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Introduction (EN)

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Alain Colmerauer passed away on May 12th 2017. A pioneer in artificial intelligence, he will go down in computer science history as the creator of the Prolog programming language. A mathematician and computer scientist, a tireless researcher and a visionary, very early on, he saw the advantage of reversing the subordinate relationship between programming and logic to create Logic Programming.. In 1969, at the University of Montreal, he developed the Q-system formalism for natural language processing. This was the start of the Prolog adventure, the first interpreter of which was created in 1971 in Marseille. This first academic success, which attracted a great deal of attention, brought Prolog and its inventor into the spotlight of many universities and the software was distributed worldwide. Prolog II introduced constraint logic programming. Prolog III and the final stage, Prolog IV, generalised the technique of solving constraints by interval reduction and propagation to discrete and continuous domains. This last development, partly unfinished, put an end to the line of Prologs from Marseilles, his life's work. Very representative of the scientist and man that he was, it sheds light on his constant desire to bring as much rigour to the theory as to its application.

Four years after his death, a day of tribute[(1)] was organised in his honour on October 8th 2021 on the Luminy campus of Aix Marseille University. This event was an opportunity to evoke his major scientific contribution, with the idea of showing that there is still a deep and lively link between his work and current lines of research[(2)], in a context made particularly active by the recent boom in numerical Artificial Intelligence techniques.

The *Prolog Heritage* and *Association for Logic Programming (ALP)* associations have declared *2022 the Year of Prolog* to to mark the 50th anniversary of Prolog's birth. A symposium[(3)] was held on November 10th 2022 at the Université Paris Cité, with the award of the Alain Colmerauer Prize by an international jury, leading to the creation of an international Alain Colmerauer prize.

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(1) `https://alain-colmerauer.lis-lab.fr`.

(2) Link to videos of talks:
`https://amupod.univ-amu.fr/videos/?tag=alain%20colmerauer`.

(3) `https://prologyear.logicprogramming.org/PrologDay.html`.

The ROIA journal decided to extend and broaden these tributes in the form of a special issue for which we were delighted to be guest editors, and for which a call for contributions was launched in October 2022.

An overview of Artificial Intelligence research in the 1960s

Artificial intelligence (AI) came into existence as a result of a program of meetings during the summer of 1956 at Darmouth College (Hanover, New Hampshire, USA) organised by two young researchers, John McCarthy and Marvin Minsky, who in different ways were to have a major impact on the development of the discipline, John McCarthy defending a purely logical vision of knowledge representation and Marvin Minsky working on formal neurons and perceptrons.

In 1956 Newell and Simon (in collaboration with J. Cliff Shaw), proposed the first computer program able to demonstrate theorems in logic, before soon presenting a General Problem Solver, based on the evaluation of the difference between the situation the solver has arrived at and the goal it has to reach.

From its earliest days, AI has focused on the development of programs able to play chess. The first programs, notably those of Arthur Samuel and Alex Bernstein, appeared in the early 1960s, and over the decades managed to beat players of increasingly high level, as Richard Greenblatt's MacHack did at the end of the 1960s.

Among the various works that mark the beginnings of AI, let's mention Thomas G. Evans' program. Evans' program, which, as in an intelligence test, was able to find by analogy the fourth generic figure completing a series of three (which also required a conceptual representation of the figures), or systems exploiting constraints by propagating them, As in David Waltz's (1975) approach to recognizing the lines corresponding to the edges of solids and their relative positions in an image, an approach that was later to be extended to many other fields where constraint representation is naturally required.

The processing of texts or dialogues in natural language, both in terms of their comprehension and their automatic production, has also preoccupied AI very early on. The ELIZA system (by Joseph Weizenbaum), by picking out key expressions in sentences and reconstructing ready-made sentences from them, was able, from 1965 onwards, to converse in natural language, by fooling for a moment human interlocutors who thought they were dealing with a human interlocutor! However, ELIZA did not construct any representation of the sentences in the dialogue and therefore had no understanding of them.

To write such programs more easily, programming languages geared towards the symbolic processing of information were needed. Specified in 1958 by John Mc Carthy, inspired by Alonzo Church's λ-calculus, LISP (List Processing), a functional programming language, has become a reference language for AI.

Artificial intelligence was first largely developed in the United States before attracting the interest of researchers in Europe from the late 1960s onwards [13]. In France, apart from the cybernetics pioneers Louis Couffignal and Paul Braffort, the first French teams explicitly claiming to be involved in AI were set up at more or less the same time in the early 1970s in Paris and Marseilles under the leadership of Jacques Pitrat [15] and Alain Colmerauer respectively.

Alain Colmerauer, pioneer of logic and constraint programming

Alain Colmerauer's early research focused on the syntactic analysis of programming languages, as part of his doctoral thesis in Grenoble in 1967. He then turned his attention to languages with a more complex syntax than programming languages, namely natural languages. From 1967 to 1970, he was assistant professor at the University of Montreal, where he developed his first work in artificial intelligence as part of the TAUM (Traduction Automatique de l'Université de Montréal) project, for which he was appointed project manager. TAUM represents one of the first industrial prototypes of translation between French and English. At the same time, he designed a formalism, "Q systems"(4), based on the manipulation of trees, which, when implemented, was applied to the automatic translation of weather reports from English into French. [7].

Returning to France in 1970 as a lecturer at the University of Aix Marseille II, he abandoned machine translation and became more interested in deduction from texts. To do this, he looked at work in progress in automatic demonstration, and more particularly at the Resolution Principle developed by Alan Robinson in 1965. In Marseille, he invited Robert Kowalski, who in Edinburgh was developing work on "SL-resolution", an extension and refinement of Robinson's method. These fruitful exchanges led to an approach that used a fragment of predicate logic and was based on "SL-resolution", which was to serve as the basis for the first theoretical model of Prolog (5). Initially, however, Alain Colmerauer's aim was rather to design a natural language communication system that could be queried [11], but from then on the team he formed with his doctoral students on the Luminy campus, initially consisting of Philippe Roussel, Robert Pasero, Marc Bergman and Jean Trudel, went on to develop a radically new programming language: Polog (for PROgrammation LOGique). More than just a language, Prolog represented a paradigm for thinking about programming in a totally different way, and proved to be a real revolution in Artificial Intelligence [12].

In the mid-1970s Alain Colmerauer also continued his work on natural language processing, in particular on the semantics of French, and then on the application of his work to the interrogation of databases [4].

From 1976 onwards, work on implementing Prolog on microcomputers, first on an Exorciser, then on an Apple II, produced a new Prolog specification. Alain Colmerauer replaced the notion of unification with that of resolution of equations in a given domain. This approach enabled him to introduce infinite trees as well as equations that could be used to test that two objects were different without having to resort to the cut operation. This work led to the development of the Prolog II [5] language, whose implementation

(4)Q for Québec.

(5)see the article by Robert Kowalski in this volume.

on an Apple II with a 64k memory represented a technical feat, and for which Alain Colmerauer, Henry Kanoui and Michel van Caneghem were awarded the Apple Golden Apple in 1982.

Alain Colmerauer's detachment to the Centre Mondial d'Informatique in Paris in the early 1980s enabled him to start research into new extensions to Prolog's basic mechanisms. Noting that equalities and non-equalities between terms are a particular form of constraint, the possibility of associating a numerical constraint solver with the Prolog kernel led to the Prolog III language and the advent of constraint programming. From the middle to the end of the 1980s, Alain Colmerauer devoted himself to developing the Prolog III language, a marketable version of which became operational at the beginning of 1990(6) [6].

The idea of a generalisation to arbitrary constraint languages began to take hold and, as he continued his reflections on constraint programming, it became clear to him that a constraint can be expressed in the form of a conjunction of elementary constraints and, more generally, in the form of a first-order formula involving operations and relations on a given domain. Alain Colmerauer then became interested in increasingly complex constraints, leading to the *Prolog IV* language, which became operational in 1996, and enables a wide variety of constraints to be processed, in particular on lists, trees, intervals and real numbers [1].

With the aim of solving the problem of the complexity induced by the conjunction of atomic constraints, he became interested at the end of the 1990s in the resolution of constraints by interval reduction [2], and then at the beginning of the 2000s in the resolution of general constraints, i.e. unrestricted first-order formulae, in the theory of trees [8]. In addition, he became interested in the complexity of universal programs in the second half of the 2000s [9, 10]. Having been particularly concerned throughout his life with the interaction between theoretical research and applications, Alain Colmerauer directed his latest work towards fundamental questions of computability, by proposing a new formal framework for evaluating the complexities of several universal programs on different machines. Alongside his research activities, Alain Colmerauer was also a pioneer in teaching computer science in Marseille. Despite an offer from Stanford University, Alain Colmerauer chose to join the Marseille Luminy University Centre in the early 1970s. Together with his team, he will be developing teaching that is closely linked to research, as a result of the introduction of a DEA (post-graduate diploma) in computer science prior to the introduction of a Master's degree and then a Bachelor's degree, in the opposite direction to the usual academic practice in other French universities. This link with research will give rise to many vocations, and the students trained in this way will themselves make a talented contribution to the development of Logic Programming and Constraint Programming. Alain Colmerauer will directly supervise around fifty theses(7).

(6) `https://www.softwarepreservation.org/projects/prolog/`.

(7) cf. annexe.

A narrative of the beginnings of Artificial Intelligence in France

This volume is a collection of testimonies and scientific papers on AI topics developed or inspired by Alain Colmerauer, reflecting different aspects of AI research since the late 1960s. This in itself makes it original compared with other already published scientific tributes. The combination of scientific papers and testimonies provides a lighting that is rarely found in scientific publications.

Organisation of contributions to this volume

We have chosen to group the texts into four parts, as follows:

(1) Prolog and Logic Programming
(2) Constraint Programming
(3) The future of Logic Programming
(4) Artificial intelligence in Marseilles and testimonies

Part 1: Prolog and Logic Programming

This first part brings together four contributions setting out the scientific and industrial issues surrounding the birth of Logic Programming. The first contribution, by Robert Kowalski, looks at the scientific background to Prolog's emergence. The second contribution, by Jean Rohmer, examines the industrial context in which Prolog was successfully used. The next two contributions, by Christian Boitet and Véronica Dahl respectively, discuss different aspects of Prolog's interest as a theoretical and practical tool for natural language processing.

Robert Kowalski is emeritus professor at Imperial College London. Logician and computer scientist, his early research focused on the automatic proof of theorems, in particular SL-resolution. Invited to Marseilles by Alain Colmerauer in 1971, then in 1972 their fruitful collaboration gave birth to logic programming. His paper looks at the beginnings of Artificial Intelligence research in Europe, in particular the work based on a declarative approach to knowledge representation and problem solving that preceded the emergence of Prolog. He then recalls the exchanges and the complementary nature of their contributions, which gave rise to Logic Programming.

Jean Rohmer is engineer and president of the Fredrik Bull Institute. He has led the Bull Group's research, development and marketing activities in Artificial Intelligence. His research has focused on parallel machines, database management and logic programming. He became aware of Alain Colmerauer's work in the early 1980s when French industry became interested in Prolog following the choice of this language for so-called 5th generation computers. His paper examines the context in which Prolog was born and evolved from an industrial, economic and geopolitical point of view.

Christian Boitet is emeritus professor at Grenoble Alpes University and is developing his research activities in the field of automatic language processing at the Grenoble Computer Science Laboratory (LIG). He first came across Alain Colmerauer's work on Q-systems during his DEA in 1970 at the CNRS CETA laboratory in Grenoble, then as part of the TAUM[(8)] project. In his paper, he discusses the contributions of Q-systems to automatic translation.

Veronica Dahl is emeritus professor at Simon Fraser University in Vancouver (Canada). Her research interests include logic programming, computational linguistics, deductive databases and bioinformatics. She discovered Artificial Intelligence in Alain Colmerauer's DEA courses and defended her Phd under Alain Colmerauer's supervision at the Université d'Aix Marseille II in 1977. Her paper summarises the research that, since the development of Prolog, has built up the theoretical foundations and tools used to process natural language using logic, the resulting computer applications, and compares them with current approaches in Automatic Language Processing.

Part 2: Constraint programming

This second part brings together three contributions devoted to Constraint Programming, pioneered by Alain Colmerauer. The first contribution, by Olivier Bartheye and Guy-Alain Narboni, presents the use of Prolog III to solve a historical problem in Constraint Programming. The way Prolog II, Prolog III and Porlog IV stem from the resolution of constraints in the form of equations and disequations in the algebra of finite or infinite trees, and the second contribution, by Thi Bich Hanh Dao, deals with the expressiveness of more general constraints in this algebra. The third contribution, by Pascal Van Hentenryck, presents a history of the development of Constraint Programming, highlighting the essential contribution of Alain Colmerauer.

Olivier Bartheye is a lecturer at the Ecole de l'Air in Salon de Provence. His research in Artificial Intelligence focuses on the use of decision-making machines in critical environments and crisis situations. He discovered Artificial Intelligence in Alain Colmerauer's DEA courses and went on to defend his Phd in 1994 at the University of Aix-Marseille II, under Alain Colmerauer's supervision. Guy-Alain Narboni is an engineer, director of the Implexe company in Marseilles and chairman of the Prolog Héritage association. He discovered Artificial Intelligence at the end of his studies at Polytechnique in the Ecole d'application des Ponts during Jean-Louis Laurière's DEA courses, then at the Turing Institute in Scotland. He worked with Alain Colmerauer when he joined the Prologia company as Scientific Director. The aim of their paper is to illustrate the power of constraint programming by means of a concrete problem: filling a rectangle with squares of different sizes, and presenting the elegant solution proposed by Alain Colmerauer in Prolog III.

Thi Bich Hanh Dao is a lecturer at the University of Orléans. Her research activities focus on constraint programming, data mining and the integration between these two fields within the Laboratoire d'Informatique Fondamentale d'Orléans (LIFO). She defended her Phd under the supervision of Alain Colmerauer in 2000 at the University of Aix-Marseille II. Her paper deals with first-order constraints in the algebra of finite or infinite trees. Pascal Van Hentenryck holder of the A. Russell Chandler III, is professor

[(8)]Traduction Automatique à l'Université de Montréal.

at the Georgia Institute of Technology in Atlanta, USA. He is credited with pioneering advances in constraint programming and stochastic optimisation, combining theory and practice to solve real-world problems in a variety of fields. He first met Alain Colmerauer at the 1990 Logic Programming conference. Alain Colmerauer then invited him to Marseilles on several occasions, in particular for a sabbatical year in 1994. His article retraces the beginnings of constraint programming, highlighting the central role played by Alain Colmerauer.

Part 3 : The future of Logic Programming

This third part brings together two contributions dealing with developments in Logic Programming following the work developed by Alain Colmerauer on Prolog. The first contribution, by Henri Prade, points out the links between Logic Programming and Knowledge Representation, paving the way for a semantics more closely linked with Knowledge Representation for Logic Programming. The second contribution, by Belaid Benhamou, Vincent Risch and Eric Würbel, presents the evolution of the treatment of negation in Logic Programming, starting with the incorporation of the *cut* mechanism into Prolog, in the context of a purely declarative semantics allowing the effective implementation of non-monotonic reasoning.

Henri Prade is emeritus CNRS director of Research at the Institut de Recherche en Informatique de Toulouse (IRIT), for several decades working on information representation and reasoning in the presence of uncertainty, incoherence or missing information. In particular, he contributed to develop possibility theory, a missing link between logic and probability, and to propose a new approach to analogue reasoning. His paper highlights some of the points of convergence between work in logic programming aimed at controlling and implementing classical logic, and studies in knowledge representation aimed at increasing the expressiveness of classical logic, with both research streams moving beyond classical logic.

Belaid Benhamou, professor at Aix Marseille University, Vincent Risch and Eric Würbel, lecturers at Aix Marseille University and members of the Laboratoire d'Informatique et Systèmes (LIS), all attended Alain Colmerauer's DEA courses and defended their Phd at Aix Marseille I University in 1993, Aix Marseille II University in 1993 and Aix Marseille I University in 2000 respectively. They are developing their research activities in the fields of knowledge representation, reasoning and AI algorithms. Their paper presents the evolution of logic programming through the problematic linked to the introduction of negation in Prolog, leading to a new logic programming paradigm succeeding Prolog and called "Answer Set Programming" (ASP).

Part 4: Artificial Intelligence in Marseilles and testimonies

This final part brings together five contributions. The first, by Odile Papini, provides some historical background to the development of Artificial Intelligence in Marseille. The next four contributions, by Marc Bergman, Henry Kanoui, Jean Trudel and Colette Colmerauer respectively, are testimonies from colleagues who recall Alain Colmerauer in the academic context they shared with him. The fourth and final contribution is a more intimate account written by Colette Colmerauer. Odile Papini is emeritus professor at Aix Marseille University. She discovered Artificial Intelligence at the GIA[9] in 1987, when she was hired as a lecturer at the University of Aix Marseille II. She developed her work in the field of knowledge representation and reasoning, in particular on belief change in the context of classical logic and, from 2000 onwards, in the context of the ASP formalism. Her article provides some historical background on the beginnings of the development of AI research, teaching and technology transfer in Marseilles following the arrival of Alain Colmeraueur.

Marc Bergman was one of the first computer science teachers in Marseilles. In 1970, he welcomed Alain Colmerauer to the Luminy campus in Marseilles. He developed research in Artificial Intelligence on automatic demonstration following the Phd he defended in 1973 under Alain Colmerauer's supervision. He was head of the training department at the International Institute of Robotics and Artificial Intelligence in Marseilles (IIRIAM), founded in 1984. In his testimony, he recalls the Alain Colmerauer's arrival in Marseilles and the beginnings of GIA.

Henry Kanoui discovered artificial intelligence in Alain Colmerauer's lectures during his DEA in 1971–1972. He then defended his Phd in 1973 under the supervision of Alain Colmerauer and developed his research activity around the development of Prolog. He took part in the adventure of the Centre Mondial before managing the Prologia company in its early days. He then joined the International Institute of Robotics and Artificial Intelligence in Marseille (IIRIAM), where he headed the research department, before returning to Aix Marseille University in 1997 to join ESIL, which he headed from 2008 to 2012. In his testimony, he recalls the years he spent with Alain Colmerauer at the Centre Mondial.

Jean Trudel discovered Artificial Intelligence during his Master's lectures with Martin Davis. He then studied with Alain Colmerauer during his Phd at the Université de Montréal. In 1971 he won a research grant from Hydro-Quebec to join the Marseilles' team led by Alain Colmerauer. His testimony relates his stay in Marseilles.

Colette Colmerauer is a linguist, lecturer at the University of Aix Marseille II, and the wife of Alain Colmerauer. A key figure on language issues, she has been with him throughout his career. Her testimony recounts the conditions of their arrival in Marseilles.

Epilogue

The scope and originality of Alain Colmerauer's contributions to the nascent paradigm of symbolic AI at the end of the twentieth century are remarkable: on the one hand because of the variety of theoretical problems he tackled and for which he proposed particularly elegant formal solutions, and on the other because of his constant concern to put these solutions into practice. On the formal side, we can mention: Q-systems,

[9] Groupe d'Intelligence Artificielle.

unification, metamorphosis grammars, the Prolog machine, tree algebra, the framework for representing and processing constraints, the complexity of universal programs, etc. The concrete applications part covers directly: TAUM, the implementation of successive versions of Prolog, their production through the company *Prologia* created for this purpose... and indirectly numerous applications based on the use of Prolog carried out on an industrial scale in France and abroad. This ongoing dialogue between theory and practice, which is relatively unusual in the French academic landscape, has proved fruitful in more ways than one, not only because these two areas have mutually enriched the work carried out by Alain Colmerauer as part of a profoundly coherent vision of his discipline, but also because they have given rise to new paradigms of study which have been taken up by other researchers.

It is also striking to note the extent to which the concerns that determined the direction of the work carried out by Alain Colmerauer are at the heart of the scientific revolution that has been taking place in Artificial Intelligence in recent years. Recent projects that are well known to the general public - translators such as DeepL and language models such as ChatGPT - have been developed as part of the numerical approaches to AI based on learning algorithms, and reflect the concerns that guided the creation of TAUM as well as the development of Prolog. These approaches, which are distinguished by the general scope of the processing they are capable of performing on language, nevertheless seem unable to avoid an alliance with symbolic methods when the question of a representation of reasoning arises. In this direction, the milestones set by Alain Colmerauer indicate a horizon that remains to be explored.

The purpose of this special issue of ROIA is to attempt to show how Alain Colmerauer's scientific thinking has profoundly influenced many of the contemporary issues addressed by AI. to show how Alain Colmerauer's scientific thinking has profoundly influenced many of the contemporary issues addressed by AI. We hope that this introduction will encourage readers to read the articles in this special tribute issue and enable them to recall or discover Alain Colmerauer's essential contribution to symbolic approaches to AI, as shown by the contributions presented at the symposium on 50 years of Prolog organised by the Association for Logic Programming (ALP, `https://logicprogramming.org/`) and *Prolog Héritage* (`http://prolog-heritage.org/`) in November 2022. Readers can also watch the documentary "Alain Colmerauer: the Prolog adventure" (`https://www.youtube.com/watch?v=74Ig_QKndvE`).

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Appendix: List of the 52 PhD theses defended under the supervision of Alain Colmerauer at the Aix Marselle Université

(1) Ph. Roussel. Définition et traitement de l'égalité formelle en démonstration automatique, thèse de 3e cycle, mai 1972.
(2) R. Pasero. Représentation du français en logique du premier ordre en vue de dialoguer avec un ordinateur, thèse de 3e cycle, mai 1973
(3) H. Kanoui. Application de la démonstration automatique aux manipulations algébriques et à l'intégration formelle sur ordinateur, thèse de 3e cycle, octobre 1973.
(4) M. Bergman. Résolution par la démonstration automatique de quelques problèmes en intégration symbolique sur calculateur, thèse de 3e cycle, octobre 1973.
(5) M. Joubert. Un système de résolution de problèmes à tendance naturelle, thèse de 3e cycle, février 1974.

(6) J. Gispert. Étude de l'optimisation et réalisation d'un éditeur de textes paginés, thèse de 3e cycle, juin 1975.
(7) G. Battani. Mise en œuvre des contraintes phonologiques, syntaxiques et sémantiques dans un système de compréhension automatique de la parole, thèse de 3e cycle, juin 1975.
(8) H. Meloni. Mise en œuvre des contraintes phonologiques, syntaxiques et sémantiques dans un système de compréhension automatique de la parole, thèse de 3e cycle, juin 1975.
(9) J. Guizol. Synthèse du français à partir d'une représentation en logique du premier ordre, thèse de 3e cycle, octobre 1975.
(10) V. Dahl. Un système déductif d'interrogation de banques de données en espagnol, thèse de 3e cycle, novembre 1977.
(11) M. Rodriguez. Un système patient d'Aide à la conception JOB, thèse de 3e cycle, octobre 1978. (En grande partie dirigée par Ph. Roussel.)
(12) Ph. Donz. Une méthode de transformation et d'optimisation de programmes Prolog. définition et implémentation, thèse de 3e cycle, juin 1979.
(13) P. Sabatier. Dialogues en Français avec un ordinateur, thèse de 3e cycle, juin 1980. (En grande partie dirigée par R. Pasero.)
(14) Ch. Giraud. Logique et conception assistée par ordinateur, thèse de 3e cycle, mai 1980.
(15) L. Périchaud. Consultation en français d'une banque de données sur fichier et mise en place du système Prolog nécessaire, thèse de 3e cycle, avril 1981.
(16) J. F. Pique. Sur un modèle logique du langage naturel et son utilisation pour l'interrogation des banques de données, thèse de 3e cycle, décembre 1981.
(17) P. Siegel. La saturation au secours de la NonMonotonie, thèse de 3e cycle, mai 1981.
(18) G. Bossu. La saturation au secours de la NonMonotonie, thèse de 3e cycle, mai 1981.
(19) H. Méloni. Étude et réalisation d'un système de reconnaissance automatique de la parole continue, thèse d'État, février 1982.
(20) J. P. Parcy. Un système expert en diagnostic sur réacteurs à neutrons rapides, thèse de 3e cycle, septembre 1982.
(21) M. Hileyan. Modélisation des fins de parties d'échecs, thèse de 3e cycle, septembre 1982.
(22) M. Van Caneghem. L'Anatomie de Prolog II, thèse d'État, octobre 1984.
(23) H. Garetta. Un compilateur Modula II écrit en Prolog, thèse de doctorat, juin 1985.
(24) S. Himbault. Un système expert en diagnostic de panne pour un réacteur nucléaire à neutrons rapides, thèse de doctorat, octobre 1985.
(25) C. Sedogbo. De la grammaire en chaîne du français à un système de questions-réponses, thèse d'État, juin 1987.
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