

MID-CBR: An Integrative Framework for Developing Case-based Reasoning Systems

TIN2006-15140-C03

Enric Plaza *

IIIA - Consejo Superior de Investigaciones Científicas

Belén Díaz Agudo †

GAIA - Universidad Complutense de Madrid

Elisabet Golobardes ‡

GRSI - Universitat Ramon Llull

Abstract

Case-based reasoning (CBR) combines in an effective manner both learning from examples and usage of domain knowledge. Techniques for case retrieval and reuse should not be studied in an isolated manner; instead they should be designed and evaluated in a framework that integrates different types of CBR systems as proposed in this project.

Keywords: Case-based reasoning, lazy learning, soft computing, knowledge-intensive CBR systems, ontologies.

1 Project Goals

The main objectives of the project can be summarized as follows: (i) new ways to use techniques of soft computing for CBR, (ii) techniques for case reuse of a declarative and generic nature, (iii) techniques for case retrieval in knowledge-intensive CBR systems, (iv) integrating ontologies both in CBR systems and retrieval and reuse techniques (v) maintenance techniques both for case bases and for CBR systems capable of dealing with issues arising from design, implementation, and deployment of industrial strength CBR systems, including the empirical evaluation of the developed techniques by means of CBR prototypes implemented for several experimental domains, and (vi) developing component-based software platforms to support CBR systems development.

These goals are pursued by the tasks and subtasks of Figure 1, that also shows their time schedule and the output (Report or Software). These tasks organize the research activity

*Email: enric@iia.csic.es

†Email: belend@sip.ucm.es

‡Email: elisabet@salleURL.edu

DURATION
 Report
 Software

Resp	Task	Subtask		T01	T02	T03	T04	T05	T06	T07	T08	T09	T10	T11	T12
EG	Task1 Retrieval	1-1	Data Intensive Retrieval												
		1-2	Knowledge Intensive Retrieval												
		1-3	Dynamic Environment Retrieval												
		1-4	Textual Case Retrieval												
EP	Task2 Reuse	2-1	Configuration Reuse												
		2-2	Planning Reuse												
		2-3	Dynamic Environment Reuse												
BDA	Task3 Maintenance & Development	3-1	Components												
		3-2	Maintenance												
		3-3	Evaluation												
EP	Task4 Coord. & Evaluation	4-1	Coordination												
		4-2	Prototype Evaluation												
		4-3	EPO Relationship												

Figure 1: Schedule of tasks and subtasks.

around types of techniques. These techniques are empirically tried out and evaluated in specific domains of application.

2 Achievement Degree of Project Goals

Concerning Subtask 1.1 (Data Intensive Retrieval), there has been a strong collaboration between the teams IIA-CSIC and GRIS-URL, specially on the melanomas domain in cooperation with our EPO (external observer company), the Barcelona Clinic Hospital. We have studied the combination of Self-Organizing Maps (SOM) for clustering cases and organizing cases bases together with induction of their symbolic descriptions. This approach has been applied both to the melanomas domain and the intrusion detection domain, developed in collaboration with ISECOM, another EPO. Moreover, a methodology for helping expert how to efficiently perform the case retrieval from clustered case memory has been defined according to the data complexity and the performance desired. Finally, many works related to the automatic definition of similarity functions and cooperation schemes have been studied in order to improve the reliability of results in complex domains.

Concerning research in Knowledge Intensive Retrieval (Subtask 1.2) we have proposed a set of methods based on the recent DLs technological improvements. These ontology based retrieval methods have been used in different application domains. Namely, component configuration for templates retrieval, teaching for retrieval of behaviours, retrieval in case based planning and retrieval of recipes in the ICCBR-08 Computing Cooking Contest. Moreover, using argumentation in a setting with multiple CBR agents allows to elucidate the most relevant

cases to be retrieved in a way that is both explicit and declarative. Concerning Textual and Conversational CBR (Subtask 1.4.) the novelty of our research is an approach to user-guided adaptation of texts based on combining IR techniques and clustering techniques. Concerning conversational CBR we have defined the model COBBER, that is based on ontologies and affective models to react to the user mood while interacting with the system.

Concerning research Retrieval and Reuse in Dynamic Environments (Subtasks 1.3 and 2.3), it has been focused on improving robot decision making in the RoboCup setting. Using CBR improved the previous strategy developed by Carnegie-Mellon University with which we've been collaborating. It's worth noting the contribution to Retrieve techniques (by exploiting world symmetries) and to Reuse techniques (by adapting the outcome to the perceived situation and taking into account adaptation cost), as well as intensive experimentation with real robots.

Concerning Subtask 3.1.(Developing component-based software platforms to support CBR systems development) we have developed a new 2-layered architecture for jCOLIBRI 2. The top layer partially automates the generation of CBR systems through the composition of the elements in the framework. This composition is guided by templates that abstract the behavior of CBR systems and can be instantiated with the different components of the bottom layer. Concerning the Subtask 3.2, the design and maintenance of Case-Based Reasoning systems, we have investigated the use of introspective reasoning to improve the performance of Case-Based Reasoning (CBR) systems, in both reactive and proactive fashion, by guiding learning to improve how a CBR system applies its cases and by identifying possible future system deficiencies. We have also performed a case study on a library of templates to prototype Recommender Systems and we plan to extend it to other types of CBR systems. Moreover, following the idea of working with cluster case-base memories, we have been working with the maintenance of this kind of organizations. Concerning Subtask 3.3, Evaluation techniques for CBR systems, we have studied and analyzed the related works in this area in order to propose an experimental methodology for allowing non experts in this topic the statical analysis of results of their machine learning systems.

Concerning Task 4.1 (Coordination) the organization of yearly plenary workshops in addition to task-specific meetings convened by the responsible researcher has worked as established in the project proposal. Regarding Prototypes evaluation (Subtask 4.1) jCOLIBRI 2 is available from August 2007 and has been downloaded 5000 times from more than 70 different countries. Our next goal now is to get contributions from other CBR researchers. There are also some commercial applications using jCOLIBRI, namely *KoBas: knowledge management system* built by the consultants Wittmann & Partner in Rumania; and EMEF (Portuguese Railway Company) gave its *1st R&D Award* to an intelligent system for failure diagnostics developed in collaboration with the University of Porto. Concerning relationship with external observer companies we have had a fluid collaboration and a satisfactory feedback from them, resulting in research actives that have lead to publications in the domains of medicine (melanoma analysis with the Barcelona Clinic Hospital), music personalization (with MusicStrands.com) and computer network intrusion (with ISECOM).

3 Assessment of Project Outcome

Concerning Task 4.1 (Coordination), we remark that the annual plenary workshop in addition to task-specific meetings has worked satisfactorily in creating synergies and team cohesiveness.

3.1 Assessment of IIIA-CSIC Project Outcome

Concerning Subtask 1.1 (Data Intensive Retrieval), one of our focus has been generating explanation to the user of the CBR system: in [3] we analyzed several usages of generalization commonly done in both lazy and eager learning methods. An application of generalizations as explanation of the retrieval was that introduced in [2] where the goal was to explain the classification of chemical compounds as carcinogenic and no carcinogenic. This application was specially useful since because the classification of carcinogenic compounds is not clear, experts can use the explanations to decide the final classification of a compound. An extension of this work was also published in [7]. In [4] we proposed to store the explanations and use them as partial concept descriptions. A second focus, in collaboration with GRSI-URL, we analyzed the combination of SOM and cluster explanations on standard domains (such as those of the UCI Repository) [23]. This approach was applied to the domain of detecting intrusions in a computer network [14], and showed that the experts could better understand the system with the symbolic explanation of clusters [15]. These approach was applied to the classification of *melanoma in situ* of the Barcelona Clinic Hospital, using CBR to help discover new ways to cluster data [25] and proposing new ways to classify them [5, 6]. Finally, we have proposed a new research line on how to reuse human experience available through the web in [55, 56].

Concerning Task 1.2 (Knowledge Intensive Retrieval), we have focused on the improvement of the retrieval process using an argumentation framework in a multi-agent setting. Our work show that agents that can justify (explain symbolically) their prediction can engage in argumentation over the correctness of possible solutions, the reasons pro and against, and the counter-examples that support such discussions; as a result we showed that (1) the individual CBR agents can learn from the argumentation with very few examples and (2) both the individual and group accuracy improves when using argumentation [12, 50, 49, 51, 52, 53, 37, 57].

Concerning research Retrieval and Reuse in Dynamic Environments (Subtasks 1.3 and 2.3), international relationship has been embodied in a strong cooperation with the RoboCup team of Manuela Veloso at Carnegie Mellon University, while the contributions have been rise to 1 finished PhD (Raquel Ros, March 1st 2008, “Action Selection in Cooperative Robot Soccer using Case-Based Reasoning”) and 1 PhD in the writing (Arnau Ramisa), both supervised by R. López de Mántaras. Several scientific publications report this research in competitive international conferences [78, 77, 74, 71, 60, 61, 62] (including the best conference paper award for [78]) and in two journals [76, 75].

Concerning Task 2.1, Reuse for configuration tasks, we have studied, in collaboration with GAIA-UCM, the use of declarative reuse techniques like *constructive adaptation* for *originality-driven tasks* (ODT)[20] — i.e. for tasks where a solution has to be a novelty when compared to preexisting ones. We showed that *constructive adaptation* improves novelty over classical *transformational adaptation* techniques. Concerning Task 2.2 (Reuse for planning and scheduling) we have focused on developing techniques that customize a sequential solution to a group of users. Specifically we worked in collaboration with our EPO MusicStrands on the domain of musical programming, developing *Poolcasting*, an *automatic DJ* that schedules songs customized to the tastes of the members of an audience [8, 9, 10, 11, 54]. The *Poolcasting* generalizes the concept of “case reuse” to include the target of the solution (i.e. the audience) and for this reason received the *Best CBR Application Paper Award* at the 2008 Int. Conf. on Case-Based Reasoning [8]. Claudio Baccigalupo’s Ph.D. is expected to be defended In June 2009 at the Univesitat Autònoma de Barcelona.

Concerning the Task 3, the design and maintenance of Case-Based Reasoning systems, the goals of the task have been achieved according to the working plan: The proactive method is the core of the CB-Inspector prototype [43, 44, 45], and has been applied to the RoboSoccer domain (Subtasks 1.3 and 2.3) and showed how founding dubiousity regions helped us to analyze the case-base of that CBR system. The reactive model has been successfully incorporated in to the Auto-CBR prototype. We have shown our model's benefits with experimental results from tests in an industrial design application ([1]). Both methods have been published at international research forums. The introspective model, developed with collaboration of Prof. David Leake (Indiana University, USA), will be described in a chapter of the book "Metareasoning: Thinking about Thinking" (The MIT Press). The PhD student Oguz Mulayim has achieved the DEA degree in 2008 [42].

3.2 Assessment of GAIA-UCM Project Outcome

The main results from the UCM group have been built around jCOLIBRI 2, an object-oriented framework in Java for building CBR systems based on the reuse of previously developed CBR systems components. The first version of jCOLIBRI [70] is a complete CBR development architecture supporting many features like graphical interfaces, Description Logics and ontologies, Textual CBR, evaluation, among others. The complete work has been published in [19]. jCOLIBRI 2 defines a two-level architecture. The *bottom layer* is oriented to java developers and provides an architecture that is able to integrate diverse CBR reusable methods in a library. This layer provides the basic blocks for building CBR systems that can be easily extended and reused by programmers. jCOLIBRI 2 was released in August 2007 and since then it has served as the integration framework to develop CBR systems, has allowed the integration of different research lines, has been the main diffusion way for our research results and the way to collaborate with other national and international research groups that have incorporated new methods to the framework.

Concerning Subtask 1.2 (Knowledge Intensive Retrieval) see [68] and [18] for a detailed description of the main knowledge intensive retrieval techniques based on DLs technology. These new methods are available in jCOLIBRI2. We have also research on the use of knowledge intensive methods to help reasoning to build natural language interfaces to CBR systems [21]. These methods have been applied in different domains. Namely templates retrieval [64, 67], retrieval of videogame behaviours represented as state machines [58, 59], retrieval in case based planning [80], and retrieval of recipes in the computing cooking contest [17].

Concerning Subtask 1.4 Textual CBR (TCBR) the work of the UCM group in textual CBR has been built in collaboration with Nirmalie Wiratunga and her group from Robert Gordon University in Scotland. In [65] the CBR textual methods have been used in Challenger 1.0 a TCBR application that addresses the Air Investigation Reports challenge proposed in the ICCBR 2007 workshop program. Textual methods have been also used in the Computer Cooking Contest application [17], and in a tutor system to answer questions in the videogame JV2M. Contributions regarding conversational CBR are the main result of the Ph.D. thesis of Hector Gomez Gauchia [38] on COBBER, a model and an architecture to design conversational systems [39].

Research in Subtask 2.1 (reuse in case based configuration) builds upon previous work of the IIIA and the UCM groups. As the main contribution in this subtask we have studied the reuse task in CBR systems from the result originality point of view. The work presented

in [20] analyzes the role of reuse in CBR systems in *originality driven tasks* (ODT). These reuse methods have also been applied in two experimentation domains: reuse of semantic web services [69, 72, 36, 73], and templates based design domain [64, 67].

Concerning Subtask 2.2 (Reuse in planning and scheduling) we have studied how well tested and reusable knowledge and techniques from the Knowledge Representation arena can be integrated into a hierarchical planner. As the experimentation domain we have used strategy board games [80] and composition of Semantic Web Services [79]. The former has been built in collaboration with Hector Mu-oz Avila and his group from University of Leigh in Maryland (USA), as the result of a three months visit from the UCM researcher (Antonio Sanchez Ruiz-Granados) to Leigh by February to April 2007. In [81] we have proposed a method of adaptation through Planning in Knowledge Intensive CBR and have applied this method in the teaching domain using games to retrieve and reuse exercises for a student taking into account the student characteristics and his/her previous knowledge.

jCOLIBRI 2 is an object-oriented framework in Java for building CBR systems based on the reuse of previously developed CBR systems components. A large effort of GAIA-UCM has been devoted to developing component-based software platforms to support CBR systems development (Subtask 3.1) based on jCOLIBRI 2 (presented in December 2008 as the Phd Thesis of Juan Antonio Recio García [63]). A CBR ontology is used to formalize syntactical, semantical and pragmatical aspects of the reusable components of the framework [67]. In [64, 66] we have presented our work on template based design of CBR systems using as case study the prototyping of Recommender Systems in jCOLIBRI. Recommender Systems Templates have been built in collaboration with professor Derek Bridge, from University College Cork in Ireland as the result of a two months visit of the UCM researcher Juan A. Recio-Garcia to Cork University (Ireland).

3.3 Assessment of GRSI-URL Project Outcome

Concerning Task 1.1 (Data Intensive Retrieval), we have focused on the context of classification problems where the cases are complex, with imprecise knowledge and with large case bases, that is, in problems with the traditional methods may not offer the expected results. For this reason, we have tackled this issue from the point of view of soft-computing because this kind of techniques allow a better management of knowledge than traditional hard computing techniques. On the one hand, we have used the searching capabilities of Genetic Programming and Grammar Evolution with the aim of automatically defining similarity functions ad hoc a domain. This is specially useful for domains where the conventional distances do not offer the expected results due to the domain geometry and/or its structure [28, 27]. The same idea has been applied for defining case retrieval strategies from ensemble systems [30] and in a more knowledge intensive approach using the melanoma domain of the HCPB [48, 47]. On the other hand, we have worked with Self-Organizing Maps in order to organize the case memory in clusters and, consequently, try to take profit from the patterns identified in order to use only the potentially useful cases. Although this should reduce the computational time without reducing the accuracy, the data complexity may difficult the pattern identification and system could not find the right solutions. This problematic has motivated the definition of a methodology for helping expert to decide how many clusters and cases have to be used according to the data complexity in order to achieve the desired performance in terms of time and accuracy [34, 35, 31, 32, 41, 40, 22]. The mechanisms used to assess the data geometry are

the complexity measures. This work promoted the relation with IIIA-CSIC as the section 3.1 described for generating symbolic explanations in order to help expert to understand better the case retrieval results in the melanoma domain [23, 25, 26, 22] and in the telematic domain [15, 34, 14, 16]. Moreover, we have also worked in defining new case retrieval strategies based on symbolic descriptions [24] and in how to improve the reliability of the reuse phase through the definition of confidence levels from the patterns [33]

Concerning Task 3.2 (Maintenance), the work has been developed at the same time than Task 1.1 due to the closer relation with the cluster case-based organization. In this sense, we have worked in the maintenance of the case memory in terms of allowing the incremental and semisupervised learning in SOM [29] even this technique does not allow it. Most of the precedent tasks in the project imply the development of new methodologies in the different phases of a CBR system. Although the project is focused on the development of these methodologies, it seems obvious that a test of the results obtained on well-known cases and new proposed problems is needed. For this reason, we have defined an experimental methodology for analyzing the results of machine learning systems based on the different types of experiments and statistics test [41]. All this work is placed in the context of the Task 3.3 (Evaluation). Concerning Task 4.2 (Evaluation prototypes), we have started to work with UCM for integrating all the cluster case-based algorithms inside the framework jCOLIBRI developed by them. Concerning Task 4.3 (EPO Relationship), the cooperation with both EPOs, ISECOM and HCPB, has been a successful because many works have been done in cooperation. Moreover, the results are positive because many works have been accepted in conferences and journals related to the telematic domain [15, 14, 16, 34] and the melanoma domain [82, 48, 47, 25, 26] along 2008. Moreover, the relation with the HCPB and ISECOM has deep contributed to the delivering of two DEAs [46, 13] and one Ph.D. will be presented in the next months.

References

- [1] J. L. Arcos, O. Mulayim, and D. Leake. Using introspective reasoning to improve CBR system performance. In M. T. Cox and A. Raja, editors, *AAAI Metareasoning Workshop*, pages 21–28. AAAI Press, AAAI Press, 2008.
- [2] E. Armengol. Discovering plausible explanations of carcinogenecity in chemical compounds. In P. Perner, editor, *Proc. Machine Learning and Data Mining MLDM-2007*, volume 4571 of *Lecture Notes in Artificial Intelligence*, pages 756–769. Springer, 2007.
- [3] E. Armengol. Usages of generalization in CBR. In R. Weber and M. M. Richter, editors, *Case-Based Reasoning Research and Development, ICCBR-07*, number 4626 in *Lecture Notes in Artificial Intelligence*, pages 31–45. Springer-Verlag, 2007.
- [4] E. Armengol. Building partial domain theories from explanations. *Künstliche Intelligenz*, 8(2):19–24, 2008.
- [5] E. Armengol. How to use explanations for knowledge discovery. In E. Hüllermeier, M. Richter, R. Weber, K. Bach, and M. Petridis, editors, *Procs. of Workshop on Uncertainty, Similarity and Knowledge Discovery of ECCBR*, pages 119–130. Tharax Verlag, Martin Schaaf, 2008.
- [6] E. Armengol. Knowledge discovery with explained case-based reasoning. In T. Alsinet, J. Puyol-Gruart, and C. Torras, editors, *Artificial Intelligence: Research and Development (CCIA-2007)*, pages 151–160. IOS Press, 2008.
- [7] E. Armengol. Using explanations for determining carcinogenecity in chemical compounds. *International Journal on Engineering Applications of Artificial Intelligence*, In press, 2008.

- [8] C. Baccigalupo and E. Plaza. A case-based song scheduler for group customised radio. In R. Weber and M. M. Richter, editors, *Case-Based Reasoning Research and Development, 7th International Conference on Case-Based Reasoning, ICCBR 2007*, volume 4626 of *Lecture Notes in Artificial Intelligence*, pages 433–448. Springer, 2007.
- [9] C. Baccigalupo and E. Plaza. Mining music social networks for automating social music services. In *Proc. ECML/KDD-07 Workshops Prior Conceptual Knowledge in Machine Learning and Data Mining and Web Mining 2.0*, pages 123–134, 2007.
- [10] C. Baccigalupo and E. Plaza. Poolcasting: a social web radio architecture for group customisation. In J. Delgado, K. Ng, P. Nesi, and P. Bellini, editors, *Third International Conference on Automated Production of Cross Media Content for Multi-Channel Distribution (AXMEDIS'07)*, pages 115–122. IEEE Computer Society, 2007.
- [11] C. Baccigalupo and E. Plaza. Sharing and combining listening experience: A social approach to web radio. In *Proceedings of the 2007 International Computer Music Conference, ICMC 2007*, pages 228–231. Suvisoft Oy Ltd, 2007.
- [12] R. Bergmann, J. Kolodner, and E. Plaza. Representation in case-based reasoning. *Knowledge Engineering Review*, 20:209–213, 2006.
- [13] G. Corral. Dea (Advanced Study Certificate), 2006.
- [14] G. Corral, E. Armengol, A. Fornells, and E. Golobardes. Data security using unsupervised learning and explanations. In E. Corchado, J. Corchado, and A. Abraham, editors, *Innovations in Hybrid Intelligent Systems*, volume 44 of *Advances in Soft-Computing*, pages 112–119. Springer, 2007.
- [15] G. Corral, E. Armengol, A. Fornells, and E. Golobardes. Explanations of unsupervised learning clustering applied to data security analysis. *Neurocomputing*, In Press.
- [16] G. Corral, A. Fornells, E. Golobardes, and J. Abella. Cohesion factors: improving the clustering capabilities of consensus. In *7th International Conference on Intelligent Data Engineering and Automated Learning*, volume 4224 of *LNCS*, pages 488–495. Springer-Verlag, 2006.
- [17] J. DeMiguel, L. Plaza, and B. Díaz-Agudo. ColibriCook: A CBR system for ontology-based recipe retrieval and adaptation. In *ECCBR Workshops 2008*, pages 199–208, 2008.
- [18] B. Díaz-Agudo and P. Gonzalez-Calero. *Ontologies: A Handbook of Principles, Concepts and Applications in Information Systems*, chapter An Ontological Approach to Develop Knowledge Intensive CBR Systems, pages 173–214. Springer, ISBN: 0-387-37019-6, September 2007.
- [19] B. Díaz-Agudo, P. A. González-Calero, J. A. Recio-García, and A. S. Ruiz-Granados. Building CBR systems with jCOLIBRI. *Special Issue on Experimental Software and Toolkits of the Journal Science of Computer Programming*, 69(1-3):68–75, 2007. Impact Factor 0.734 Journal Citation Reports® 2005, published by Thomson Scientific.
- [20] B. Díaz-Agudo, E. Plaza, J. A. Recio-García, and J.-L. Arcos. Noticeably new: Case reuse in originality-driven tasks. In K. D. Althoff, R. Bergmann, M. Minor, and A. Hanft, editors, *Advances in Case-Based Reasoning: 9th European Conference, ECCBR 2008*, volume 5239 of *Lecture Notes in Artificial Intelligence*, pages 165–179. Springer Verlag, 2008.
- [21] B. Díaz-Agudo, J. A. Recio-García, and P. A. González-Calero. Natural language queries in CBR systems. In *19th IEEE International Conference on Tools with Artificial Intelligence (ICTAI 2007), October 29-31, 2007, Patras, Greece, Volume 2*, pages 468–472. IEEE Computer Society, 2007.
- [22] A. Fornells. *An Integrative Framework for Integrating the Soft-Computing and Knowledge Discovery Capabilities of Self-Organizing Maps in a Case-Based Reasoning System*. PhD thesis, Ingeniería i Arquitectura La Salle, 2007.

- [23] A. Fornells, E. Armengol, and E. Golobardes. Explanation of a clustered case memory organization. In C. Angulo and L. Godo, editors, *Artificial Intelligence: Research and Development (CCIA-2007)*, pages 153–160. IOS Press, 2007.
- [24] A. Fornells, E. Armengol, and E. Golobardes. Retrieval based on self-explicative memories. In *9th European Conference on Case-Based Reasoning*, volume 5239 of *LNAI*, Springer-Verlag, pages 210–224. Lecture Notes in Computer Science, Springer-Verlag, 2008.
- [25] A. Fornells, E. Armengol, E. Golobardes, S. Puig, and J. Malveyh. Experiences using clustering and generalizations for knowledge discovery in melanomas domain. In P. Perner, editor, *Advances in Data Mining, Proc. ICDM 2008*, volume 5077 of *Lecture Notes in Computer Science*, pages 57–71. Springer, Springer, 2008.
- [26] A. Fornells, E. Armengol, E. Golobardes, S. Puig, and J. Malveyh. Experiences using clustering and generalizations for knowledge discovery in melanomas domain. *Transactions on Machine Learning and Data Mining*, 1:49–65, 2008.
- [27] A. Fornells, J. Camps, E. Golobardes, and J. Garrell. Comparison of strategies based on evolutionary computation for the design of similarity functions. In *Artificial Intelligence Research and Development*, volume 131, pages 231–238. IOS Press, 2005.
- [28] A. Fornells, J. Camps, E. Golobardes, and J. Garrell. Incorporación de conocimiento en forma de restricciones sobre algoritmos evolutivos para la búsqueda de funciones de similitud. In *IV Congreso Español sobre Metaheurísticas, Algoritmos Evolutivos y Bioinspirados*, pages 397–404. Thomson, 2005.
- [29] A. Fornells and E. Golobardes. Case-base maintenance in an associative memory organized by a self-organizing map. In E. Corchado, J. Corchado, and A. Abraham, editors, *Innovations in Hybrid Intelligent Systems*, volume 44, pages 312–319. Springer-Verlag, 2007.
- [30] A. Fornells, E. Golobardes, E. Bernadó, and J. Martí. Decision support system for breast cancer diagnosis by a meta-learning approach based on grammar evolution. In *8th International Conference on Enterprise Information Systems*, volume 233, pages 222–239. INSTICC Press, 2006.
- [31] A. Fornells, E. Golobardes, J. Martorell, J. Garrell, E. Bernadó, and N. Macià. Measuring the applicability of self-organizing maps in a case-based reasoning system. In *3rd Iberian Conference on Pattern Recognition and Image Analysis*, volume 4478 of *LNCS*, pages 532–539. Springer-Verlag, 2007.
- [32] A. Fornells, E. Golobardes, J. Martorell, J. Garrell, N. Macià, and E. Bernadó. A methodology for analyzing the case retrieval from a clustered case memory. In *7th Int. Conference on Case-Based Reasoning*, volume 4626 of *LNAI*, pages 122–136. Springer-Verlag, 2007.
- [33] A. Fornells, E. Golobardes, J. M. Martorell, and J. M. Garrell. Patterns out of cases using kohonen maps in breast cancer diagnosis. *International Journal of Neural Systems*, 18:33–43, 2008.
- [34] A. Fornells, E. Golobardes, D. Vernet, and G. Corral. Unsupervised case memory organization: Analysing computational time and soft computing capabilities. In *8th European Conference on Case-Based Reasoning*, volume 4106 of *LNAI*, pages 241–255. Springer-Verlag, 2006.
- [35] A. Fornells, E. Golobardes, X. Vilasís, and J. Martí. Integration of strategies based on relevance feedback into a tool for retrieval of mammographic images. In *7th International Conference on Intelligent Data Engineering and Automated Learning*, volume 4224 of *LNCS*, pages 116–124. Springer-Verlag, 2006.
- [36] J. M. Gomez, M. Mencke, J. Chamizo, R. Colomo, and A. Garcia-Crespo. EsaCake: A semantic software environment for sharing software projects knowledge based on the esa software methodology. *Internet and Web Applications and Services, International Conference on*, 0:535–540, 2008.

- [37] M. Gómez and E. Plaza. The orcas e-institution: a platform to develop open, reusable and configurable multi-agent systems. *International Journal of Intelligent Control and Systems*, 12(2):130–141, 2007.
- [38] H. Gomez-Gauchia. *COBBER: Un Enfoque Sistémico, Afectivo y Ontológico para el Razonamiento Basado en Casos Conversacional*. PhD in Computer Science, Universidad Complutense de Madrid. Grupo GAIA, February 2008. Belen Diaz Agudo, Pedro Gonzalez Calero (Supervisors).
- [39] H. Gomez-Gauchia, B. Díaz-Agudo, and P. A. González-Calero. Conversational strategies in cobber: an affective c-cbr framework. *Journal of Experimental & Theoretical Artificial Intelligence*, 18(4):449–469, 2006.
- [40] N. Macià, E. Bernadó, A. Fornells, E. Golobardes, J. Martorell, and J. Garrell. Revisión sobre métricas de complejidad en el modelado de clústers de un sistema CBR. In *V Taller nacional de minería de datos y aprendizaje*, 2007.
- [41] J. Martorell. *Definition of an experimental methodology for analyzing the results of machine learning systems*. PhD thesis, Enginyeria i Arquitectura La Salle, 2007.
- [42] O. Mulayim. Reactive and proactive approaches for introspective CBR. Master’s thesis, Universitat Autònoma de Barcelona, 2008.
- [43] O. Mulayim and J. L. Arcos. Exploring dubious future problems. In M. Petridis, editor, *Twelfth UK Workshop on Case-Based Reasoning*, pages 52–63. CMS Press, University of Greenwich, CMS Press, University of Greenwich, 2007.
- [44] O. Mulayim and J. L. Arcos. Understanding dubious future problems. In D. Althoff, R. Bergmann, M. Minor, and A. Hanft, editors, *Advances in Case-Based Reasoning, ECCBR 2008*, volume 5239 of *Lecture Notes in Artificial Intelligence*, pages 385–399, Trier, Germany, 2008. Springer Verlag.
- [45] O. Mulayim and J. L. Arcos. Predicting dubiousity in CBR systems. *Expert UPDATE*, page (to appear), 2009.
- [46] R. Nicolas. DEA (Advanced Study Certificate), 2008.
- [47] R. Nicolas, E. Golobardes, A. Fornells, S. Segura, S. Puig, C. Carrera, J. Palou, and J. Malveyh. Identification of relevant knowledge for characterizing the melanoma domain. In *2nd International Workshop on Practical Applications of Computational Biology and Bioinformatics (IWPACBB 2008)*, volume 49 of *Advances in Soft-Computing, Springer Berlin - Heidelberg*, pages 55–59, 2008.
- [48] R. Nicolas, E. Golobardes, A. Fornells, S. Segura, S. Puig, C. Carrera, J. Palou, and J. Malveyh. Using ensemble-based reasoning to help experts in melanoma diagnosis. In *Frontiers in Artificial Intelligence and Applications*, volume 184, pages 178–185. IOS Press, 2008.
- [49] S. Ontañón and E. Plaza. An argumentation-based approach to multi-agent learning. In *Proc. The 20th International FLAIRS Conference*, pages 405–410, 2007.
- [50] S. Ontañón and E. Plaza. Arguments and counterexamples in case-based joint deliberation. In N. Maudet, S. Parsons, and I. Rahwan, editors, *Argumentation in Multi-Agent Systems*, volume 4766 of *Lecture Notes in Artificial Intelligence*, pages 36–53. Springer Verlag, 2007.
- [51] S. Ontañón and E. Plaza. Case-based learning from proactive communication. In *Proc. 20th International Joint Conference on Artificial Intelligence (IJCAI 2007)*, pages 999–1004. IJCAI Press, 2007.
- [52] S. Ontañón and E. Plaza. Learning and joint deliberation through argumentation in multi-agent systems. In *Proc. 6th International Joint Conference on Autonomous Agents and Multiagent Systems AAMAS 2007*, pages 971–978. ACM, 2007.

- [53] S. Ontañón and E. Plaza. An argumentation-based framework for deliberation in multi-agent systems. In I. Rahwan, S. Parsons, and C. Reed, editors, *Argumentation in Multi-Agent Systems*, volume 4946 of *Lecture Notes in Artificial Intelligence*, pages 178–196. Springer Verlag, 2008.
- [54] S. Ontañón and E. Plaza. Argumentation-based information exchange in prediction markets. In *Proc. AAMAS-08 Fifth International Workshop on Argumentation in Multi-Agent Systems (ArgMAS 2008)*, Estoril, Portugal, May 12, 2008, pages 111–123, 2008.
- [55] E. Plaza. Semantics and experience in the future web. In K. D. Althoff, R. Bergmann, M. Minor, and A. Hanft, editors, *Advances in Case-Based Reasoning: 9th European Conference, ECCBR 2008*, volume 5239 of *Lecture Notes in Artificial Intelligence*, pages 44–58. Springer Verlag, 2008.
- [56] E. Plaza. On reusing other people’s experiences. *Künstliche Intelligenz*, 9(1):18–23, 2009.
- [57] E. Plaza and L. McGinty. Distributed case-based reasoning. *Knowledge Engineering Review*, 20:261–265, 2006.
- [58] G. F. Puga, B. Díaz-Agudo, and P. A. González-Calero. Experience-based design of behaviors in videogames. In *Advances in Case-Based Reasoning, ECCBR 2008*, volume 5239 of *LNCS*, pages 180–194. Springer, 2008.
- [59] G. F. Puga, M. A. Gómez-Martín, B. Díaz-Agudo, and P. A. González-Calero. Dynamic expansion of behaviour trees. In *Procs of the Fourth Artificial Intelligence and Interactive Digital Entertainment Conference, October 22-24, Stanford, California, USA*. The AAAI Press, 2008.
- [60] A. Ramisa, R. L. de Mántaras, D. Aldavert, and R. Toledo. Comparing combinations of feature regions for panoramic vslam. In *ICINCO-07 4th International Conference on Informatics in Control, Automation and Robotics, Angers, France*, pages 292–297, 2007.
- [61] A. Ramisa, A. Tapus, R. L. de Mántaras, and R. Toledo. Mobile robot localization using panoramic vision and combinations of feature region detectors. In *IEEE International Conference on Robotics and Automation*, pages 538–543, Pasadena, California, 2008. IEEE Press, IEEE Press.
- [62] A. Ramisa, S. Vasudevan, D. Scharamuzza, R. L. de Mántaras, and R. Siegwart. A tale of two object recognition methods for mobile robots. In *6th International Conference on Computer Visions Systems*, volume 5008, pages 353–362, Santorini, Greece, 2008. Springer Verlag.
- [63] J. A. Recio-García. *jCOLIBRI: A multi-level platform for building and generating CBR systems*. PhD in Computer Science, Universidad Complutense de Madrid. Grupo GAIA, December 2008. Belen Diaz Agudo, Pedro Gonzalez Calero (Supervisors).
- [64] J. A. Recio-García, D. G. Bridge, B. Díaz-Agudo, and P. A. González-Calero. CBR for CBR: A case-based template recommender system for building case-based systems. In *Advances in Case-Based Reasoning, ECCBR 2008*, volume 5239 of *LNCS*, pages 459–473. Springer, 2008.
- [65] J. A. Recio-García, B. Díaz-Agudo, and P. A. González-Calero. Textual CBR in jCOLIBRI: From retrieval to reuse. In D. C. Wilson and D. Khemani, editors, *Proceedings of the ICCBR 2007 Workshop on Textual Case-Based Reasoning: Beyond Retrieval.*, pages 217–226, August 2007.
- [66] J. A. Recio-García, B. Díaz-Agudo, and P. A. González-Calero. Prototyping recommender systems in jCOLIBRI. In *Proceedings of the 2008 ACM Conference on Recommender Systems, RecSys 2008*, pages 243–250, 2008.
- [67] J. A. Recio-García, B. Díaz-Agudo, and P. A. González-Calero. Semantic templates for case-based reasoning systems. *Knowledge Engineering Review*, in press, 2008.

- [68] J. A. Recio-García, B. Díaz-Agudo, P. A. González-Calero, and A. Sánchez-Ruiz-Granados. Ontology based CBR with jCOLIBRI. In *Applications and Innovations in Intelligent Systems XIV. Procs of AI-2006, the 26th SGAI Int. Conference on Innovative Techniques and Applications of Artificial Intelligence*, pages 149–162, Cambridge, United Kingdom, December 2006. Springer.
- [69] J. A. Recio-García, J. M. Gomez-Berbis, B. Díaz-Agudo, and P. A. González-Calero. The WINGS of jCOLIBRI: A CBR architecture for semantic web services. *International Journal of Web Services Practices*, 3(1):36–41, 2008.
- [70] J. A. Recio-García, A. Sanchez, B. Díaz-Agudo, and P. A. González-Calero. jCOLIBRI 1.0 in a nutshell. *Expert Update*, 9(2):2–10, 2007.
- [71] A. Ribes, A. Ramisa, R. L. de Mántaras, and R. Toledo. Object-based place recognition for mobile robots using panoramas. In *Artificial Intelligence Research and Development (CCIA-2008)*, volume 184, pages 388–397. IOS Press, 2008.
- [72] I. Rivera, M. Mencke, J. Chamizo, and J. M. Gomez. Suma: A semantic business process management architecture. In *Electronics, Robotics, and Automotive Mechanics Conference (CERMA) 2008*, 2008.
- [73] I. Rivera, M. Mencke, J. M. Gomez, R. Posada-Gómez, and A. Garcia-Crespo. SmartWorld: More than meets the eye in enterprise application integration. *Systems, Second International Conference on*, 0:144–149, 2008.
- [74] R. Ros and J. L. Arcos. Acquiring a robust case base for the robot soccer domain. In M. Veloso, editor, *Proceedings of the 20th International Joint Conference on Artificial Intelligence (IJCAI 2007)*, pages 1029–1034. AAAI Press, AAAI Press, 2007.
- [75] R. Ros, R. L. de Mántaras, J. L. Arcos, and M. Veloso. A case-based approach for coordinated action selection in robot soccer. *Artificial Intelligence*, In Print.
- [76] R. Ros and C. Sierra. A negotiation meta-strategy combining trade-off and concession moves. *Journal of Autonomous Agents and Multiagent Systems*, 12(2):163–181, 2006.
- [77] R. Ros and M. Veloso. Executing multi-robot cases through a single coordinator. *Proc. Autonomous Agents and Multiagent Systems*, pages 1264 – 1266, 2007.
- [78] R. Ros, M. Veloso, R. L. de Mántaras, C. Sierra, and J. L. Arcos. Retrieving and reusing game plays for robot soccer. In *Advances in Case-Based Reasoning, ECCBR’06*, volume 4106 of *Lecture Notes in Artificial Intelligence*, pages 47–61. Springer, 2006.
- [79] A. S. Ruiz-Granados, B. Díaz-Agudo, and P. A. González-Calero. Combining HTN-DL planning and CBR to compound semantic web services. In *Procs. of the KWEPSY2007 Knowledge Web PhD Symposium (ESWC)*, 2007.
- [80] A. S. Ruiz-Granados, S. Lee-Urban, H. Muñoz-Avila, P. A. González-Calero, and B. Díaz-Agudo. Game ai for a turn-based strategy game with plan adaptation and ontology-based retrieval. In *Procs. of the ICAPS 2007 Workshop on Planning in Games*, 2007.
- [81] A. A. Sánchez-Ruiz-Granados, P. P. Gómez-Martín, B. Díaz-Agudo, and P. A. González-Calero. Adaptation through planning in knowledge intensive CBR. In *Advances in Case-Based Reasoning, ECCBR 2008*, volume 5239 of *LNCS*, pages 503–517. Springer, 2008.
- [82] D. Vernet, R. Nicolas, E. Golobardes, A. Fornells, C. Garriga, S. Puig, and J. Malveyh. Pattern discovery in melanoma domain using partitional clustering. In *Frontiers in Artificial Intelligence and Applications*, volume 184, pages 323–330. IOSPress, 2008.