Summary of the Habilitation Report

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1 Introduction

1.1 Research topics

My work is on the *formalisation of reasoning in logic*, and covers a field reaching from knowledge representation to automated reasoning methods. In that perspective I have studied the *dynamics of knowledge bases*, which is a problem that is essential in AI and more generally in computer science. It includes a large range of topics such as updating databases, generating plans in robotics, and revising beliefs in man-machine dialogues. My approach consists in first of all formally modelling these processes, and then associating automated proof procedures to them.

In all these applications there appear in a natural way the concepts of belief, knowledge, intention, and obligation, as well as that of uncertainty. In logical languages one can associate to each of these concepts an intensional (modal) operator. We obtain thus a family of modal operators that are parametrized by concepts. Thus the modal formula

$$[p]A$$

can be read "agent p knows that A", "agent p believes that A", "it is mandatory for agent p that A", etc.

My general aim is therefore to put beliefs and their dynamics in a unified framework by defining non-classical formalisms that are sufficiently expressive, and to equip them with automated reasoning methods. The classical way of doing this amounts to first of all study separately the non-classical logic associated to each concept, and then integrate several of these logics in a single logic.

Modal logics of knowledge, belief and obligation are part of the classical systems of philosophical logic (v. the work of Hintikka on epistemic logics). Modal operators have as well been associated to actions: the formula $[p]A$ can be read "after the execution of action p, A will be true". Such actions can be iterated, and a plan then corresponds to a sequence of actions $p_1, \ldots, p_n$. Philosophers such as Segerberg have compared the execution of an action to that of a computer program, motivating thus the use of dynamic logic as a logic of actions and plans.

Instead of taking actions to be abstract one can as well study them through their results. An action is thus confused with the set of formulas its execution makes true. Hence the parameter p can be analyzed as $do(B)$, where B is a formula. The modal formula $[do(B)]A$ is read "after making B true, A will be true", or "after updating by B, A will be true", or "under hypothesis B, A is true". The last formula has the form of a conditional, and if we rewrite this using an arrow-like symbol (as usually done for conditionals) then the above formula can be written

$$A \Rightarrow B$$

where $\Rightarrow$ (also noted $>$) is an implication symbol different from material implication $\rightarrow$ of classical logic. Such conditional logics have been studied in formal philosophy.

Via their link with hypothetical reasoning, conditional logics allow to naturally handle the dynamic aspects of knowledge bases: if $C = upd(B, A)$ is the result of updating belief base B with a new piece of information A, then we have

$$upd(B, A) \rightarrow C \text{ if and only if } B \rightarrow (A \Rightarrow C)$$

Thus if we assert a conditional $A \Rightarrow C$ we want to say that C is the result of a (hypothetical) update by A. This equivalence is known in the literature under the name "Ramsey Test". Via this test, conditional logics can be applied to analyse and formalise update operations.

In the logical formalisms that I have mentioned several difficulties arise, among which the famous problem of persistence of information through change (the frame problem), which corresponds to the problem of inheritance in nonmonotonic reasoning. More generally this happens in all the formalisms that have been proposed in the literature in order to take into account the dynamics of knowledge bases, such as the formalisms for nonmonotonic reasoning, updating or reasoning about actions. The approaches to solve these problems — which is first of all a problem of knowledge representation — have encountered difficulties both on the model-theoretic level (lack of semantics e.g. of the so-called syntax-based approaches) and on the proof-theoretic level (lack of results on axiomatizability or decidability).

I have based my work on the hypothesis that the difficulties are due to the fact that traditionally in logic it is supposed that the set of atoms of a logical language has no structure, in the sense that everything that is not declared dependent is supposed to be independent. (Note that the contrary is the case in probability theory.) As many authors in the literature have noted, material implication $P \rightarrow Q$ of classical logic is not sufficient to represent such dependences.

In my work I have introduced dependence structures into logic. My aims are the following:

1. to study this concept in detail in appropriated frameworks (probability theory, possibility theory, theories of causality),

2. to integrate dependence structures into logic,
3. to study the notion of deduction for non-classical logics in general and dependence-based logics in particular,
4. to define generale procedures of automated deduction,
5. to put to work such procedures in applications such as belief base updating, plan generation, or belief reconstruction in man-machine dialogues.

1.2 A chronicle

In my work I have developped both aspects, viz. modelling of belief dynamics and automated deduction. This has been done sometimes in an alternating way and sometimes in parallel.

While my master thesis and the year after were rather about the dynamic aspect, my thesis and the beginnings of my work as a CNRS researcher were mostly devoted to the definition of a general method of automated deduction for non-classical logics. It is recent work that achieved a synthesis of these two activities, based on the key concept of dependence: since 1994 I have dedicated almost all my publications to automated deduction methods for logical systems of the non-classical type that are based on dependence and that formalize and mechanize the dynamics of belief. Finally, very recently I have applied this methodology to man-machine dialogues.

My work throughout these years are in the context of the Applied Logic Group of IRIT headed by Luis Fariñas del Cerro, and a lot of my publications are coauthored by him and other members of the group.

Right from the start I was interested in the relation between belief revision, database update operations, and conditionals. In my 1986 master thesis I have studied a conditional logic where the semantics of the connective $\Rightarrow$ is that of intuitionistic logic. The results have been taken up again and published in 1996 [Fariñas del Cerro et Herzig, 1996b].

In the beginning of my thesis I have sketched in 1988 a semantics for updates in the framework of a logic of conditionals close to Winslett's "Possible Models Approach" (PMA) [Fariñas del Cerro et Herzig, 1988]. I have continued to develop this approach from 1992 on. In 1993, the general interest of the French AI community in updates was at the origin of the national project "Gestion de l'evolutif et de l'incertain dans une base de connaissances" ('Update and uncertainty management in knowledge bases') gathering researchers coming from AI, databases, and control, which I headed together with Ch. Froidevaux. The results of the group are collected in [Collectif, 1995].

At that time I considered important to investigate the state of the art in the research on conditional logics, and together with G. Crocco and L. Fariñas del Cerro I have started in 1993 the edition of the book "Conditionals: From Philosophy to Computer Science" [Crocco *et al.*, 1995].

Both intuitively and formally there is a strong link between a conditional $A \Rightarrow C$ and a nonmonotonic inference $A \mid\!\sim C$. I have studied the links between conditional logics and the general properties of nonmonotonic inference relations in collaboration with L. Fariñas del Cerro and J. Lang of the group "Plausible Reasoning, decision and proof methods" of IRIT. Extending a result of Gärdenfors and Makinson we have shown that at the base of both formalisms ther is the very same uncertainty theory, viz. possibility theory. The results have been published first of all at ECAI [Fariñas del Cerro *et al.*, 1992] and then in the AI Journal [Fariñas del Cerro *et al.*, 1994]. The latter paper is part I of the document.

In the sequel I have proposed in [Fariñas del Cerro et Herzig, 1994b, Fariñas del Cerro et Herzig, 1995a] a general framework for updates based on a combination of conditional logic with a dependence relation. Therein, to the axiomatics of conditional logic I add a generic frame axiom that is parametrised by dependence. This axiom takes the form

$$C \rightarrow (A \Rightarrow C) \quad \text{if } A \text{ and } C \text{ are independent}$$

and stipulates that if C holds and "has nothing to do" with A, then C continues to hold after updating by A.

In this very framework, I have associated to the PMA an axiomatics [Fariñas del Cerro et Herzig, 1994a, Fariñas del Cerro et Herzig, 1995d, Fariñas del Cerro et Herzig, 1997] and an automated deduction method [Herzig, 1996]. The PMA being subject to criticism for some of its properties, in recent work I have reviewed the corrections that have been proposed in the literature, and I have proposed a dependence-based variation whose theoretical complexity is particulary interesting (in NP) and which I have equiped with a rewriting-based automated deduction procedure [Herzig et Rifi, 1998].

Updates and the relation with conditionals is the theme of an overview paper in the "Handbook of Defeasible Reasoning and Uncertainty Management" [Herzig, to appear] and is part II of the document. In that paper it is shown in particular how starting from the Ramsey Test one can transfer existing results on conditionals to the update frameworks proposed by Katsuno, Mendelzon, Satoh and Grahne. I have also shown how this framework can be generalised following the lines of the literature on conditional logics. The result seems to have interesting philosophical consequences in what concerns the distinction between update and revision usually made in the literature, and I have written a paper on that topic in collaboration with G. Crocco of the departement of philosophy of the University of Konstanz (Germany) [Crocco et Herzig, 1997].

My approach being based on the concept of dependence, since 1993 I have investigated the foundations and properties of that notion. These reflections have also taken place within a working group of the French AI program "Lois, structures et dependances" (LSD) ('laws, structures and dependences') that I headed and whose discussions have been published in [Collectif, 1997].

There are at least three options in what concerns the foundations. The first and easiest one is to consider dependence to be a primitive concept, from which e.g. causality can be defined. This option had been chosed in [Fariñas del Cerro et Herzig, 1994b, Fariñas del Cerro et Herzig, 1995a], and it is also the (often implicit) choice in most of the causal approaches in the recent literature on reasoning about actions. An inconvenient of such approaches is that due to the *ad hoc* character of their dependence notion we get only little ideas about the characteristics and properties of dependence, all the more our intuitions on the subject seem to be not that clear. E.g. should we accept properties such as the 'Conjunction Criterion for Dependence' CCD

if C depends on A and C depends on B then C depends on $A \wedge B$

that has been postulated by J.M. Keynes in 1921 and studied by Gärdenfors? Indeed, none of the approaches mentions such questions that are nevertheless fundamental.

This observation made me study uncertainty-based notions of dependence. Indeed, in probability theory there is a well-known notion of independence defined through the Multiplication Law:

A and B are independent if and only if $P(A \wedge B) = P(A) \cdot P(B)$

and formal results exist in the literature (in particular an axiomatics). Nevertheless, these formalisations are quite complex and delicate to manipulate. Moreover, as probability theory is a numerical framework, it turned out to be difficult to transfer the associated dependence notion to a logical framework. That motivated my interest in possibility theory, which is an ordinal theory of uncertainty (Gärdenfors and Makinson [Gärdenfors et Makinson, 1994] use the expression "a 'lazy man's approximation' to a probability districution"), and whose 'founders' are D. Dubois and H. Prade of the group "Plausible Reasoning, Decision and Proof Methods" of IRIT. Possibility theory can be identified with Gärdenfors's epistemic entrenchment, which is the base of two important belief dynamics formalisms, viz. AGM belief revision and KLM nonmonotonic inferences. (I had studied the link in [Fariñas del Cerro *et al.*, 1994].) In collaboration with L. Fariñas del Cerro and D. Dubois and H. Prade I have thus undertaken an in-depth study of that option, which has permitted us to obtain axiomatics and completenenss results. First of all we directly started from AGM belief revision operations, defining A and C as being dependents w.r.t. a belief base B if C is a consequence of B but not of $B - A$, where $B - A$ is the contraction of B by A [Fariñas del Cerro et Herzig, 1994c, Fariñas del Cerro et Herzig, 1995c, Fariñas del Cerro et Herzig, 1996a]. In the sequel we have obtained similar results defining directly a notion of possibilistic independence via conditionalisation, i.e. studying the relation between the degree of possibility $\Pi(C)$ of a formula C and the degree of conditional possibility $\Pi(C|A)$ [Dubois *et al.*, 1994, Dubois *et al.*, 1997, Dubois *et al.*, 1998]. Part IV of the document contains [Fariñas del Cerro et Herzig, 1996a] and [Dubois *et al.*, 1998].

A third avenue towards the foundation of dependence is given by the notion of topic of interest. Here, inspired by work in computational linguistics and formal philosophy, one considers that to every sentence one can associate a set of topics it is about. E.g. if A means "the switch is up" then the topic of A can be considered to be the position of the switch, the state of the lamp, and the brightness of the room. Two formulas can then said to be independent if they have no topic in common. Such a notion is *a priori* only a syntactical one. Despite that drawback it has interesting properties when it comes to knowledge representation, and e.g. the CCD is naturally validated. It is due to that simplicity that topic-based dependence has appeared most appropriate to me as the base of a theory of belief dynamics that is both sufficiently rich from a theoretical and expressiveness point of view, and sufficiently simple from a practical point of view, i.e. with 'reasonable' computational properties. Therefore I adopted it for the sequel.

Indeed, the variation of the PMA that I have proposed recently in [Herzig et Rifi, 1998] is topic-based (while the formalisations of the PMA that I had studied previously can be seen as based on a particular instance of that). The same holds for an approach to belief base revision whose compatibility with the AGM approach I have studied in [Herzig, 1997].

I have also adopted that foundation from 1995 on in my research on reasoning about actions. Here, topics are associated not only to formulas, but also to actions. For example the action of toggling a switch is associated with the topic of the position of that switch as well as the state of the lamp and the brightness of the room. A formula is then said to be independent of an action if both have no topic in common, and we can thus formulate a generic frame axiom in a way similar to that for conditionals:

$$C \to [p]C \quad \text{if } p \text{ and } C \text{ are independent}$$

In collaboration with M. A. Castilho and O. Gasquet I have added to dynamic logic a notion of dependence between actions and formules in order to solve the frame problem. In order to mechanize that logic I have adapted the standard semantic tableaux methods for modal logics in order to take into account dependence relations. This method allows also to generate plans [Castilho *et al.*, 1997b]. A paper extending that work has been submitted to the Journal of Logic and Computation. (After a "accepted subject to modifications", a corrected version has been resubmitted recently.) This is part III of the document.

It turned out that the tableau method for my modal logic of actions generalizes the existing methods in an interesting way. This observation has allowed us to go far beyond these methods and to handle modal logics for which no deduction method was known up to now, such as those associated to dense or confluent accessibility relations. This approach has been studied in collaboration with M. A. Castilho, L. Fariñas del Cerro and O. Gasquet. It has been published in Fundamenta Informaticae [Castilho *et al.*, 1997a] and is part V of the document. The approach has led us in 1997 to define an ambitious project. Within this project an automated theorem prover has just been implemented that is accessible through Internet.

Our tableau method isdecidable, and is thus an interesting alternative to the translation into classical first-order logic that I had proposed in my thesis and that I had continued to study in a series of papers [Gasquet et Herzig, 1993, Gasquet et Herzig, 1994b, Balbiani et Herzig, 1994, Gasquet et Herzig, 1994a, Gasquet et Herzig, 1995, Gasquet et Herzig, 1996, Gasquet et Herzig, 1996]. All these results are overviewed in the "Handbook of Logic in Artificial Intelligence and Logic Programming" [Fariñas del Cerro et Herzig, 1995b]. The extension of the translation method to action logics augmented with dependence should not present major problems, but has not been undertaken up to now. I have chosen not to include these works in the present document.

2 Perspectives

Having achieved a structuring of belief states via the notion of dependence, I have integrated that notion with two important non-classical frameworks, viz. conditional and dynamic logic. I have been able to associate decision procedures to these formalisms, taking profit of previous work of mine on general methods of automated deduction for non-classical logics.

These were important advances in my research program. Now it is time to on the one hand extend the approach to richer formalisms, and on the other hand to proceed to the next step and to put to work this methodology in the aforementioned applications. These two goals will be pursued in parallel and are expected to interact.

Indeed, the logical frameworks that I have established focus on dynamics and do not integrate operators of belief or intention yet. Such a direction has just been taken in collaboration with L. Fariñas del Cerro, D. Longin and O. Rifi, and the first results are in [Fariñas del Cerro *et al.*, 1998].

As well, the latter paper is about an application that seems particularly promising to me, viz. cooperative man-machine dialogues, where the beliefs of speaker and hearer must be reconstructed after a speech act.

At the origin of the latter application there is an industrial project with France Telecom (since 1997), and it is hoped that the methodology can be extended to more ambitious applications such as the 'personal agent'.

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