# Contributions in Logic, Linguistics and Computer Science

Christian Retoré

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## Contents

# 1 Collaborations: places, topics, people, projects

## 1.1 Labs and places

In PARIS, LONDON, ANGERS, NICE from 1988 to 1994
working on *Linear logic and theoretical computer science*
with local researchers J.-Y. GIRARD, S. ABRAMSKY, J.-J. LOEB, G. BOUDOL
and with other French researchers G. ZÉMOR
as well as with researchers from abroad M. ABRUSCI (ROME)

In NANCY from 1994 to 1997
working on *Categorial grammars and linear logic*
with local researchers PH. DE GROOTE, D. BECHET, G. PERRIER
and with other French researchers A. LECOMTE (GRENOBLE)
as well as with researchers from abroad M. ABRUSCI (ROME), M. MOORTGAT (UTRECHT)

In RENNES, NANTES from 1997 to 2002
working on *Learning categorial grammars, minimalist and categorial grammars*
with local researchers A. LECOMTE, A. FORET, PH. DARONDEAU, J. NICOLAS, A. DIKOVSKY
and with other French researchers S. POGODALLA (NANCY), J.-Y. MARION (NANCY), I. TELLIER (LILLE), M. TOMMASI (LILLE)
as well as with researchers from abroad M. MOORTGAT (UTRECHT), E. STABLER (UCLA), M. ABRUSCI (ROME), C. CASADIO (CHIETI)

In BORDEAUX from 2002 to 2007
working on *Minimalist categorial grammars, syntax and semantics, sign languages*
with local researchers R. MOOT, M. AMBLARD, G. HUET
and with other French researchers C. GARDENT (NANCY), A. LECOMTE (GRENOBLE), S. POGODALLA (NANCY)
as well as with researchers from abroad G. KOBELE (CHICAGO), D. DELFITTO (VERONA), R. MUSKENS (TILBURG), E. STABLER (UCLA)

In BORDEAUX, TOULOUSE from 2007 to 2013
working on *Formal semantics, lexical semantics, type theory*
with local researchers R. MOOT, CH. BASSAC, B. MERY, B. EREZ, J. GILLIBERT
and with other French researchers F. CORBLIN (PARIS), A. LECOMTE (PARIS), M. AMBLARD (NANCY), S. POGODALLA (NANCY), N. ASHER (TOULOUSE), S. SOLOVIEV (TOULOUSE)
as well as with researchers from abroad M. ABRUSCI (ROMA), LIVY REAL(CURITIBA), Z. LUO (LONDON), S. CHATZIKYRIAKIDIS (LONDON)

## 1.2 Official projects

BILATERAL PROJECTS (1998–2005): *Categorial grammars and linear logic* with UTRECHT (M. MOORTGAT, R. MOOT, V. VERMAAT), ROME (M. ABRUSCI, C. CASADIO, E. MARINGELLI, M. PIAZZA) *In the past I conducted two two-year bilateral projects:*
*One with Italy (Roma) on non commutative linear logic and categorial grammars.*
*One with the Netherlands (Utrecht) on multimodal categorial grammars and minimalist grammars.*

RÉGION AQUITAINE PROJECT ON SIGN LANGUAGES (2004–2006): *Video corpus and study of French sign language syntax* with INSTITUT NATIONAL DES JEUNES SOURDS, DÉPARTEMENT DE LINGUISTIQUE *I supervised this project which has been an opportunity to study sign language which i know for personal reason, and to develop local contacts with the deaf community. A PhD was funded (Emilie Voisin, 2008).*

ARC INRIA MOSAIQUE (2006–2007): *Convergence of syntactical formalisms* with BORDEAUX, NANCY, PARIS, RENNES, AIX *This project lead by a colleague has been an opportunity to connect all the French team working on automated syntactic analysis in various formalisms.*

ARC INRIA GRACQ (2001–2003): *Learning categorial grammars* with NANCY, RENNES, NANTES, LILLE, BORDEAUX *I conducted this national INRIA project on learning categorial grammars. It was an opportunity to meet the researchers from Lille (Tellier, Tommasi, Denis) from whom i learnt a lot.*

GDR SÉMANTIQUE ET MODÉLISATION (2002-2010): *Formal semantics* with ALL THE FRENCH LABS DEALING WITH FORMAL SEMANTICS, BOTH IN LINGUISTICS AND IN COMPUTER SCIENCE *This project organised as a network helped us to link our team with other teams in France, in particular with the people from Institut Jean Nicod in Paris (F. Corblin, C. Beyssade, D. Nicolas, A. Mari). We organised the Bordeaux 2006 meeting, launched a joint spring school for PhDs, and the spring school in the Toulouse 2008 meeting.*

ARC INRIA CAULD (2010–2011): *Automatic Construction of Logical Representations of Discourse* with BORDEAUX (RETORÉ, MERY, MOOT), NANCY (POGODALLA, AMBLARD, DE GROOTE), PARIS (AMSILI), TOULOUSE (ASHER) *I was site manager for this project conducted by a former student of mine, Pogodalla. We developed relation with discourse experts from Toulouse and Paris.*

RÉGION AQUITAINE-MIDI-PYRÉNÉES ITIPY (2009–2013): *Itinerary reconstruction from an historical and regional corpus of travel stories through the Pyrenees* with TOULOUSE (N. ASHER,, PH. MULLER), PAU (M. GAIO) *This project conducted by Richard Moot included a PhD that I supervised (AnaÃŕs Lefeuvre, February 2014). It is an opportunity to apply our categorial methods on a real corpus, for a work that requires a deep syntactic, semantic and pragmatic analysis.*

ANR PRÉLUDE LOCI (2007–2014): *Modelling of interaction with ludics, in particular for natural language semantics and for the study of dialogue* with BORDEAUX (RETORÉ), NANCY (POGODALLA), MARSEILLE (QUATRINI), PARIS (FOUQUERÉ, LECOMTE), , LONDON (KEMPSON), ROMA (ABRUSCI) *I am the site leader of this project, initially called Prélude renewed for four years and rechristened Loci. It is a national project with two foreign sites with whom we developed good partnership, in particular on logical aspects of semantics. I thus reactivated some collaboration on linear logic, with Fouqueré and Quatrini.*

PEPS CNRS COLAN COMPLEXITÉ ET LANGAGE : UNE ÉTUDE FORMELLE ET EXPÉRIMENTALE DES MÉCANISMES DE COMPRÉHENSION (2013): *A renewable one year project, combining formal study and* *experimental study.* with BORDEAUX (MOOT, RETORÉ), AIX:LPL (BLACHE, CHAMPAGNE-LAVAU, DUFOUR, RAUZY), MONTPELLIER: LIRMM (PROST), MARSEILLE: IML (QUATRINI) *This project that I chair is the opportunity to connect our formal world with experimental studies on natural language understanding.*

## 1.3 Team and other networks

INRIA SIGNES (2002–2011): *An INRIA project team on computational linguistics, focused on the syntax semantics interface, gathering linguist and commuter scientists* with CH. BASSAC, J. BUSQUETS, L. CLÉMENT, G. HUET, R. MOOT, S. SALVATI AND MANY COLLABORATORS AND VISITORS *I launched this INRIA project team in Bordeaux where there were formal language theory and some linguistics but nothing related to computational linguistics. The project has been a success, and positively evaluated, but after ten years, the rule it to renew it, and there was not enough people on the Bordeaux site to propose another project team in computational linguistics. It continues as a small CNRS team, but that's not a project, just a group of three researchers.*

CNRS SABBATICAL IN TOULOUSE: AUTOMATED SEMANTIC ANALYSIS OF NATURAL LANGUAGE IN TYPE THEORY (2012–2013): *A one year visit at IRIT* with N. ASHER, S. SOLOVIEV, F. DEL PRETE, M. ABRUSAN, T. VAN DE CRUYS *This was opportunity to tighten the links i have in Toulouse, mainly with the people in discourse analysis and ontologies, but also with the theoretical computer sciences persons on type theory.*

LOGICAL ASPECTS OF COMPUTATIONAL LINGUISTICS (1996↦): *A conference series* with LECOMTE, MOORTGAT, DE GROOTE, MORRILL, BLACHE, STABLER, POGODALLA, PROST, DIKOVSKY, BECHET, ASHER, SOLOVIEV *An international conference series that i launched as a workshop in 1995 (published in the journal of logic, language and information in 1998), and as an international conference the year after (LACL1996, chair) , the other editions, being published by Springer. Every two year, 2014 edition in Toulouse organised by Asher and Soloviev. I am president of the steering committee.*

FOUNDATION FOR LOGIC, LINGUISTICS AND INFORMATION (1997↦): *A scientific society* with MOORTGAT, VAN BENTHEM *I have been involved in FoLLI and in particular in the yearly two-week ESSLLI summer schools, where i learnt a lot, and my lecture were selected in 1997 (Aix), 1999 (Utrecht), 2000 (Birmingham), 2003 (Vienna), 2006 (Malaga), 2012 (Opole), 2014 (TÃijbingen). I was on the program committee for ESSLLI (2005, Edinburg) and I was on the standing committee from 2006 to 2008. I organised ESSLLI 2009 in Bordeaux (520 participants).*

ATALA: FRENCH NLP SOCIETY (2001↦): *A scientific society* with PH. BLACHE, L. DANLOS, C. GARDENT, V. PRINCE *I have been involved since 2001 in this society that started in 1959. First as an editor of the journal (TAL), later as the editor in chief of this journal, and almost any years in the program committee of the yearly conference (TALN).*

SMF FRENCH MATHEMATICAL SOCIETY (2008↦): *A scientific society* with C. EHRHARD, F. PATRAS, S. NGỌC-VŨ *I have been involved for more than five years as an editor of the bulletin of the French mathematical society where i promote logic.*

## 1.4 Today's main collaborations

To sum up the people I have mainly worked with over the years are Richard Moot (Bordeaux), Alain Lecomte (Paris), Philippe de Groote (Nancy), Edward Stabler (Los Angeles), Michele Abrusci (Roma) and two of my former PhD students Sylvain Pogodalla and Maxime Amblard (who were both hired in Nancy, in 2002 and in 2008).

I am presently working with LIVY REAL (Curitiba, linguistics), FRANCIS CORBLIN (Paris, linguistics), STERGIOS CHATZIKYRIAKIDIS ZHAOHUI LUO (London, computer science), SERGEÏSOLOVIEV (Toulouse, computer science), PHILIPPE BLACHE, LAURENT PRÉVOT (Aix, linguistics), BOAS, EREZ JEAN GILLIBERT (Bordeaux, maths), and pursuing joint work with RICHARD MOOT (Bordeaux), ALAIN LECOMTE (Paris), MICHELE ABRUSCI (Roma), SYLVAIN POGODALLA (Nancy), MAXIME AMBLARD (Nancy), BRUNO MERY (Bordeaux).

Presently i am the site leader of two projects POLYMNIE (BORDEAUX, NANCY, TOULOUSE, PARIS), and LOCI (BORDEAUX, PARIS, MARSEILLE, LONDON, ROME), and the leader of a project COLAN (BORDEAUX, AIX, MARSEILLE, MONTPELLIER).

I have mainly two coauthors A. LECOMTE (11, although we never were at the same place), R. MOOT (10 including a book), then some close collaborators M. Amblard (6), B. Mery (6), Ch. Bassac (3) R. Bonato (3), S. Pogodalla (3), and others with whom i wrote one or two papers, from abroad M. Abrusci (2x, Rome), P. Blackburn, G. Kobele (2, Chicago), A. Ranta (Gothenburg) L. Real (2, Curitiba), E. Stabler (UCLA, Los Angeles) or from France: D. Bechet (2), A. Dikovsky, M. Dymetman, A. Foret, J. Gillibert, P. Guitteny (2), Ph. de Groote (2), O. De Langhe (2), F. Lamarche, Y. Le Nir, A. Lefeuvre (2), E. Moreau, L. Prévot (2), H. Portine (2), S. Salvati (2), N.-F. Sandillon-Rezer, I. Tellier, E. Villemonte de la Clergerie.

# 2 Classical and intuitionnistic logic

## 2.1 History of logic: French semi intuitionnists (1992)

My first published paper (1992) was in a book on the history of logic and the foundations of mathematics, a kind of "From Frege to Gödel" with translations into French and lengthier presentations of the texts. I presented the correspondence between Baire, Borel, Hadamard and Lebesgue on the merits and dangers of the Axiom of Choice. These mathematicians are known as the French semi-intuitionnists. While intuitionism rejects the application of reasoning principles designed for finite sets to infinite sets, the French intuitionnists agree to apply reasoning principles designed for finite sets to countable sets but not to uncountable sets. It is not surprising, they were working in measure theory, where after their discussion Banach-Tarski paradox was found, (one ball is cut in finitely many unmeasurable pieces which can be reassembled into several balls, each having the volume of the initial ball) relies on the axiom of choice for uncountable sets. Just before i wrote this paper someone showed that a weak version of the axiome of choice is enough for this paradox i spoke a bit of that in the explanations included in my presentation of this famous correspondence. I did not pursuer the work on this topic, but the book still sells well and can be found in bookshops. [2]

## 2.2 A primitive recursive proof of strong normalisation for $D$ typable $\lambda$-terms (1994)

It is known from Dezani Coppo Sallé that strongly normalising lambda terms are exactly the ones chat can by typed in intersection types (system $D$). I proved that the strong normalisation of $D$-typable terms can be inferred from the strong normalisation of natural deduction of intuitionistic propositional logic with implication and conjunction, which itself, thanks to Robin Gandy can be derived in primitive recursive arithmetic. Unfortunately this 1994 INRIA report was not submitted in time. When i submitted it to a retrospective volume (2006?) on intersection types, I was told this was published by René David in 2001. [6]

## 2.3 Hilbert's epsilon calculus (2011$\mapsto$)

The Hilbert operator is a curiosity in mathematical logic. It was introduced around 1920 by Hilbert and studied by Hibert, Ackerman and Bernays, in order to achieve the foundational program of Hilbert by elimination of epsilon (which bears some resemblance to cut elimination). The proof rules for Hilbert epsilon are quite natural, they are the standard quantification rules. With such rules Hibert proved the two epsilon theorems. They say that what can be derived concerning epsilon formulae that correspond to first order formulae with the epsilon can be done without and from this Hilbert gives the first correct proof of Herbrand theorem. A part from this initial work most of the work on the topic on cut elimination, on models etc. is unsound. I studied partly with Michele Abrusci the rules for epsilon in sequent calculus and the way such operators can be used for generalised quantification — without generalised quantifiers but with terms as in Ancient and mediaeval logic. Besides this logical work I also use this epsilon in linguistic semantics for the compositional semantics of determiners and quantifiers see paragraph 6.2. [64, 75, 65, 90]

## 2.4 Subtyping in system F (2013$\mapsto$)

In second order lambda calculus (system F) that generalises Church simple type by quantifying over variable types, it is difficult to have a proper notion of sub typing; for instance, Cardelli-Curien $F_\omega^{sub}$ has very complicated constraints. I started to define a notion of coercive sub typing for system F. Subtyping relations are given on base types, and they constitute a partial order. Then they extend inductively to all the types using transitivity, co and contra variance of $\rightarrow$, and natural rules for quantification over type. I firstly showed that such rules never add any extra subtyping relation on base types (this is called hierarchical coherence in category theory). [83, 81]

# 3 Combinatorics

## 3.1 Perfect matchings (1996-2004)

I provided a characterisation of graphs that possess a unique perfect matching — a matching is a set of edges that are pairwise non incident, and it is said to be perfect whenever any vertex is incident to an edge of the matching. Graph with a unique perfect matching are first shown to be exactly the one that exempt from elementary cycles that alternate edges in the matching and not in the matching. Next we showed that these graphs are exactly the ones that are obtained inductively by connecting two graphs with a bridge and edges at the two tips of the bridge (this is more or less related to an old result by Koztig, in Slovac). This result unifies several arguments used in sequentialisation theorem which establish that a correct proof net correspond to at least one proof of sequent calculus. [43, 28]

## 3.2 Cographs, series parallel partial orders (1997)

With Denis Bechet and Philippe de Groote i give a complete rewrite system that derives any subcograph of a cograph (such graphs can be viewed as terms, the constants are the vertices, and the operations are the series and the parallel composition, or complete bipartite and disjoint union constructions). The rewriting rule is known as Godement law, or as the interchange law in concurrency: $(a \parallel b);(c \parallel d) \rightsquigarrow (a;c) \parallel (b;d)$. When one has both directed and undirected composition, it is a bit trickier but it works as well, with several interchange laws. Cographs and their rewriting is especially useful to have a better notion of a proof net as explained in paragraph 4.3, and with term this work has been extensively used by A. Guglielmi and L. Strasburger. [16]

# 4 Linear logic

Linear logic comes from a proof theoretical restriction of intuitionnistic logic, leaving out the fact that hypotheses can be used ad libitum: this is relevant in computer science, in order to logically manage resources, and in natural language where resources are features. It draws a distinction between additive connectives (the additive conjunction & shares the context of the components) and multiplicative connectives (the multiplicative conjunction $\otimes$, the comma on the left hand side of sequence). It has a negation $(\_)^\perp$ and the disjunctions corresponding to & and $\otimes$ respectively are $\oplus$ and $\wp$ (the comma on the right hand side of sequents). In order to recover intuitionistic logic where , there is a modality $!A$ which means as many $A$ as one wishes (its dual is written $?A$). The linear implication corresponding to the sequent operator $A \vdash B$ is written $A \multimap B$.

## 4.1 The MIX rule (1989-1994)

My first result obtained with A. Fleury was the characterisation of proof nets for the mix rule (and multiplicative units). The MIX rules actually says that two proofs of commutative multiplicative linear logic can be viewed as a single proof. I actually refuted a conjecture by Girard saying that correction should be $\#(CC) - \#(\perp) = 1$ in any correction graph obtained by erasing one edge of each $\wp$ link — $CC$ means connected component and $\perp$ is the number of times the $\wp$ unit is introduced. When every correction graph is acyclic it is easily seen that $\#(CC)$ is the same. The counter example is quite simple $\perp \otimes (1 \wp 1)$, which is not provable. But for mix we succeeded: provable with mix: each correction graph is acyclic, and the number of CC of any correction graph is the number of MIX rule in any sequent calculus version of this proof. This result has often been reused and cited (even by Girard himself, who consider our result as a sign that MIX should be left out). [5]

## 4.2 Proof nets and denotational semantics (1994-1997)

I proved that the two following property of a proof structure of multiplicative linear logic are equivalent:

1. the syntactic correctness of proof net (with MIX), i.e. the proof net is acyclic

2. the fact that its interpretation in coherence spaces is a clique (such interpretations of proofs are invariant w.r.t cut elimination).

The fact that syntactically correct object do have a proper interpretation which is preserved during cut elimination was proven in the original paper on linear logic by Girard. I established the converse with MIX (which semantically holds). This result is a sort of denotational completeness for multipliiative linear logic wrt coherence spaces. This result also holds for pomset logic. [7, 22]

Michele Pagani made his PhD (2006) on extending this result to exponentials (in order to have the result for intuitionistic logic and simply typed lambda calculus) and even his recent habilitation (2013) includes extension of such result to the differential lambda calculus of Th. Ehrhard.

## 4.3 Handsome proof nets (1996↦)

I found a description of proof net in without links representing the connectives. A formula, in negative normal form (negation only appears on atoms) is viewed as a simple graph, a cograph, whose vertices are the propositional variables in the formulae and their negation. The axioms are not incident edges that link an occurrence of a propositional variable and its dual. The criterion asserts that every elementary alternate cycle (axiom edge / formula edge) contains a chord (of the formula) It has been used by Dominic Hughes for defining proof nets for propositional classical logic as the superimposition (fibration) of such proof nets. [43, 28]

I am still working on this to have handsome proof nets for cyclic linear logic, Lambek calculus, partially commutative linear logic etc. [46]

## 4.4 Pomset logic (1993-2002)

This paper accounts for a large part of my PhD that was about designing a non commutative logic very different for Lambek, Abrusci and such. This work started from the denotation semantics, in which I find that besides $\otimes$ and $\wp$ there is a self dual non commutative connective: $A \wp B \multimap A \prec B \multimap A \otimes B$ (and $A \wp B \multimap B \prec A \multimap A \otimes B$ too) with $(A \prec B)^{\perp} \equiv (A^{\perp} \prec B^{\perp})$. It possesses an elegant proof net syntax, both with traditional proof nets and with handsome proof nets (see paragraph 4.3) that exactly matches denotational semantics (see paragraph 4.2). This calculus is the basis for the *calculus of structures*, a term calculus (rather than a graph calculus), that has been defined Alessio Guglielmi, Lutz Strasburger etc. who are still developing and studying it. For linguistic applications see paragraph 5.3 [21, 4]

## 4.5 Lambek calculus (1994↦)

Regarding the Lambek calculus I proved that a proof net with non crossing axioms corresponds to a proof in the Lambek calculus — Roorda proved that Lambek proofs yield non crossing proof nets, but not the converse. This result is not so difficult to prove when using the proper combinatorics , but it is very important result because it justifies to replace proof search by proof net construction, as most people do nowadays. Although some might be unaware of the importance of this completeness result, it is a very important result (at least one person ignore this result on purpose, arguing that it was published in French). [14]

Regarding the grammars based on non-associative Lambek calculus Sylvain Salvati and I proved that NL grammars can be represented by second order abstract categorial grammars. [58, 63]

With Sylvain Pogodalla we defined a criterion for proof nets of the Lambek calculus in the style of handsome proof nets where formulae are viewed up to algebraic properties of the connectives. We did so by mapping the formulae to a directed cograph on the axioms (see paragraphs 3.2 and 4.3). They are much more complicated than the undirected ones that correspond to the commutative calculus. We solved the question for cut free proof nets in [46].

But this criterion is difficult to extend to proof nets with cuts, we just found (2013) a solution that needs to be checked.

### 4.6 Partially commutative linear logic (1996-2008)

In 1996, before Paul Ruet did in the classical case, Philippe de Groote introduced a multiplicative intuitionnistic linear logic that combines commutative and non commutative connectives. In the published paper, the only relation between the commutative and non commutative system is that one conjunction is stronger than the other — strangely enough, the system works no matter whether the commutative conjunction is stronger than the non commutative one, or the other way round. In such a setting the set of hypotheses is endowed with a series parallel partial order.

I studied this calculus in the more general case where any sub series parallel partial order among the hypotheses can be inferred from a given series partial parallel order hypotheses — the inclusion of series parallel partial orders is a rewrite system, see paragraph 3.2. Firstly i proved cut elimination, and i showed that this calculus embeds the truly concurrent executions of a Petri net, that is the one in which some transitions can be fired simultaneously. [38]

I also studied the natural deduction of such a system, which is rather tricky because of the product elimination rules, be they commutative or not. This is quite important because that is the system that we use for categorial minimalist grammars relies on this logic. With Maxime Amblard we were able to find a normalisation result for these proofs. [52]

## 5 Natural language syntax

### 5.1 Learning categorial grammars (2000-2003 & 2013)

Although it is possible to type an electronic grammar, it is also possible to learn it from (structured) data, like annotated copora. This task can be related to the modelling of child language acquisition, a fascinating topic at the basis of generative grammar. Hence I studied with Roberto Bonato the learning of categorial grammars, after Buskowski, Penn, Kanazawa who only studied the AB grammars (Lambek grammars without introduction rules). We were able to prove there is a learning algorithm that converges in Gold's sense for Lambek grammar, and we recently extended our result to Lambek grammar with product. The input are proof structures that look a bit like dependency structures. Such a result also has some practical outcomes: it is possible to turn non rigid grammar to rigid grammars with a part of speech tagger or by clustering techniques. [33, 53, 87]

### 5.2 Classical categorial grammars: Lambek, multimodal (1995- 2005)

With Philippe de Groote we show that proof net can be used to compute the semantic representation of a sentence. From a parse structure given as a proof net, and with the semantic lambda terms provided by the lexicon, a labelling algorithm computes, as the label of the output, the lambda term corresponding to the semantics of the sentence. This work is often used by others like Glyn Morrill. [11]

With Richard Moot we showed that Moortgat's multimodal categorial grammars (MMCG) can nicely handle clitics, clitic climbing and still provide the proper semantic reading even with modal and control verbs. [51]

Richard Moot and I wrote a **monograph on Lambek calculus and grammars**, associative or not, which goes from classics to our research contributions, e.g on proof nets: This book is a contemporary and comprehensive introduction to categorial grammars in the logical tradition initiated by the work of Lambek. It guides students and researchers through the fundamental results in the field, providing modern proofs of many classic theorems, as well as original recent advances. Numerous examples and exercises illustrate the motivations and applications of these results from a linguistic, computational and logical point of view. The Lambek calculus and its variants, and the corresponding grammars, are at the heart of these lecture notes. A chapter is devoted to a key feature of these categorial grammars: their very elegant syntax-semantic interface. In addition, we adapt linear logic proof nets to these calculi since they provide efficient parsing algorithms as exemplified in the Grail parser. This book shows how categorial grammars weave together converging ideas from formal linguistics, typed lambda calculus, Montague semantics, proof theory and linear logic, thus yielding a coherent and formally elegant framework for natural language syntax and semantics. Chapters: 1) AB grammars, 2) Lambek's Syntactic Calculus, 3) Lambek Calculus and Montague Grammar, 4) The non-associative Lambek calculus, 5) The multimodal Lambek calculus, 6) Proof nets for linear logic and the Lambek calculus, 7) Multimodal proof nets. [74]

### 5.3 Words as modules of pomset proof nets (1996-1998)

With Alain Lecomte we designed a grammatical framework by mapping each word to a partial proof net. It is already a two level formalism as Lambda grammars of ACG: the words are assembled in order to obtain a correct proof net of pomset logic. Form this structure that may be called a deep structure, we were able to compute word order (which can be partial, i.e. underspecified when phrases are allowed to be permuted) and also a semantic term Ãă la Montague. In this setting we were able, for instance, to recover tree adjoining grammars, with a standard categorial semantics. It is not so far from Joshi and Kulick partial proof tree as building blocks for a categorical grammar. [13, 24, 20]

A particular property of this kind of grammar is that when two phrases are composed, the relation between them is fully symmetric: one provides a feature, the other as well, and it is hard to tell which phrase is the head. As linguists disliked this property, we stopped this study of this kind of grammar. It was also hard to communicate on this formalism in the computational linguistic community because of the absence of sequent calculus or natural deduction for pomset logic (which only possesses a proof net syntax). But we kept some guidelines of this calculus for our categorial study of minimalist grammars.

### 5.4 Categorial minimalist grammars (1999–2010)

In order to endow Stabler's minimalist grammars with a systematic computational semantics we studied with Alain Lecomte how to define minimalist grammar as categorial grammars. Of course the difficulty is movement. Hence we opted for a two layer formalism a deep structure is derived from which one computes both the proper word order (with agreement, case etc.) by a traversal of the proof (usually written in natural deduction). From the deep structure one also compute the semantics that generative grammar call logical form.

Basically the movement of minimalist grammars is encoded by the product elimination rule. There after we discover that the commutative product works better the logical system for deriving deep structures was partially commutative linear logic (see paragraph 4.6). In the other direction, the main difference is that instead of a list of feature, categorial grammar has structured non terminals (e.g. with /) that can be nested and that yield the pleasant syntax/semantics interface via variants of Curry-Howard. Hence the to systems share the view that syntactical composition is resource consumption, as noted by Berwick and Epstein long ago, but they treat it differently, and we manage with Alain Lecomte, Maxime Amblard, Houda Anoun to fill the gap, focusing on syntax/semantics questions.

Regarding the semantics, we studied classical things like ambiguous quantifier scopes, control verbs, clitics, relative clauses, following the syntax of minimalism. A phenomena that causes problems in standard categorial grammars is the fact that for obtaining the proper interpretation, the syntactical category of a quantifier depends on the syntactic position it is going to occupy: in the subject, in the object, in a PP. We solved this by using a single category on the syntactical side, but using the non confluent $\lambda\mu$ calculus for computing the semantics. So once the quantifier is applied to the common noun, it looks for a main predicate. Another quantified noun phrase possibly also looks for a main predicate. The non confluence of $\lambda\mu$ yield the different quantifier scopes and the corresponding readings. In order to include some discursive phenomena (and also for some technocal reasons concerning discourse referents) we rather use $\lambda$-DRT introduced by Muskens than plain Montague semantics. [40, 61, 34, 42, 27, 26]

## 6 A semantic framework for lexical and compositional issues

### 6.1 The Montagovian generative lexicon MGL (2007$\mapsto$)

I discovered the work by Pustejovsky and Asher on integrating some lexical semantics into compositional semantics about 2002 in a PhD. In 2006 a PhD student, Bruno Mery, and a colleague of mine, Christian

Bassac, were interested in such issues, which involves both semantics and knowledge representation — it also involves deep logical questions.

Roughly speaking we want to filter out semantically illformed sentences. For instance "*a chair barks*". The basic idea is to refine Montague's type of entities and to say that complements subjects etc. are presupposed to be of a given type. So an uninterpretable composition results in a type clash: "*barks*" requires an animal as its subject, and "*chair*" is not an animal.

Then one has to accommodate or to coerce some types, since although a "*book*" is not an action, one can say *I finished my book*.

We here depart from standard analyses initiated by Asher and Putejovsky. We do not think that the type of the word, which si somehow ontological, is enough to coerce the word. For example French noun "*classe*" which is a group, in particular of students, can be coerced into a classroom, while "*promotion*" which is ontologically similar cannot.

Hence we reorganised the lexicon: a word is endowed with its usual lambda term with more refined types, and several optional modifiers are provided in the lexicon. So the possible coercions are provided by the word and not by its type.

The different senses in which a word can be coerced are sometimes compatible and sometimes not. For instance one can say "*Liverpool is a big-place and voted labour.*" but "*Liverpool is a big-place and won.*" is unlikely. We solved this by putting that some senses are exclusive.

As we have many types, in order to factorise operation that acts uniformly over families of typed terms like conjunction/coordination and quantification, we use second order lambda calculus that is system F. it seems that we do not use the full expressive power of system F, but that only the polynomial part of it is needed as in Lafont's Soft Linear Logic.

So we have second order lambda calculus for meaning assembly (the compositional machinery) and multi sorted logic for expressing the logical forms.

Related to this issue there are related question of formal semantics, since system F and many sorted HOL offer various possibilities.

For instance what relation is there between the type $A$ and the characteristic property of being an $A$ object, i.e. $\hat{A}(x)$? The type judgement cannot be negated, while the predicate can. The functionalities offered by second order lambda calculus which include integers, lists, trees etc. open new perspectives in formal semantics. [55, 56, 62, 91]

## 6.2 Formal semantics in the MGL: quantifiers, determiners, plurals etc. (2011$\mapsto$)

With the possibility to quantify over types, despite the numerous types and sorts that we have in our framework, a single constant $\forall$ (or $\exists$ of type $\Pi\alpha.\ (\alpha \to t) \to t$ is enough.

But we prefer to use typed Hilbert's operators for quantification (see paragraph 2.3), a subject that von Heusinger initiated and that we are currently discussing with Michele Abrsuci (Rome) and Nicholas Asher (Toulouse). Indeed, they better match the syntactic structure of the sentence, the asymmetry between the two predicates in en existential statement (which generalised quantifiers ignore), and aloo the quantified noun phrase to refer by itself. They are especially natural in our setting, and we thus provided a faithful account of the semantic of determiners. [82]

An interesting opportunity is that one can introduce Hilbert's operators which are a kind of generic elements for generalised and vague quantifiers, thus obtaining from syntax a logical form with such quantifiers operating on one predicate. We did so, and we also studied how such operators can be given a meaning in proof theoretical terms. (see also paragraph 2.3). [70, 73, 81]

In this setting we also studied plurals with Richard Moot and Bruno Mery, and discussed with Zhaohui Luo and Stergios Chatzikyriakidis (London). It is worth noticing that integers, lists and such inductive types can be defined within system F. With constructs that are standard in typed functional programming, we were able to define a model for handling basic facts about plurals, yieldings the proper readings, distributive, covering, collective. [76, 68]

We would like to address the semantics of mass nouns in this setting.

## 6.3 Lexical semantics in the MGL: copredication, ontology, deverbals, fictive motion,... (2010$\mapsto$)

We studied fictive motion in this setting, with Richard Moot and Laurent Prévot (Aix). For instance when one says *The path descends for two hours* one needs to coerce the path into the event of following the path, which involves someone who may not exist. We did so using our formalisation of coercions in system F, and we properly accounts for adverbs and modifiers: *The beautiful path descends pleasantly for two hours.*. We did so in Montague semantics and in lambda DRT, the later solution being implemented. [66, 67, 71, 72]

Our word driven approach was shown by Livy Real (Curitiba) and I o be successful for handling deverbal meanings. Indeed, there are some sense related to the verb that are available, but only some of them are possible. We studied and properly formalised the semantics of deverbal for a variety of romance language (French, Italian, Spanish, Catalan, Portuguese). [80, 89]

Ontological inclusion like "*Dogs are mammals*" or "*Cars are vehicles*" can be described by the optional coercions as we did. Given that such coercions are type driven as opposed to others that are idiosyncratically anchored in words, it would be better to have type inclusion that is sub typing. We recently introduced such a notion for system F. (see also paragraph 2.4) and this is ongoing work with Zhaohui Luo (London) and SergïSoloviev (Toulouse). [83]

In our model, the base types that are used can be discussed. Pustejovsky and Asher initially wanted a dozen of ontologically motivated types, Luo consider every common noun as a base type. We thought that semantics is more about language use than about world knowledge, and on the other hand the restriction of selection in a dictionary are not any possible common noun. Hence with Bruno Mery we supported the idea that the base type should correspond to classifiers in language with classifiers (sign languages, Chinese, Japanese). This is the source of many discussion with Nicholas Asher (Toulouse) and Zhaohui Luo (London). [78]

The idiosyncratic constraints on the felicity of copredication can possibly be encoded within linear types instead of external rules on the composition of terms. This is an on going research to be pursued with Bruno Mery and Richard Moot.

## 6.4 Experimental semantics: towards measures of complexity in human processing (2013$\mapsto$)

Thanks to a CNRS project, we just had the possibility to make some experiments in semantics, with people from Aix (Philippe Blache, Maud Champagne Lavau, Laurent Prévot). Its a tricky task because we want to observe the understanding process, that is the mental construction of semantic representation. But the only way to observe these representation is to observe the semantic representations are to observe their effect on a simple reasoning task (model checking). We hope to find, in the formal model described above parameters that would measure the complexity of understanding, and we defend the claim that ambiguity is a source of complexity.

We started experiments on the understanding of quantifiers and scope question, checking whether the reader think sentences are true or not in a given situation which is as simple as possible. However the main difficulty is to tell apart pragmatics and common senses reasoning. We measure the time of reaction, and record the eye movement for deciding whether the sentence holds in the situation described by a drawing. Further experiments, in particular for lexical coercions are presently being defined. [84]

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