. In Michele Abrusci and Claudia Casadio, [4], pages 199–208. Bologna:CLUEB, 1996.

[25] Philippe de Groote. Non-associative Lambek calculus in polynomial time. In N. V. Murray, editor, *8$^t h$ Automated Reasoning with analytic tableaux and related methods, TABLEAUX'99*, number 1617 in Lecture Notes in Artificial Intelligence. Springer-Verlag, June 1999. pages 128–139.

[26] Philippe de Groote and Christian Retoré. Semantic readings of proof nets. In Geert-Jan Kruijff, Glyn Morrill, and Dick Oehrle, editors, *Formal Grammar*, pages 57–70, Prague, August 1996. FoLLI.

[27] Jason Eisner. Efficient generation in Primitive Optimality Theory. In *Proceedings of the 35th Annual Meeting of the Association for Computational Linguistics*, 1997.

[28] Mark T. Ellison. Phonological derivation in optimality theory. In *Procs. 15th Int. Conf. on Computational Linguistics*, pages 1007–1013, 1994. (Also available at the Edinburgh Computational Phonology Archive).

[29] Sean Fulop. *On the Logic and Learning of Language*. PhD thesis, University of California, Los Angeles, 1999.

[30] Jean-Yves Girard. Linear logic. *Theoretical Computer Science*, 50(1):1–102, 1987.

[31] Jean-Yves Girard. Linear logic: its syntax and semantics. In Jean-Yves Girard, Yves Lafont, and Laurent Regnier, editors, *Advances in Linear Logic*, volume 222 of *London Mathematical Society Lecture Notes*, pages 1–42. Cambridge University Press, 1995.

[32] Jean-Yves Girard. Towards a geometry of interaction. In *Categories in Logic and Computer Science—Boulder, June 1987*, volume 92 of *Contemporary Mathematics*, pages 68–109. AMS, 1990.

[33] Jean-Yves Girard, Yves Lafont, and Paul Taylor. *Proofs and Types*. Number 7 in Cambridge Tracts in Theoretical Computer Science. Cambridge University Press, 1988.

[34] L.R. Gleitman and M. Liberman, editors. *An invitation to cognitive sciences, Vol. 1: Language*. MIT Press, 1995.

[35] L.R. Gleitman and E.L. Newport. The invention of language by children: Environmental and biological influences on the acquisition of language. In Gleitman and Liberman [34], chapter 1, pages 1–24.

[36] E. Mark Gold. Language identification in the limit. *Information and Control*, 10:447–474, 1967.

[37] Irene Heim and Angelika Kratzer. *Semantics in Generative Grammar*. Blackwell, Oxford, 1988.

[38] Ray Jackendoff. *The Architecture of the Language Faculty*. Number 28 in Linguistic Inquiry Monographs. M.I.T. Press, Cambridge, Massachusetts, 1995.

[39] Gerhard Jäger. On the generative capacity of multi-modal categorial logics. IRCS technical report 98-26, University of Pennsylvania, 1987.

[40] Mark E. Johnson. Proof nets and the complexity of processing center-embedded constructions. In Retoré [79], pages 433–447, 1998.

[41] Aravind Joshi and Seth Kulick. Partial proof trees, resource sensitive logics and syntactic constraints. In Retoré [78], pages 21–42.

[42] Aravind Joshi, Seth Kulick, and Natasha Kurtonina. An LTAG perspective on categorial inference. In Moortgat [64].

[43] Aravind K. Joshi and Yves Schabes. Tree-adjoining grammars. In G. Rozenberg and A. Salomaa, editors, *Handbook of Formal Languages, Volume 3: Beyond Words*, pages 69–124. Springer, NY, 1997.

[44] Makoto Kanazawa. Lambek calculus: recognizing power and complexity. Chiba University, 1998.

[45] Makoto Kanazawa. *Learnable Classes of Categorial Grammmars*. CSLI Publications/FOLLI, Stanford, California, 1998. (Revised 1994 Ph.D.thesis, Stanford University).

[46] Richard Kayne. Connectedness. *Linguistic Inquiry*, 14:223–249, 1983.

[47] Richard Kayne. *The Antisymmetry of Syntax*. Number 25 in Linguistic Inquiry Monographs. M.I.T. Press, Cambridge, Massachusetts, 1994.

[48] Natasha Kurtonina and Michael Moortgat. Structural control. In P. Blackburn and M. de Rijke, editors, *Specifying Syntactic Structures*, pages 75–113. CSLI, 1997. Distributed by Cambridge University Press.

[49] François Lamarche and Christian Retoré. Proof nets for the Lambek calculus – an overview. In Abrusci and Casadio [4], pages 241–262.

[50] Joachim Lambek. The mathematics of sentence structure. *American Mathematical Monthly*, 65:154–170, 1958.

[51] Joachim Lambek. On the calculus of syntactic types. In Roman Jakobson, editor, *Structure of language and its mathematical aspects*, pages 166–178. American Mathematical Society, 1961.

[52] Bernard Lang. Recognition can be harder than parsing. *Computational Intelligence*, 10, 1994.

[53] Richard K. Larson. *Knowledge of Meaning*. MIT Press, Cambridge, Massachusetts, 1995.

[54] Alain Lecomte, François Lamarche, and Guy Perrier, editors. *Logical Aspects of Computational Linguistics, LACL'97*, volume 1582 of *LNCS/LNAI*. Springer-Verlag, 1999.

[55] Alain Lecomte. Proof-nets, hybrid logics and minimalist representations. In *Mathematics of Languages 6*.

[56] Alain Lecomte and Christian Retoré. Pomset logic as an alternative categorial grammar. In Glyn Morrill and Richard Oehrle, editors, *Formal Grammar*, pages 181–196, Barcelona, August 1995. FoLLI.

[57] Alain Lecomte and Christian Retoré. Words as modules: a lexicalised grammar in the framework of linear logic proof nets. In Carlos Martin-Vide, editor, *Mathematical and Computational Analysis of Natural Language — selected papers from ICML'96*, volume 45 of *Studies in Functional and Structural Linguistics*, pages 129–144. John Benjamins publishing company, 1998.

[58] Alain Lecomte and Christian Retoré. Towards a minimal logic for minimalist grammars: Another use of Lambek calculus. In *Formal Grammar, FG'99*. FoLLI, 1999.

[59] J. McCarthy and Alan Prince. Prosodic morphology. In John A. Goldsmith, editor, *The Handbook of Phonological Theory*. Blackwell, Oxford, 1995.

[60] Jens Michaelis. Derivational minimalism is mildly context-sensitive. In Moortgat [64].

[61] Jens Michaelis and Marcus Kracht. Semilinearity as a syntactic invariant. In Retoré [78] , pages 37–40.

[62] Michael Moortgat. *Categorial Investigations*. Foris, Dordrecht, 1988.

[63] Michael Moortgat. Categorial type logic. In van Benthem and ter Meulen [95], chapter 2, pages 93–177.

[64] Michael Moortgat, editor. *Logical Aspects of Computational Linguistics, LACL'98, selected papers*, LNCS/LNAI. Springer-Verlag, 1999. To appear.

[65] Glyn V. Morrill. *Type-logical Grammar: Categorial Logic of Signs*. Kluwer, Dordrecht, 1994.

[66] Glyn V. Morrill. Incremental processing and acceptability. Research Report LSI-98-48-R, Universitat Politècnica di Catalunya, 1998.

[67] Ryuichi Nakanishi, Keita Takada, and Hiroyuki Seki. An efficient recognition algorithm for multiple context free languages. In *Proceedings of the Fifth Meeting on Mathematics of Language, MOL5*, 1997.

[68] Jacques Nicolas. Grammatical inference as unification. Rapport de Recherche RR-3632, INRIA, 1999. http://www.inria.fr/RRRT/publications-eng.html.

[69] Mati Pentus. Product-free Lambek calculus and context-free grammars. *Journal of Symbolic Logic*, 62(2):648–660, 1997.

[70] Fernando C.N. Pereira and Michael D. Riley. Speech recognition by composition of weighted finite automata. In Emmanuel Roche and Yves Schabes, editors, *Finite-State Language Processing*. MIT Press, Cambridge, Massachusetts, 1997.

[71] Steven Pinker. Language acquisition. In Gleitman and Liberman [34], chapter 6, pages 135–182.

[72] Sylvain Pogodalla. Lexicalized proof-nets in Pomset logic and TAG. In Moortgat [64].

[73] Carl Pollard and Ivan Sag. *Head-driven Phrase Structure Grammar*. The University of Chicago Press, Chicago, 1994.

[74] Alan Prince and Paul Smolensky. *Optimality Theory: Constraint Interaction in Generative Grammar*. Forthcoming, 1993.

[75] Christian Retoré. *Réseaux et Séquents Ordonnés*. Thèse de Doctorat, spécialité Mathématiques, Université Paris 7, février 1993.

[76] Christian Retoré. Calcul de Lambek et logique linéaire. *Traitement Automatique des Langues*, 37(2):39–70, 1996.

[77] Christian Retoré. Pomset logic: a non-commutative extension of classical linear logic. In Ph. de Groote and J. R. Hindley, editors, *Typed Lambda Calculus and Applications, TLCA'97*, volume 1210 of *LNCS*, pages 300–318, 1997.

[78] Christian Retoré, editor. *Logical Aspects of Computational Linguistics, LACL'96*, volume 1328 of *LNCS/LNAI*. Springer-Verlag, 1997.

[79] Christian Retoré, guest editor. Recent advances in logical and algebraic approaches to grammar. Special issue of the *Journal of Logic Language and Information*, 7(4), 1998.

[80] Christian Retoré. Handsome proof-nets: perfect matchings and cographs. *Theoretical Computer Science*, 1999. To appear. Preliminary report: Handsome proof-nets: R&B-graphs, perfect matchings and series-parallel graphs. Rapport de Recherche RR-3652, INRIA, March 1999. http://www.inria.fr/RRRT/publications-eng.html.

[81] Norvin Richards. The principle of minimal compliance. *Linguistic Inquiry*, 29:599–629, 1998.

[82] Dirk Roorda. *Resource logic: proof theoretical investigations*. PhD thesis, FWI, Universiteit van Amsterdam, 1991.

[83] Paul Ruet. *Logique non-commutative et programmation concurrente*. Thse de doctorat, spcialit logique et fondements de l'informatique, Universit Paris 7, 1997.

[84] Hiroyuki Seki, Takashi Matsumura, Mamoru Fujii, and Tadao Kasami. On multiple context-free grammars. *Theoretical Computer Science*, 88:191–229, 1991.

[85] Edward P. Stabler. *Acquiring and parsing languages with movement*. 1996. UCLA manuscript. Revised version forthcoming.

[86] Edward P. Stabler. Derivational minimalism. In Retoré [78], pages 68–95.

[87] Edward P. Stabler. Acquiring grammars with movement. *Syntax*, 1:72–97, 1998. Draft available at http://phonetics.ling.ucla.edu/.

[88] Edward P. Stabler. Remnant movement and complexity. In *Joint Conference on Formal Grammar, Head-Driven Phrase Structure Grammar, and Categorial Grammar, FHCG-98*, Saarbrücken, Germany, 1998. Universität des Saarlandes.

[89] Anna Szabolcsi, editor. *Ways of Scope Taking*. Kluwer, Boston, 1996.

[90] Isabelle Tellier. Meaning helps learning syntax. In *Fourth International Colloquium on Grammatical Inference, ICG'98*, 1998.

[91] Hans-Jörg Tiede. *Deductive Systems and Grammars: Proofs as Grammatical Structures*. PhD thesis, Illinois Wesleyan University, 1999.

[92] Hans-Jörg Tiede. Lambek calculus proofs and tree automata. In Moortgat [64].

[93] Anne Sjerp Troelstra. *Lectures on Linear Logic*, volume 29 of *CSLI Lecture Notes*. CSLI, 1992. (distributed by Cambridge University Press).

[94] Johan van Benthem. *Essays in Logical Semantics*. Reidel, Dordrecht, 1986.

[95] J. van Benthem and A. ter Meulen, editors. *Handbook of Logic and Language.* North-Holland Elsevier, Amsterdam, 1997.

[96] Johan van Benthem. *Language in Action: Categories, Lambdas and Dynamic Logic*, volume 130 of *Studies in logic and the foundation of mathematics*. North-Holland, Amsterdam, 1991.

[97] Willemijn Vermaat. Controlling Movement: Minimalism in a Deductive Perspective. Masters Thesis, Universiteit Utrecht.

[98] K. Vijayashanker. *A Study of Tree Adjoining Languages*. PhD thesis, University of Pennsylvania, 1987.

[99] David Weir. *Characterizing mildly context-sensitive grammar formalisms*. PhD thesis, University of Pennsylvania, Philadelphia, 1988.

[100] D. N. Yetter. Quantales and (non-commutative) linear logic. *Journal of Symbolic Logic*, 55:41–64, 1990.