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Man is still the most extraordinary computer of all.
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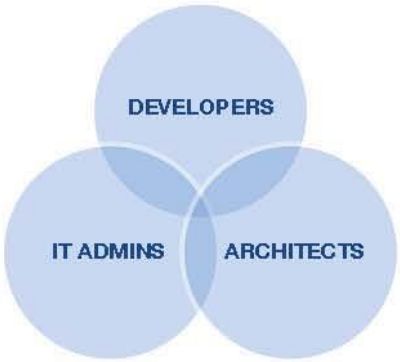

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SPECIAL ISSUE ON INTELLIGENT SYSTEMS AND APPLICATIONS
Vol. I, Number 6.

Editor's Note

I. INTRODUCTION

The International Journal of Interactive Multimedia and Artificial Intelligence provides an interdisciplinary forum in which scientists and professionals can share their research results and report new advances on Artificial Intelligence and Interactive Multimedia techniques.

This special issue includes six extended versions of selected papers from CISTI 2012 - 7th Iberian Conference on Information Systems and Technologies, held in Madrid, Spain, June 20 - 23, 2012 - and one paper from a regular submission to the journal. The issue includes, thus, seven selected papers, describing innovative research work, on several areas of Artificial Intelligence and Interactive Multimedia including, among others: optimization, soft computing, machine learning, web mining, semantic web, ontology networks, object relational databases, multimedia content management, emotion recognition and intelligent agents.

We would like to thank all the contributing authors, as well as the members of the conference coordinating, organizing and scientific committees for their hard and valuable work that assured the high scientific standard of the conference and enabled us to edit this special issue. Finally, the Guest Editors would also like to thank the Editors-in-Chief of International Journal of Interactive Multimedia and Artificial Intelligence for the publication of this special issue.

Álvaro Rocha (University Fernando Pessoa), Luís Paulo Reis (University of Minho)

II. WELCOME TO NEW MEMBERS

Álvaro Rocha has a ScD in Information Science from University Fernando Pessoa, Portugal, and a PhD in Information Systems and Technologies from University of Minho, Portugal. He is a Professor at the University Fernando Pessoa, Portugal, and an Invited Professor at the University of Santiago de Compostela, Spain. He is teaching and researching subjects on Software Engineering, Management Information Systems and Healthcare Information Systems. He is co-founder and Chair of GIMED (Medical Informatics Research Group) at the University Fernando Pessoa and co-founder and President of AISTI - Iberian Association for Information Systems and Technologies. He is the Editor-in-Chief for the Software Engineering journal and the Editor-in-Chief for the RISTI - Iberian Journal of Information Systems and Technologies

Luis Paulo Reis is an Associate Professor at the University of Minho, Portugal and a member of the Directive Board of the Artificial Intelligence and Computer Science Lab at the University of Porto, Portugal. He received his BSc, MSc and PhD degrees on Electric Engineering from the University of Porto in 1993, 1995 and 2003. During the last 20 years he has lectured courses on Artificial Intelligence, Intelligent Robotics, Multi-Agent Systems, Simulation, Planning and Scheduling and Logic Programming mostly at the PhD level. He was principal investigator of more than 10 research projects on those areas. He is the team leader of FC Portugal robotic soccer team/project, three times World Champion and eight times European Champion in RoboCup. He supervised 10 PhD theses and 75 MSc theses to completion and is currently supervising 15 PhD theses. He is the author of more than 250 publications in international conferences and journals and belonged to the PC of more than 100 international conferences. He is the president of the general assembly of both SPR - Portuguese Society for Robotics and AISTI - Iberian association for Information Systems and Technology.

Dr. Jörg Thomaschewski is professor of "Internet Applications" at the University of Emden / Leer, Germany with the teaching and research focus on human computer interaction, e-learning and software engineering. He is author of various online modules, e.g. "Human Computer Communication", which is used in the Virtual University (Online) at six university sites. He has wide experience in usability training, analysis and consulting.

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A Useful Metaheuristic for Dynamic Channel Assignment in Mobile Cellular Systems

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Abstract —**The prime objective of a Channel Assignment Problem (CAP) is to assign appropriate number of required channels to each cell in a way to achieve both efficient frequency spectrum utilization and minimization of interference effects (by satisfying a number of channel reuse constraints). Dynamic Channel Assignment (DCA) assigns the channels to the cells dynamically according to traffic demand, and hence, can provide higher capacity (or lower call blocking probability), fidelity and quality of service than the fixed assignment schemes. Channel assignment algorithms are formulated as combinatorial optimization problems and are NP-hard. Devising a DCA, that is practical, efficient, and which can generate high quality assignments, is challenging. Though Metaheuristic Search techniques like Evolutionary Algorithms, Differential Evolution, Particle Swarm Optimization prove effective in the solution of Fixed Channel Assignment (FCA) problems but they still require high computational time and therefore may be inefficient for DCA. A number of approaches have been proposed for the solution of DCA problem but the high complexity of these proposed approaches makes them unsuitable/less efficient for practical use. Therefore, this paper presents an effective and efficient Hybrid Discrete Binary Differential Evolution Algorithm (HDB-DE) for the solution of DCA Problem.**

Keywords **—Dynamic Channel Assignment, Mobile Networks, Optimization and Soft Computing.**

I. INTRODUCTION

It is important to efficiently utilize the scarce radio spectrum using a proper channel assignment scheme [1]. The aim of a channel assignment algorithm is to determine a spectrum efficient assignment of channels to the cells such that the traffic demand can be met as far as possible while satisfying the channel reuse constraints: co-channel constraints, channels separation constraints, and co-site constraints. A channel can be reused is that the same channel can be assigned to multiple cells simultaneously due to the radio propagation path loss. Channel assignment algorithms can be classified as static or dynamic. In a static approach, which is commonly called Fixed Channel Assignment (FCA) the channels are allocated and prefixed to each cell during the setup according to the traffic intensity estimated by the designer in the cell. FCA is still in use because it requires a moderate amount of BS radio installer and equipment and a simple monitoring procedure/algorithm. However, high efficiency of total channel usage over the whole service area if the traffic varies dynamically from cell to cell cannot be attained by FCA. To solve this problem, DCA [2] has been in trend since last twenty years. In DCA, channels are assigned dynamically over the cells in accordance with traffic load. FCA being a static technique can afford to spend more time to generate a better solution and is also easier to implement FCA in practice. However, from a resource utilization point of view, DCA is more preferable over FCA as DCA is designed to adjust resource assignment according to traffic demand, and hence, can support a higher capacity (or lower call blocking probability). The advantages of DCA are that it has a lower blocking rate than FCA at low traffic intensity and a lower forced call termination rate than FCA when blocking rates are equal [3].

DCA Problem is NP-hard and its effectiveness depends on its algorithm's efficiency in determining fast solution, good quality solution and its ease of implementation. Thus, devising a DCA, that is practical, efficient, and which can generate high quality assignments, is a challenging problem [4]. Metaheuristic Search techniques prove effective in the solution of DCA problem. A number of approaches [5-13,17,19,20,21,22] have been proposed for the solution of Channel Assignment Problem. The initial efforts for the solution of FCA were based on deterministic methods but as the problem is NP-hard these methods proved ineffective and inefficient for practical implementation for the next generation of mobile systems in which higher traffic demand was expected. To overcome the difficulties associated with the deterministic methods other heuristic methods such as Simulated Annealing [5], Tabu Search [6], Neural Networks [7,8] and Genetic Algorithms [9,11,12] were used for the solution of FCA problem. Later, Feedforward Neural Networks [19], Hopfield Neural Networks [20,21], Genetic Algorithms [10,13], Combinatorial Evolution Strategy [22], and Particle Swarm Optimization [17] have been used for the solution of DCA problem. However, the ever increasing number of mobile cellular users and the increasing demand for bandwidth call for more and more efficient Dynamic Channel Assignment strategies. Therefore, this paper presents an effective and efficient Hybrid Discrete Binary Differential Evolution (HDB-DE) for the solution of DCA Problem.

HDB-DE is a discrete binary version of Differential Evolution [23] which is an effective stochastic parallel search evolutionary algorithm for global optimization. The problem formulation and the implementation of HDB-DE take care of the soft constraints as well as hard constraints and hence focuses search only in the feasible regions of the search space

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resulting in fast convergence. The features of HDB-DE also help in the reduction of the population size which consequently reduces the computation time, and also results in better global/ near global solution.

Section II briefly describes the constraints in CAP, assumptions pertaining to cellular model and call arrival and then the problem formulation of DCA. Section III briefly describes Hybrid Discrete Binary Differential Evolution Algorithm (HDB-DE) for the solution of DCA Problem**.** The implementation details of HDB-DE algorithm are given in Section IV. The performance of HDB-DE is evaluated on standard benchmark problems. The details of these benchmark problems, simulations and the obtained results are presented in Section V. Conclusions are presented in Section VI.

II. Problem Formulation For DCA

A. Constraints in Channel Assignment Problem

In any cellular network, whenever two cells use the same channel or when two cells use channels adjacent to each other on the spectrum or when two channels are assigned to the same cell, interference occurs; these types of interference are called Co-channel Interference, Adjacent Channel Interference and Co-site Interference respectively [14].

They lower the signal-to-noise ratio at the receiving end, leading to the deterioration of system performance. Though the computation of the actual level of interference is tough, primarily owing to its dependence on the topology of the real environment, experiments show that the effect of interference is reasonably low if the following three constraints are satisfied:

Co-Channel Constraint (CCC): The same channel cannot be simultaneously allocated to a pair of cells unless there is a minimum geographical separation between them.

Adjacent Channel Constraint (ACC): Adjacent channels cannot be assigned to a pair of cells unless there is a minimum distance between them.

Co-Site Constraint (CSC): A pair of channels can be employed in the same cell only if there is a minimum separation in frequency between them. These constraints are called Electromagnetic Compatibility Constraints, which together with the traffic demand constraint, are known as *hard constraints*.

Apart from the *hard constraints*, another set of constraints called *soft constraints* is also considered, which may be described as follows:

The *packing condition* requires that a channel, in use in one cell, should be reused in another cell as close as possible (but obviously not interfering with the former) so that the number of channels used by the network is minimal, thereby lowering the probability of future call blocking in other cells.

The *resonance condition* tries to ensure that same channels are assigned to cells belonging to the same *reuse scheme* [4], as far as possible.

Another soft constraint is that, when a call arrives, minimum number of channel reassignment operations should be performed because excessive reassignment in a cell may lead to increase in blocking probability.

A solution to the CAP must satisfy the hard constraints whereas a soft constraint may be violated; the latter only helps maximize the utilization of resources and/or improve the quality of service.

Apart from the traffic demand constraint, the only other hard constraint that we have taken into account is Co-channel Constraint; other sources of interference are assumed to be absent, as reported in literature Vidyarthi et al [15], Battiti et al [16], and Chakraborty et al [17].

B. Assumption Pertaining to Cellular Model and Call Arrival

1) The topological model is a group of hexagonal cells that form a parallelogram shape (equal number of cells along x-axis and y-axis) as shown in figure 1(adapted from [15], figure 1]).

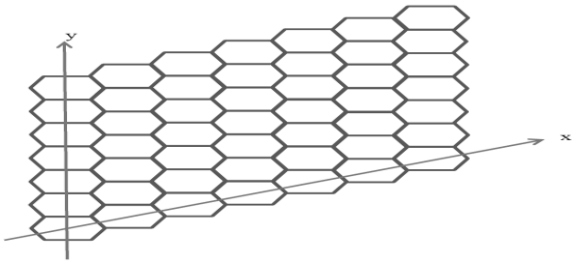

Fig.1. Cellular network model.

2) Cells are grouped in cluster of size 7 cells.
3) Each channel may serve only one call (i.e., multiplexing techniques are ignored). In DCA, all channels are put in central pool. A channel is assigned to an incoming call by a central controller that supervises the whole cellular network.
4) The selection of a channel is only subject to co-channel interference shown in figure 2. Other sources of interference are ignored.

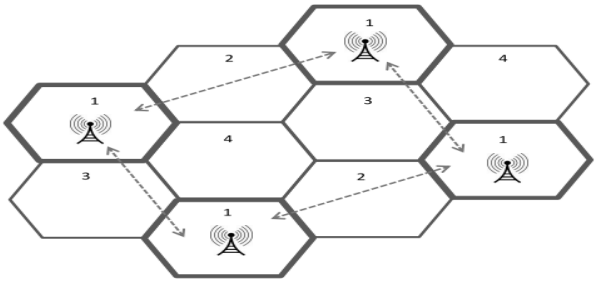

Fig.2. Co-channel interference

5) We consider not the start-up situation but the situation at a certain intermediate time-instant *t* when a certain number of calls is already being served by the network.
6) At time *t*, only one new call arrives at only one cell, called the host cell, all other conditions in the entire network remaining unaltered.
7) We set a minimum "reuse distance", which represents the minimum allowable normalized distance between two cells which may use the same channel at the same time as shown in figure 3.

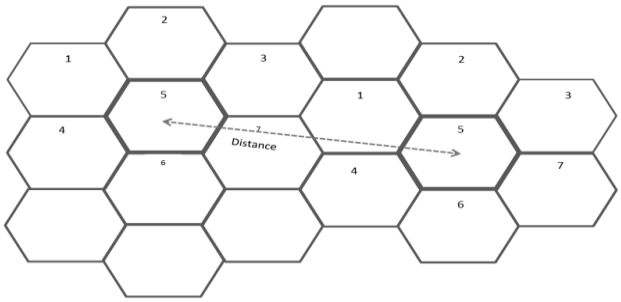

Fig.3. Frequency reuse distance.

8) A call is blocked if the entire set of channels in the network is in use in the cell involved in call arrival and its neighborhood that is there is no channel that satisfies the co-channel interference.
9) Existing calls in a cell involved in a new call arrival may be rearranged.

C. Formulation of Fitness Function

The equations 1, 2, 3 & 4 given below correspond to the different conditions i.e. co-channel interference, packing conditions, resonance conditions, and discouraging excessive rearrangement condition. These equations are combined to constitute a quadratic energy function (equation 5) whose minimization leads to an optimal solution for DCA [13].

$$f_1(X) = \sum_{j=1}^{CH} \sum_{\substack{i=1 \\ i \neq k}}^{CE} V_{k,j} * A_{i,j} * interf\,(i,k) \qquad (1)$$

Equation (1) expresses the hard condition. Where V_k is output vector for cell k, with dimension channel (CH). $V_{k,j}=1$ if channel j is assigned to cell k, otherwise $V_{k,j}=0$. Here k signifies in which cell, call arrives. The energy function increases in case a channel j which is assigned in cell i is selected by cell k that interferes with i. It thus ensures that solutions with no interference give *better* (smaller) fitness values. $A_{i,j}$ is the ij[th] element of the assignment table A, which is 1 if channel j is assigned to cell i, and 0 otherwise.

$$f_2(X) = \sum_{j=1}^{CH} \sum_{\substack{i=1 \\ i \neq k}}^{CE} V_{k,j} * A_{i,j} * \frac{(1 - interf\,(i,k))}{dist(i,k)} \qquad (2)$$

This term expresses the *packing condition*. The energy decreases if channel j assigned to cell k is also selected by cell and interf (i, k) =0. Energy reduction depends on the distance between i and k. The packing condition requires that a channel, in use in one cell, should be reused in another cell as close as possible (but obviously not interfering with the former) so that the number of channels used by the network is minimal, thereby lowering the probability of future call blocking in other cells.

$$f_3(X) = \sum_{j=1}^{CH} \sum_{\substack{i=1 \\ i \neq k}}^{CE} V_{k,j} * A_{i,j} * \big(1 - res\,(i,k)\big) \qquad (3)$$

Where res(i, k) is function whose value is 1 if cells i and k belongs to the same reuse scheme, otherwise 0. Equation (3) symbolize the *resonance condition*. The resonance condition tries to ensure that same channels are assigned to cells belonging to the same reuse scheme, as far as possible.

$$f_4(X) = \sum_{j=1}^{CH} V_{k,j} * A_{k,j} \qquad (4)$$

Which subtracts 1 whenever a channel already being used by cell *k*, before the arrival of the new call, is considered in the candidate solution (i.e. in the new configuration) so that a mobile terminal being served need not change its channel too often.

Finally, the fitness function $F(X)$ is given by,

$$F(X) = W_1 * f_1(X) - W_2 * f_2(X) + W_3 * f_3(X) - W_4 * f_4(X) \qquad (5)$$

Where W_1, W_2, W_3, W_4 are *weights* that determine the importance of various terms. Clearly, $f_1(X)$ accounts for the *hard constraint* which should be given a high weightage over the other terms those are associated with the *soft constraints*. The coefficient values as used in Battiti et al [16] have been used. Where W_1=7000, W_2=1.2625, W_3=0.01, W_4= 4.17625.

III. HDB-DE

HDB-DE is a discrete binary version of Differential Evolution which is an effective stochastic parallel search evolutionary algorithm for global optimization. Unlike DE here the individuals are initialized as binary strings. HDB-DE algorithm consists of three major operations – mutation, crossover and selection, which are carried out for each member of the population (called as target vector). Mutation on each target vector of the population generates a new mutant vector uniquely associated with it. The resultant mutant vector is no longer binary because of the difference operator and the control parameter. Therefore, the discretization process from a real continuous space to a binary space is done. Then the crossover operation generates a new trial vector using the mutant vector and the target vector itself. In selection phase the fitness of the trial vector is compared with the target vector and the vector with higher fitness replaces the target vector in the population for the next iteration.

A. Pseudo-Code of HDB-DE

1) Initialize parameters t=0, NP (NP is number of individuals in population), CR and F. Where $CR \in (0,1)$ is crossover constant, $F \in (0,2)$ is mutant constant.
2) Initialize target population X^t.
3) Evaluate each individual i in the population using the objective function.
4) Obtain the mutant population (a mutant individual, $V_i^t = [v_{i1}^t, v_{i2}^t, ..., v_{in}^t]$ is determined such that

$$V_i^t = X_{ai}^t + F * (rand * X_{bi}^t - rand * X_{ci}^t)$$

Where X_{ai}^t, X_{bi}^t *and* X_{ci}^t are three randomly chosen individuals from the population such that $ai \neq bi \neq ci$.

5) Discretization process from a real continuous space to binary space is done according to the following equation

$$V_i^t = \begin{Bmatrix} 1 \; if \; rand(0,1) \le sigmoid(V_i^t) \\ 0 \; if \; rand(0,1) > sigmoid(V_i^t) \end{Bmatrix}$$

Where *sigmoid( )* is a sigmoid limiting transformation function.

6) Obtain the trial population (For each mutant individual, $V_i^t = [v_{i1}^t, v_{i2}^t, ..., v_{in}^t]$ an integer random number between 1 and *n*, i.e., $D_i \in (1,2,...,n)$, is chosen, and a trial individual, $U_i^t = [U_1^t, U_2^t, ..., U_{NP}^t]$ is generated such that:

$$U_i^t = \begin{Bmatrix} V_{ji}^t, if\,(rand(0,1) \le CR) \; or \; (j = I_{rand}) \\ X_{ji}^t, if\,(rand(0,1) > CR) \; and \; (j \ne I_{rand}) \end{Bmatrix}$$

Where I_{rand} refers to a randomly chosen dimension (*j=1,2,..,n*))

7) Evaluate trial population
8) Selection (The selection is based on the survival of the fittest among the trial population and target population such that:

$$X_i^{t+1} = \begin{cases} U_i^{t+1}, & if \quad f(U_i^{t+1}) \ge f(X_i^t) \\ X_i^t, & otherwise \end{cases}$$

9) Repeat steps 2 to 8 While Termination condition not reached.
10) Output best solution.

IV. Implementation Details of HDB-DE For DCA

The Dynamic Channel Assignment problem is specified in the literature in terms of the number of cells in the network (N_{ce}), the number of channels in the pool (N_{ch}) and a *demand vector* ***D*** which is a vector whose i^{th} element denotes the traffic demand in cell *i*, *i*= 1,2,…, N_{ce}.

We assume that the new call demand is placed at cell *k* which is already serving demand (*k*) calls where demand (*k*) denotes the total traffic load (ongoing) in cell *k* at time *t*; and no ongoing call is terminated in the entire network. Our problem is to assign an available channel to the incoming call with possible reassignment of channels to the calls in progress in cell *k*.

A. Solution Representation

The candidate solution to the problem is represented as a binary string X which is the representation of V_k mentioned earlier where k signifies the cell in which call arrives. The size of the vector X is equal to the number of available channels (N_{ch}) and $X_{k,j}$=1 if channel j is assigned to cell k, otherwise $X_{k,j}$=0. The number of 1s in each solution vector is equal to demand(*k*)+1 i.e. the total ongoing calls plus the call that arrives at the concerned time instant.

B. Mutation

A new mutation operator has been designed for HDB-DE which is more effective than the one which has been used earlier [17] for mutation of solutions with binary representation in DE. The new mutation operator is as given below:

$$V_i^t = X_{ai}^t + F * (rand * X_{bi}^t - rand * X_{ci}^t)$$

The effectiveness of the operator can be seen from the fact that if both X_{bi}^t and X_{ci}^t assume a value 1 then in the earlier mutation operation the difference becomes 0 and therefore does not result in any change in the value of X_{ai}^t whereas in the newly designed mutation operation it does not happen so and leads to the generation of better mutants and thereby faster convergence.

V. Computational Results

HDB-DE algorithm was implemented in Matlab and the following benchmark problems were used for its evaluation:

1) The first benchmark problem CSys 49 [13] consists of 49 hexagonal cells that are arranged to form a parallelogram structure with 70 channels available to the system.
2) The second and third benchmark problems i.e. HEX 1 and HEX 3 [18] are based on a 21-cell system.
3) The last four benchmark problems i.e. EX 1, EX 2, KUNZ 1 and KUNZ 2 [18] are based on a 4, 5, 10 and 15-cell system respectively.

The details of the benchmark problems and the used demand vectors are summarized in Table I.

TABLE I.
Details of Benchmark Problems

Problem	N_{ce}	N_{ch}	Demand Vector (demand)
CSys 49	49	70	4,2,6,4,4,6,2,4,2,4,4,2,2,4,4,4,4,4,2,2,6,2,6,6,2,4,8,2,2,2,4, 2,2,4,2,4,6,2,4,6,4,2,6,4,4,2,2,6,4,4,4
HEX 1	21	37	2,6,2,2,2,4,4,13,19,7,4,4,7,4,9,14,7,2,2,4,2
HEX 3	21	21	1,1,1,2,3,6,7,6,10,10,11,5,7,6,4,4,7,5,5,5,6
EX 1	4	11	1,1,1,2
EX 2	5	17	2,2,2,3,3
KUNZ 1	10	30	10,11,9,5,9,4,4,7,4,8
KUNZ 2	15	44	10,11,9,5,9,4,4,7,4,8,8,9,10,7,7

For each of the considered problems it has been assumed that all cells are arranged in the form of a parallelogram, the given N_{ce} of each problem is expressed in the form $r \times c$, where *r*, *c* are integers, and hence determine the configuration of the cellular network by setting the number of rows to *r* and the number of all columns to *c* [17]. A cell is arbitrarily selected and then it is assumed that, just before a call demand arrives in this cell at time *t*, *demand(i)* calls were already in progress in the i^{th} cell, *i* =1 ,2,…, N_{ce}, and *demand(k)* calls are ongoing in the k^{th} cell. Accordingly, N_{ce} X N_{ch} assignment matrix, avoiding co-channel interference has been manually determined which describes the status of ongoing calls in each cell before the new call arrival and thus represents the initial condition. The assignment table used for HEX3 problem is given in Table II.

Whenever a simulation results in a solution, which violates *Co-Channel Constraint* (CCC) the call is rejected. C*all Rejection Probability* (CRP) as given in [17] is used as a parameter for determining the effectiveness of the proposed method.

$$CRP = N_{rejected} / N_{total}$$

Where $N_{rejected}$ = number of simulations in which the incoming call is rejected in the host cell considered; N_{total} = total number of simulations.

TABLE II.
INITIAL ASSIGNMENT MATRIX FOR HEX3

Problem	Initial Assignment Matrix
HEX3	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 1 0 1 0 0 0 1 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 1 0 0 0 1 0 1 0 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 1 0 1 0 1 0 0 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 0 0 0 0 0 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 0 0 0 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 1 0 0 1 0 1 0 0 0 0 0 0 1 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 1 0 1 0 0 1 0 1 0 0 0 0 0 1 0 0 1 0 1 0 0 0 0 0 0 0 1 0 1 0 0 1 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 1 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1 0 0 1 0 0 0 0 0 0 1 0 1 0 0 0 0 0

Thus, CRP is the cumulative proportion of simulations, for which the call is rejected, in the long run. This parameter CRP is based on but different from the *call blocking probability* used in the [13,14]. The former characterizes a particular cell under a given initial condition while the latter characterizes the cellular network as a whole.

TABLE III.
SIMULATION RESULTS

Problem	Host Cell	Number of simulations	Number of times, call is rejected				CRP			
			Method							
			PSO [17]	SGA	MGA	HDBDE	PSO [17]	SGA	MGA	HDBDE
CSys 49	6	250	-	14	0	**0**	-	0.06	0	**0**
HEX1	6	104	21	8	0	**0**	0.20	0.08	0	**0**
HEX3	5	105	32	12	0	**0**	0.31	0.11	0	**0**
EX1	4	112	32	6	0	**0**	0.28	0.05	0	**0**
EX2	4	100	28	9	0	**0**	0.28	0.09	0	**0**
KUNZ1	7	110	39	11	0	**0**	0.35	0.10	0	**0**
KUNZ2	7	100	20	11	0	**0**	0.20	0.11	0	**0**

The parameters used in HDB-DE are as follows:
Population size=30,
Mutation factor F=1.2,
Crossover constant CR= 0.6 and
Maximum number of generations=50.

The simulation results obtained by HDB-DE and those obtained by Simple Genetic Algorithm (SGA), Modified Genetic Algorithm (MGA) [24] and PSO [17] for the different benchmark problems are shown in Table III.

The results shown in table III indicate that the performance of HDB-DE and MGA is good compared to PSO. The comparison of the convergence curves and the average number of Evaluation expended to yield the best solution over a good number of runs of the algorithms will further throw light on the efficiency, efficacy and consistency of the algorithms.

Figure 4, 5, 6, 7, 8, 9, and 10 shows the convergence curve of HDB-DE, MGA and SGA for the seven benchmark problems CSys 49, HEX 1, HEX 3, EX 1, EX 2, KUNZ 1 and KUNZ 2 respectively.

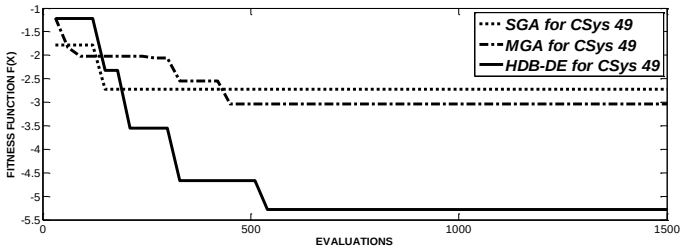

Fig.4. Convergence curve for CSys 49 consists of 49 hexagonal cells with 70 channels.

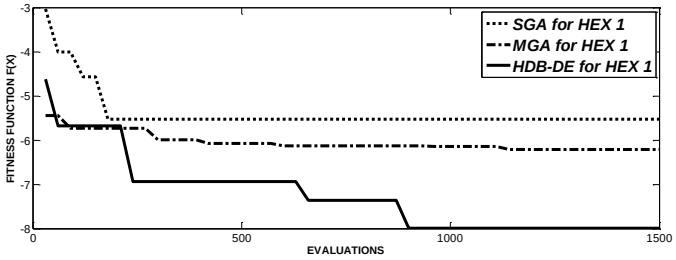

Fig.5. Convergence curve for HEX 1 consists of 21 hexagonal cells with 37 channels

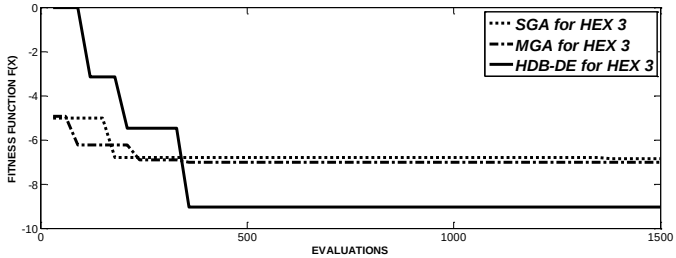

Fig.6. Convergence curve for HEX 3 consists of 21 hexagonal cells with 21 channels.

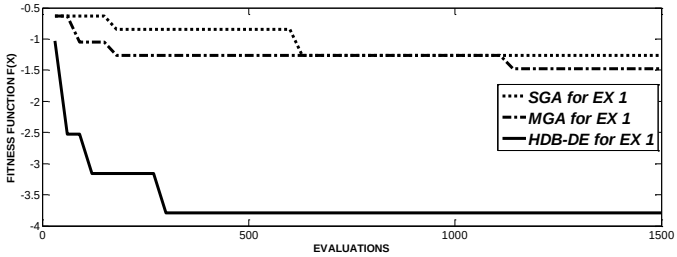

Fig.7. Convergence curve for EX 1 consists of 4 hexagonal cells with 11 channels.

TABLE IV.
SIMULATION RESULTS OBTAINED BY HDB-DE AND GA FOR ALL BENCHMARK PROBLEMS

Benchmark	**CSys 49**			**HEX 1**			**HEX 3**			**EX 1**			**EX 2**			**KUNZ 1**			**KUNZ 2**		
Algorithm	***HDBDE***	***MGA [24]***	***SGA***	***HDBDE***	***MGA [24]***	***SGA***	***HDBDE***	***MGA [24]***	***SGA***	***HDBDE***	***MGA [24]***	***SGA***	***HDBDE***	***MGA [24]***	***SGA***	***HDBDE***	***MGA [24]***	***SGA***	***HDBDE***	***MGA [24]***	***SGA***
Best # of Evaluations	**90**	200	450	**60**	150	380	**60**	100	250	**28**	65	210	**60**	85	250	**60**	160	230	**90**	150	230
Worst # of Evaluations	**300**	410	900	**170**	360	750	**130**	270	600	**65**	130	410	**95**	240	550	**160**	410	550	**180**	350	650
Average # of Fitness Evaluations	**163**	301	681	**98**	249	512	**93**	180	416	**47**	97	312	**79**	156	394	**99**	255	368	**123**	236	387

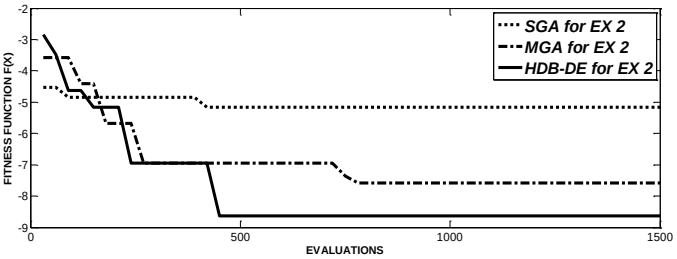

Fig.8. Convergence curve for EX 2 consists of 5 hexagonal cells with 17 channels.

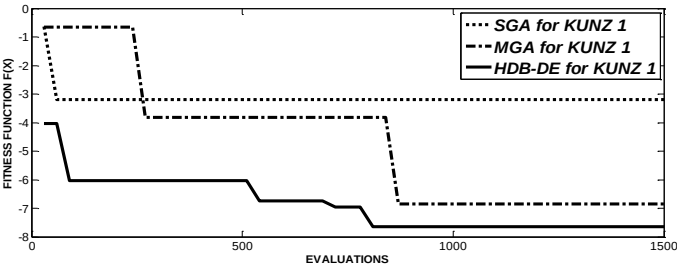

Fig.9. Convergence curve for KUNZ 1 consists of 10 hexagonal cells with 30 channels.

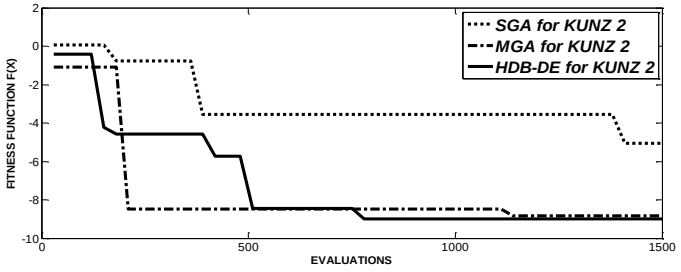

Fig.10. Convergence curve for KUNZ 2 consists of 15 hexagonal cells with 44 channels.

Table IV presents the results in terms of Best number of evaluations, Worst Number of evaluations and average number of evaluations expended by HDB-DE, MGA and SGA to give the final best solution in 30 independent runs on each benchmark problem.

The convergence curves shown in figures 4 to 10, and the results presented in Tables III and IV clearly indicate the superior and consistent performance of HDB-DE over the other methods reported in the literature in terms of quality of solutions and speed of convergence. The results are promising and indicate the suitability of HDB-DE for the solution of even bigger instances of real-world DCA problem.

VI. CONCLUSION

This paper presents an effective and efficient Hybrid Discrete Binary Differential Evolution (HDB-DE) Algorithm for the solution of Dynamic Channel Assignment Problem in cellular radio networks. The features of HDB-DE help in achieving fast convergence and good solution. The problem formulation and the implementation of HDB-DE for DCA takes care of the soft constraints as well as hard constraints and hence focuses search only in the feasible regions of the search space resulting in fast convergence. HDB-DE algorithm has been evaluated on benchmark problems for DCA. The obtained results and their comparison with those obtained by the other methods establish the superiority of HDB-DE over other methods and indicates its suitability for the solution of even bigger instances of dynamic channel assignment in cellular networks resulting in lower call rejection probability, higher capacity utilization and a good quality of service.

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Improving Web Learning through model Optimization using Bootstrap for a Tour-Guide Robot

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***Abstract* —We perform a review of Web Mining techniques and we describe a Bootstrap Statistics methodology applied to pattern model classifier optimization and verification for Supervised Learning for Tour-Guide Robot knowledge repository management. It is virtually impossible to test thoroughly Web Page Classifiers and many other Internet Applications with pure empirical data, due to the need for human intervention to generate training sets and test sets. We propose using the computer-based Bootstrap paradigm to design a test environment where they are checked with better reliability.**

***Keywords* —Web Mining, Supervised Learning, Bootstrap, Patterns Mining, Web Classifiers, Knowledge Management.**

I. Introduction

THE Internet is an enormous information repository with spectacular growth and a high degree of updating. Using this exceptional database in an automatic way is a challenging field of research. Data mining has been extensively used by many organizations, large amount of data are processed to extract relevant information; applying these technologies to the Web it is possible to build systems that considerably improve the process of information gathering from the Internet. Web Mining has peculiarities that made it a subject of research in its own right. It can be applied to several aspects of the network like page content, user click stream, link structure of the web or social community opinion. Internet mining is performed in several steps: web pages covering a particular matter or belonging to a social community are searched and classified. Then, they are processed to remove all the words and tags that have no influence in the meaning of text and a mining algorithm is applied to harvest useful information from the pages. This knowledge can be used in several manners: analysis to study behavior patterns, social community opinions and product success or it can be incorporated into a knowledge repository that is the application for our robot.

In this article, we have dedicated our efforts to pattern classifiers that allow a binary classification of Web pages. Classification models that use patterns to define features or rules have been built for a long time. These models can be either more accurate or less precise, but they achieve more understandable results for humans. A lot of work has been performed on pattern finding and selection, algorithms and model building, but there is scarce work on model verification and comparison as stated in [1] by B. Bringmann. We have developed a test environment that implements Bootstrap resample strategy allowing to determine with more confidence how the model performs, so criteria can be clearly defined to compare between models performance, thus improving the whole learning process.

Bootstrap is a computer approach to get statistical accuracy. It is applied to a wide variety of statistical procedures like non parametric regressions, classification trees or density estimation. This technique requires fewer assumptions and offers greater accuracy and insight than other standard methods for many problems. Bootstrapping is an analogy in which the observed data assume the role of an underlying population: variances, distributions and confidence intervals are obtained by drawing samples from the empirical sample, as R. Stinewrotein [2]. A typical problem in applied statistics involves the estimation of an unknown parameter. The two main questions are: what estimator should be used? and having chosen a particular one, how accurate is the estimator? Bootstrap is a general methodology to answer the second question, as stated by Efron and Tibshiraniin [3].

This work is framed within the Intelligent Control Group, Universidad Politécnica de Madrid, whose members are carrying out research into robotics and intelligent control systems. Three robots have already been built which are designed to show visitors round museums and fairs described by Rodriguez-Losada in [4]. Research covers a wide number of areas: path finding, navigation, speaking, facial expression, mood and knowledge management.

II. Software Architecture for based on Intelligent Agents

We have developed our own interactive mobile robot called Urbano specially designed to be a tour guide in exhibitions. Urbano is a B21r platform from iRobot, equipped with a four

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wheeled synchrodrive locomotion system, a SICK LMS200 laser scanner mounted horizontally on the top used for navigationas well as a mechatronic face and a robotic arm used to express emotions such as happiness, sadness, surprise or anger. The robot is also equipped with two sonar rings and one infrared ring, which allows detecting obstacles at different heights that can be used for obstruction avoidance and safety. The platform also has two onboard PCs and one touch screen, as explained by J. Rainer in [5].

The software is structured in several executable modules to allow a decoupled development by several teams of programmers, and they are connected via TCP/IP and CORBA. Most of these programs are conceived as servers or service providers, as the face control, the arm control, the navigation systems voice synthesis and recognition, and the web server. The client-server paradigm is used, the only client being a central module that we call the Urbano Kernel. This kernel is responsible for managing the whole system, as illustrated in [4].

Modules with a more advanced implementation are: Decision Making, Knowledge Server, Automatic Presentation Generator and Acquisition of Information, as can be seen at Fig. 1.

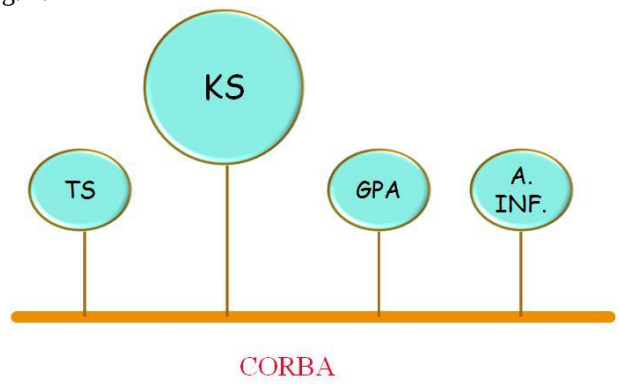

Fig. 1. Modular Architecture based on Intelligent Agents: TS, Decision Making, KS, Knowledge Server, GPA, Automatic Presentation Generator, and A. Inf., Acquisition of Information

We have built the Acquisition of Information Agent which aims to automate as much as possible the incorporation of information to the Knowledge Server, using the Internet the as primary source of Information.

A. KS: Knowledge Server, Urbano Ontology Implementation

Knowledge Server is at the center of the architecture, providing data and intelligence to the behavior of the rest of the components. It incorporates cognitive inspired ontologies that store the information and concepts. Feeding these ontologies in an automated way is a challenge. URBANOntology consists of a foundational ontology (DOLCE) plus different domain specific ontologies, like art, history etc. The robot is able to give presentations about different topics as domain ontologies that are mapped to DOLCE as described in [6]-[8]. It is not only a classification; it also provides the tools needed to conceptualize the world and describes how the different objects relate to each other. DOLCE is made up of categories based on perception and human common sense, cultural details and social conventions.

Using DOLCE as a fundamental ontology, we are setting out a general framework that can be tailored to any specific domain; in this way the URBANOntology can serve as a reliable tool to potentially generate presentations in all possible areas. Every component in the Museum Ontology must be mapped to its respective fundamental concept in DOLCE. The use of a knowledge server means having a useful tool with which to meet the needs of handling the knowledge. By abstraction of knowledge we understand a learning process that involves the formation of new concepts or categories based on information available about the world. The knowledge server consists of a Java application developed using the libraries of Protégé-OWL API. In [5], J. Rainer y R. Galán explain it with more detail.

The robot changes between museums and exhibition fairs makes it necessary to update its knowledge database for each location. We have optimized the information gathering process, including the option of Web Mining from the Internet, as shown in Fig. 2.

Web Learning is performed in several steps, in this paper we suggest an improvement for the Page Selection phase, proposing a test environment that increases the reliability of

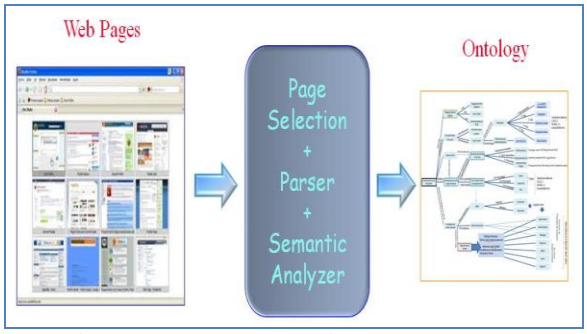

Fig. 2. Information extraction process from the Internet

the results obtained by the Selection Models. The robot's environment has been enriched with the application of these techniques.

III. A REVIEW ON MINING TECHNIQUES APPLIED TO WEB LEARNING

We present in this section a review of mining techniques that have been developed and theoretical support for Web Mining. Many approaches have been proposed to extract information from raw data, ranging from those involving more human intervention, supervised methods, to more unattended systems, unsupervised ones. The selection depends on several factors like the type, heterogeneity and volume of data.

Supervised learning is also known as classification or inductive learning. It is similar to the human behavior of

learning from past experiences thus gaining new knowledge and abilities. The experiences are represented as past data, so there are the following sets of data: training data, that allow model training, test data, that allow the verification of the classification and the real data that are processed by the model. The Accuracy of the classifier is evaluated in terms of the number of correct classifications versus the total number of cases. Decision tree is one of the most popular methods of classification; it is efficient and can compete with other classification techniques, like Bayesian Classification, D. Hand in [9], or Support Vector Machines, V. Vapnik in [10].

Another approach is Unsupervised Learning that discovers patterns in the attributes of the data, that are used to predict the value of class attribute of future instances. The classes are used to classify items, for example decide if a web text is a social science article or if it is about microelectronics. When the data have no class attributes, clustering techniques are applied to find similarity groups. Clustering makes partitions of data or can have a hierarchical approach. A distance function is chosen between data points, and a set of centroids are calculated and recalculated recursively until similar groups are found. K-means Algorithm is an example of this strategy, as explained by MacQueen in [11].

There is an intermediate approach that is Partially Supervised Learning. Supervised Learning requires a lot of human effort and a large set of labeled data, therefore an alternative was proposed. To minimize the tedious task of labeling data, the model is trained with labeled and unlabeled examples, also known as LU learning, an example of the algorithm used is EM, Expectation and Maximization, A. Dempster in [12]. There is a lot of classified data and a large set of unlabelled data that are used to improve learning of the model. Subsequently the learning process uses positive and unlabeled data, PU learning, assuming a two classes set of data. This method can be applied successfully for classification of web pages.

In this section a number of general mining techniques have been described. As stated before, we have focused our efforts on mining patterns for Supervised Learning and their use to build a Web page classifier.

A. Peculiarities of Web Mining

Web mining is an activity that discovers useful information from the Web. It can target data or hyperlinks and can be classified into three kinds: Web Structure Mining, Web Content Mining and Web Usage Mining. Web Structure Mining discovers useful knowledge from hyperlinks structure. It is used to find important sites and communities and gives an image of the structure of the Internet itself. Web Content Mining extracts useful information from page contents. Web Usage Mining discovers how the users make use of a Web Server. Analyzing the Web logs it is possible to review the click stream and determine the user behavior and what he likes and what he dislikes, as stated by Bing Liu in [13].

One key step for Web mining is the pre-processing of the Web pages. To begin with HTML information is identified to classify the importance of the different paragraphs of the page. HTML codes allow recognizing titles, main content blocks or anchor text; this information can be used to speed up the identification and processing of the page.

Subsequently HTML tags are removed in order to extract the information in a more efficient way. When the page text has no tags it is clean from words that form syntactic constructions that have little influence on the meaning of the phrases, stop words like prepositions, conjunctions and articles are removed. The rest of the words are converted to their roots in a procedure called stemming. Verbs are transformed to the infinitive form and suffixes are stripped from words to get the roots which are easier to recall. A good example of stemming algorithm is from M. Porter in [14]. After the page is pre-processed a better precision for classification is obtained, getting improved results using distance functions like cosine similarity.

Parts of Speech, POS, can be used at a later stage in order to get the sentiments and semantic meaning attached to the text. With these techniques a word is identified in its category: noun, verb, adjective, adverb, pronoun, etc. Knowing the type of word it is possible for a machine to perform further processing to extract information from a text, being able to identify pictures by a painter, dates of birth or companies working in a particular sector. An algorithm implementing this approach was proposed by P. Turney in [15]. Using methodologies like Latent Semantic Analysis, was proposed by S. Dreewester [16], it is possible to apply statistical analysis to find the Singular Value Decomposition of a Web page, discerning when several texts have the same semantic meaning expressed with different words.

IV. USING STATISTICAL TECHNIQUES TO TEST AND DEVELOP

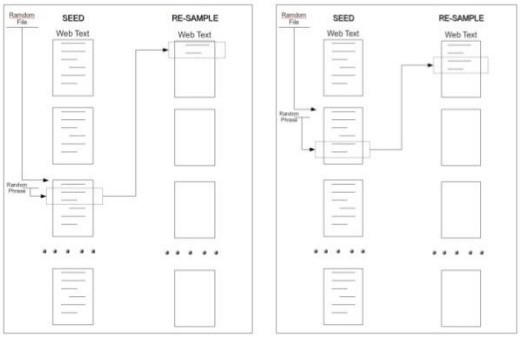

Fig. 3. Generation process of the new sample

SUPERVISED LEARNING MODELS

One of the main challenges of Supervised Learning Models like classifiers for Web Pages is the sheer number of pages that has to be processed, but the training and test pages set have a limited size due to the need for a human operator that classifies pages manually. There is a plethora of algorithms and literature about pattern classifiers, but fewer studies have

been carried out so far on verification and comparison between models. To solve this problem, we have developed a methodology based on the statistical paradigm called Bootstrap that allows one to synthesize re-samples automatically with replacement therefore greatly improving the accuracy of the verification and refining phase of the models, strengthening the reliability of their results and giving a clear idea about their optimum working conditions. Bootstrap is a computer approach to get statistical accuracy. It is applied to a wide variety of statistical procedures like non parametric regressions, classification trees or density estimation. We go a little further, iteratively varying the attributes of the population and applying Bootstrap for each situation.

A. The Bootstrap estimate

In our case we used Bootstrap to estimate parameters for a classifier. From an equally distributed empirical population, a collection of samples are constructed replacing randomly the original dataset. Given a set of independent and identically distributed observations, web pages in our case:

$$x_i,\ i = 1,2,\dots,n \quad (1)$$

from an unknown probability distribution F has been observed. To estimate a parameter of interest $\theta = t(F)$ on the basis of x. For this purpose we calculate estimate $\hat{\theta} = s(x)$ from x. To know how accurate $\hat{\theta}$ is, Bootstrap was introduced as a computer based method. It is completely automatic no matter how complicated the estimator is from a mathematical point of view. Let $\hat{F}$ be the empirical distribution with a probability of 1/n on each of the observed values:

$$x^*(x_1^*, x_2^*, \dots\dots, x_n^*) \quad (2)$$

A bootstrap sample is defined as a random sample of size n drawn from $\hat{F}$, say

$$x^* = (x_1^*, x_2^*, \dots\dots, x_n^*) \quad (3)$$

$$\hat{F} \rightarrow x^* = (x_1^*, x_2^*, \dots\dots, x_n^*) \quad (4)$$

Corresponding to bootstrap dataset x^*, the sample of pages that are generated, is a Bootstrap replication of $\hat{\theta}$:

$$\hat{\theta} = s(x^*) \quad (5)$$

It is necessary to evaluate the bootstrap replication corresponding to each bootstrap sample:

$$\hat{\theta} = s(x^{*b})_{b=1,2,\dots,B} \quad (6)$$

As an example, to estimate an estimator as the standard error:

$$se_F = (\hat{\theta}) \quad (7)$$

The sample standard deviation of the B replications:

$$\widehat{se}_B = \left\{\sum_{b=1}^{B}\left[\hat{\theta}^*(b) - \hat{\theta}^*(.)\right]^2/(B-1)\right\}^{1/2} \quad (8)$$

Where:

$$\hat{\theta}^*(.) = \sum_{b=1}^{B}\hat{\theta}^*(b)/B \quad (9)$$

As stated by Efron and Tibshiraniin [17].

V. TEST ENVIRONMENT

As explained above, the test environment is based on Bootstrap statistical estimation and it is applied to evaluate pattern classifier models and how they perform when some features of the pages change. The generation of Web page re-samples with replacement is as follows: from a set of thoroughly classified web pages used as seeds, a page is selected at random and inside this page, a phrase is randomly chosen and is written in the new sample, as can be seen in Fig. 3.

Bootstrap demonstrates that the new sample has the same underlying conditions than the original. We create two sets of pages: one from pages referring to Francisco de Goya as a painter and other one from pages that have to be discarded by the model. The two sets are evaluated and the confusion matrix is built:

		Actual value	
		p	N
PredictedValue	p'	A	B
	n'	C	D

Then we calculate the statistical tests Sensibility and Specificity for the model according to the following equations:

$$sensibility^* = \frac{A}{A+C} \quad (10)$$

$$sensibility^* = \frac{D}{B+D} \quad (11)$$

We greatly improve the accuracy of the verification and refining phase of the models, strengthening the confidence in their results and giving a clear idea about their optimum working conditions. With this information for example, we are able to adjust the models more precisely, improving their performance and enabling the building of dynamic strategies that obtain better results.

In our case we have tested how the models are affected by the size of the pages. The sample generation process can be easily modified to configure different page sizes for the generated sample. It is very difficult to implement this test

with pure empirical data, selecting a big enough set of pages manually according to size and accuracy.

We have implemented classifiers based on text patterns that recognize if a Web page is about the Spanish painter Francisco de Goya, discarding pages about Goya Street, Goya Awards, Goya Train, etc. Search engines return links to a collection of Web pages that have to be filtered. In a mining process of information about Goya, is necessary to discard all the pages that, while referring to the painter's name, are about other matters. To perform the page filtering, models implement a variety of approaches: from a simple static configuration to more advanced and dynamic methods.

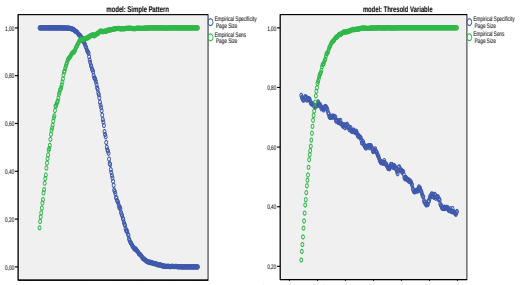

Fig. 4 and 5. Sensibility and Specificity of Model 1 and Model 2

A. Implementation details

The implementation is written in Python language and is modular, using a collection of classes that provide a flexible test environment to analyze new models. These classes are:

The control program: that implements the global loop, and calls the other classes.

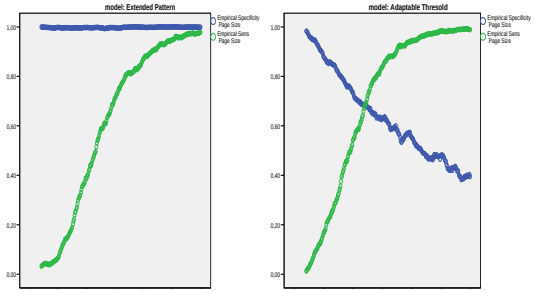

Fig. 6 and 7. Sensibility and Specificity of Model 3 and Model 4

The extraction class: that extracts text from web pages. Dynamic content adds noise to the text data of web pages and is hard to remove completely. Fortunately, this noise has very little effect on pattern mining that precisely is a good tool to filter it.

The generation class: that is responsible for generating the samples. It uses a method that generates the pages and another that is responsible for cleaning the samples in preparation for the next iteration.

The model classes: they implement a collection of models. In addition they use two of methods: one to calculate the sensibility and the other the specificity.

A random set of 200 files of re-sampled pages are created, increasing the page size with one phrase at each iteration. They are built from positive and negative seeds and placed in a directory where the model being assessed is applied. Then, the corresponding sensitivity and specificity are calculated. The results are rendered in the next section.

VI. RESULTS ANALYSIS

As described above, we have run our models over samples of 200 correct pages and 200 bad pages, with increasing size from 10 to 300 phrases. We have chosen to test the influence of the size of the page on the performance of the classifier.

We were able to verify that the size of the pages is strongly related to the performance of the models. As can be seen on the graphics, when the pages are small, models have low Sensibility: a lot of good pages are classified as bad pages. But when the pages are larger, the classifiers fail to recognize bad pages, so the Specificity decreases.

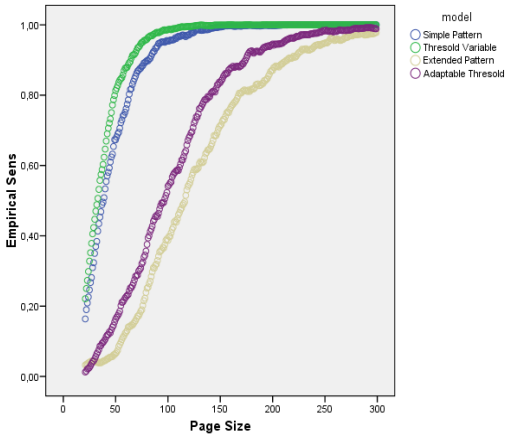

Fig. 8. Sensibility comparison for all Models

The result obtained Model 1 is shown in Fig. 4. It is the simplest approach, being static and using a short set of patterns. It has its best performance with pages of around 90 phrases where sensibility and specificity curves crossover.

We can see in Fig. 5 the results for Model 2, it has a similar pattern set to Model 1, but dynamically adjusted to the size of the page. Its performance is better than Model 1, having linear decrease of its specificity.

Model 3 and Model 4 use a larger set of patterns and both are dynamic but with different thresholds. We can see in Fig. 6 and 7 that their results are better than Models 1 and 2.

In Fig. 8 we can see the comparison of sensibilities of all the models and in Fig. 9 we see the comparison of specificities.

As we have stated, our test environment provides us with a clear comparison between models and how they perform with respect to the feature that we are analyzing. With this information, we can adapt the models and we can determine the best working conditions for them or design a strategy

where models are dynamically selected based on the size of the page.

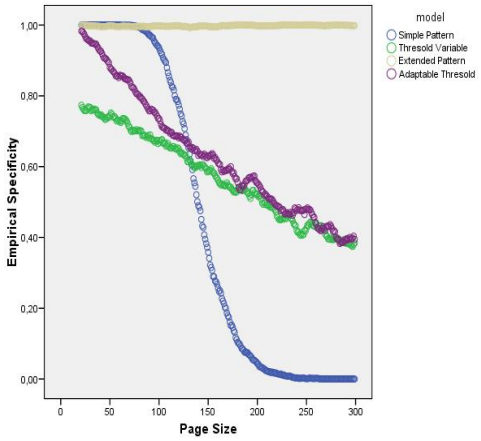

Fig. 9. Specificity comparison for all Models

VII. CONCLUSIONS

It is possible to improve the Web Learning process by refining page selection using Bootstrap technique to evaluate, refine and compare models based on patterns implemented for binary classification. A pure empirical sample for training and testing is limited, because the need for human intervention and the difficulty in finding pages with the desired qualities. Bootstrap provides a computer-based methodology that helps to have a wider dataset, where specific page features can be tested to determine how they really affect model performance and its outcome when real data are processed. We go further, by varying the characteristics of the sample and applying Bootstrap for each case analyzing model performance.

In our case, we were able to test how a pattern classifier is affected by the size of the page. We observed that if the page size was too small, the number of false negatives was excessively high and if the page size was big enough, the model performed better. This is an intrinsic problem for pattern models. Bootstrap technique provides excellent support for building dynamic models and their evaluation.

In addition, Bootstrap technique is a powerful tool for all related works with the Internet. It allows creating test environments that can simulate real conditions involving less human effort. Further work can be accomplished including new page and model features on the test environment as well as more advanced statistical techniques related with Bootstrap.

Web Learning improvement is used in the Urbano Robot environment. Information management is a key aspect of the robot software architecture; it allows a higher level of control providing intelligence to all the agents that comprise the system.

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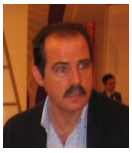

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Conceptualizing the e-Learning Assessment Domain using an Ontology Network

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***Abstract* —During the last year, approaches that use ontologies, the backbone of the Semantic Web technologies, for different purposes in the assessment domain of e-Learning have emerged. One of these purposes is the use of ontologies as a mean of providing a structure to guide the automated design of assessments. The most of the approaches that deal with this problem have proposed individual ontologies that model only a part of the assessment domain. The main contribution of this paper is an ontology network, called AONet, that conceptualizes the e-assessment domain with the aim of supporting the semi-automatic generation of it. The main advantage of this network is that it is enriched with rules for considering not only technical aspects of an assessment but also pedagogic.**

***Keywords* —e-assessment, ontology network, e-learning**

I. INTRODUCTION

In the last decade use of the Semantic Web technologies as tools for generating, organizing and personalizing e-learning content including e-assessment has attracted a great deal of attention [1], [2], [3], [4]. Within the applications related to assessment, these technologies could be used for different purposes [5]: (1) to capture the structure of a domain, (2) to capture experts representation of a domain, (3) to encode and bind content to a domain structure, (4) to score knowledge map, (5) to package and deliver content at different grain sizes, (6) to be part of a recommender system, and (7) to provide a structure to guide the automated design of assessment.

In literature, different approaches that define an ontology as an structure to guide the automated design of assessment can be found [5], [6], [7]. In [5] the authors have defined an ontology for supporting open questions generation whereas in [6] the authors only model simple choice questions. In [7], ontologies are used to generate individual problems examples for students that consist of a question and its solution. In spite of the advances done in this area, previous approaches have defined lightweight ontologies that only model the assessment domain from a technical viewpoint.

In order to e-Assessment be accepted by educators, a tool for supporting devising of valid and reliable assessments, from a pedagogical perspective, is needed. That means, it is required to establish an alignment of teaching, learning and assessment, and to define a mechanism for validating if the assessment covers all the learning objectives of a course and satisfies certain pedagogical principles [8]. With the aim of solving this problem, two main challenges have to be addressed. On the one hand, it is necessary to link the different knowledge sources involved in e-Assessment: the subject domain, the assessment domain and the learning objects in which the assessment has to be based. On the other hand, a set of rules that model the pedagogical principles that an e-Assessment has to fulfill is needed.

The main contribution of this paper is an ontology network, called AONet, that formalizes the conceptualization of the knowledge related to assessments in e-learning environments considering technical and pedagogical aspects. The use of networked ontologies in the context of e-Learning has been addressed by other authors. In [9] the authors address the problem of specifying the semantics relationships between networked ontologies by defining an specification of these semantic relationships for the conceptualization of a Educational Recommender Systems. In contrast to this work, the contribution of this paper is the conceptualization of the assessment in e-Learning.

The present paper is organized as follow. Section 2 defines the main concepts around the approach of this paper. Section 3 presents the main components of the AONet ontology network. Section 4 discusses an example of the AONet population. Finally, Section 5 is devoted to the conclusions and future work.

II. BACKGROUND

A. Ontology Definition

An ontology gives an explicit definition of the shared conceptualization of a certain domain [10]. Since ontology were used for different purposes in different discipline, several definition were built. Then, it is necessary to clarify what we have in mind when we talk about ontology. The definition used in this paper is based on [11].

From a pragmatic perspective, an ontology can be defined as a representational artifact based on four kinds of modeling components: concepts, roles, restrictions and individuals. *Concept* represents classes of objects. *Roles* describe binary relations among concepts; hence they also allow the description of properties of concepts. *Restrictions*

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are used to express properties of roles, i.e. cardinality. *Individuals* represent instances of classes, i.e. objects. Additionally, it is possible to use axioms and rules to infer new information. *Axioms* are logical sentences always true that express the properties of model paradigm. *Rules* are logical sentences that express characteristics of the domain, i.e. business rules. Formally,

Definition 1. *An ontology is a 6-tuple O:= {C, R, H, rel, A, Ru} where:*

- *Two disjoint sets, C(concepts) and R (relations).*
- *A concept hierarchy, a directed relation $H \rightarrow C \times C$ which is called concept hierarchy or taxonomy. So, H(C1, C2) means C1 is a subconcept of C2.*
- *A function rel: $R \rightarrow C \times C$ that relates the concepts non taxonomically.*
- *A set of axioms A expressed in an appropriate logical language.*
- *A set of rules Ru expressed in an appropriate logical language.*

In ontological community, ontologies can be classified as lightweight or heavyweight. A lightweight ontology is an ontology simply based on a hierarchy of concepts and a hierarchy of relations whereas a heavyweight ontology is a lightweight ontology enriched with rules used to fix the semantic interpretation of concepts and relations [10].

The component that differentiates an ontology is the set of rules. This set has to be expressed in an appropriate logical language. Considering that the OWL language is the standard for implementing an ontology and this is not always enough to do some deduction, then it is needed to combine OWL with other representation formalism as rules. One of the integration approaches is the Semantic Web Rule Language (SWRL), which provides the ability to express Horn-like rules in terms of OWL concepts [12].

In order to extract information from OWL ontologies a query language is needed. The most powerful language is SQWRL, which is based on the SWRL rule language and uses SWRL's strong semantic foundation as its formal underpinning. It also contains novel set operators that can be used to perform closure operations to allow limited forms of negation as fail-true, counting, and aggregation [13].

B. Ontology Network

An ontology network is a set of ontologies related together via a variety of different relationships such as mapping, modularization, version, and dependency. The elements of this set are called Networked Ontologies [14].

An ontology network differs from a set of interconnected individual ontologies in the relations among ontologies since in a ontology network the meta-relationships among the networked ontologies are explicitly expressed [9]. There are some models that cover both the syntactic and semantic aspects of dealing with ontology relationships in networked ontologies. In the DOOR (Descriptive Ontology of Ontology Relations) ontology, general relations between ontologies, such as includedIn, equivalentTo, similarTo, and versioning were defined by using ontological primitives and rules [14].

Concerning a support for implementing and management ontology networks, the NeOn Project can be mentioned (http://www.neon-project.org). NeOn has developed an open service-centered reference architecture for managing the complete life cycle of networked ontologies and metadata. This architecture is realized through the NeOn Toolkit and complemented by the NeOn methodology, which is a scenario-based methodology that supports the collaborative aspects of ontology development and reuse [15].

From a model integration point of view, within an ontology network each ontology conceptualizes a specific domain and plays a particular role. Then, the main advantage of using an ontology network is the conceptualization of a given domain in a modular way. The networked ontology is small enough to be understandable by any person and its maintenance is easy. In addition, several ontology designers could work on different networked ontologies concurrently.

C. The Assessment Domain

Assessment is an indispensable part of teaching and learning. Essentially, it is assessment that reinforces the learning approach a student adopts. If a student is often tested on higher-order thinking skills, they are likely to adopt the desirable deep holistic approach to e-Learning. On the contrary, if students are tested on lower-order thinking skills, they would probably be encouraged to practice the undesirable surface atomistic approach to learning [16]. An assessment can be considered as difficult to be realized within a distance learning phase.

Assessment can be classified in formal, informal and semi-formal assessment, depending on the formality and structure of assessment instruments [17]. Thereby the formal assessments are structured: there is a place and a time setting where they are carried out. There are different types of formal assessment: simple choice, multiple choice, correspondence, conceptual maps and performance evaluation among others. The semi-formal assessments are homework and tasks that the student makes during lesson day and continue out of it. These types of assessments are for example reading comprehension, mathematical problems, trials, projects development, programming, conclusion development, outcome analysis among other. The informal assessments are not structured at all. They consist of quizzes and activities observations that the teacher makes during class and consume a few minutes. Some instruments that are used for systematize these types of assessments are: class daily (class journal), control list, anecdotic annotations among other.

It is considered that an assessment is composed of

reactive. When teacher elaborates a reactive in order to make an assessment, uses the Bloom taxonomy [18]. This taxonomy is used to classify the course or programs goals as function of six level of complexity:

--First, click on the View menu and choose Print Layout.Knowledge: in this level teacher wants to evaluate the concept memorized by students, for example question about concepts.

--Comprehension: teacher wants to evaluate if the student understands the semantic relation of information taught. For example, conceptual maps.

--Application: teacher wants to evaluate if student can use the information taught to solve practical problems, for example mathematic problem.

--Analysis: teacher wants to evaluate the structure of knowledge, for example, outcome analysis.

--Synthesis: teacher wants to evaluate if student can elaborate original approaches base on concepts taught, for example trial.

--Evaluation: teacher wants to evaluate if the student can make a value judgment on topics taught, for example, conclusion development.

III. The AONet Ontology Network

With the aim of developing the AONet ontology network (Figure 1), the guidelines defined by NeOn Methodology were followed [15]. All of the ontologies defined in the AONet are implemented in OWL DL 1.0. Following, each of the ontology that composes the AONet is described

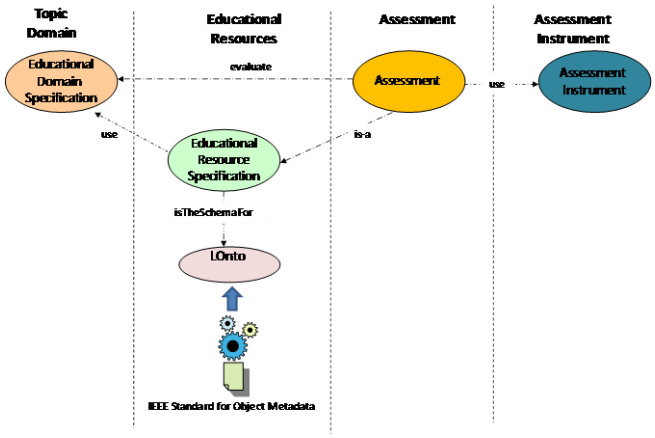

Fig. 1. The AONet ontology network

The *Educational Domain Specification* Ontology comprises concepts and relations defined in the knowledge domain that is evaluated. As can be noted, its structure and content depends on each particular domain.

The *Educational Resource Specification* Ontology comprises the educational resources used by educator in the teaching-learning process (TL). Some standards emerge to overcome the formalization of educational resources which are constantly evolving. In most cases, the use of learning object (LO) definition and its description by LOM [19] is the common denominator. In this way, it is possible to optimize the educational resource development process. This ontology is related with *Educational Domain Specification* ontology throughout *use* relationship. This relation identifies the connection between educational resources and concepts belonging to the specific domain. That is to say, an educational resource is developed in order to overcome different concepts, relations and definitions about to a domain topic. A LO metadata instance describes relevant characteristics of an educational resource, with the aims of facilitate the search, acquisition, interchange and evaluation of a resource by teacher, students and software systems. For this reason, we add to the ontology network the *LOnto* ontology built by Romero and Godoy (2010), which conceptualizes the semantic definition of LO based on *LOM* IEEE 1484.12.1 standard [18]. Then, the Educational Resource Specification ontology is related with LOnto through *isSchemaFor* relationship. The LOnto ontology is described in the next sub-section.

Assessments are part of the educational resources involved in the TL process when teacher wants to evaluate the concepts and skills acquired by students. In this context, the ontology network has the *Assessment* ontology which is related with *Educational Resource Specification* ontology through *is-a* relationship. In the same way, this ontology is related with *Educational Domain Specification* ontology through the *evaluate* relationship. These relations describe that an assessment is used to evaluate the results of the TL process about the Knowledge Domain.

There are different instruments to evaluate, which are modeled by the *Assessment Instrument* ontology. These instruments are used by teacher to generate an assessment. For instance an instrument is a True/False question, a conceptual map, an exercise, an essay activity among other. Then, the *Assessment* ontology has the *use* relationship with *Assessment Instrument* ontology.

The next sub-sections describe in detail the networked ontologies proposed in this paper.

A. The Assessment Ontology

The *Assessment* ontology (Figure 2) is the core of the AONet ontology network. This ontology conceptualizes the fact that an *Assessment* is an *Educational Resource* that is described by the LOM metadata (defined in the *LOnto* ontology). Each Assessment is composed by *Activity*. An *Activity* is a motto or exercise that evaluates a particular domain topic and it is composed by one or more *Reactive* which is an item that uses an *Instrument* (defined in the *AssessmentInstrument* ontology).

The objective of an assessment is to show that the learner has achieved competency in the topics of the unit or course being evaluated. These topics are conceptualizes in the

Educational Domain Specification ontology. This ontology is dependant of the course and how it could be built is out of the scope of this paper.

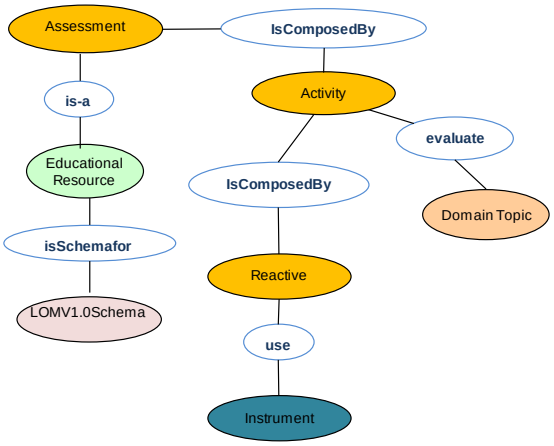

Fig. 2. The Assesment Ontology.

B. LOnto Ontology

The *LOnto* ontology is based on the IEEE Standard for Object Metadata LOM. This ontology was built by performing the activities defined in the Methontology methodogy. A deeper description of the *LOnto* ontology can be found in [2].

The *LOnto* ontology is defined around the concept of *LOMv1*.0schema which is the superclass of all the elements and data types of the LOM schema. In the upper level LOM has nine metadata categories:

--General: general information to describe LO as for instance title, keywords, abstract among other.

--Lifecycle: life cycle characteristics of a LO and revision.

--Meta-Metadata: information about the metadata instances.

--Technical: characteristics and technical requirement of a LO.

--Educational: characteristics of the LO relevant to the TL process.

--Rights: copy rights properties

--Relation: characteristics that relate the LO described and other instances.

--Annotation: comments about LO in educational environments, and information about when and who develop its content.

--Classification: describes a LO related to a particular classification system (taxonomy).

For each metadata category above mentioned it has been defined in the *LOnto* ontology a class that extends *LOMv1.0schema* depicting the aim of the metadata in this category. Classes are specialized in subclasses representing each particular element. Figure 3 shows a part of the LOnto ontology. As can be seen, there are nine subclasses of *LOMv1.0schema*: *Technical_Metadata*, *Lifecycle*, *Meta-Metadata*, *Educational*, *Right*, *Annotation* and *General*_Metadata. So, *General_Metadata* has two subclasses *Title* and *General*. Note that standard LOM describes a taxonomy of metadata for LO while LOnto not only takes into account this taxonomy but also add relation among elements and restriction rules.

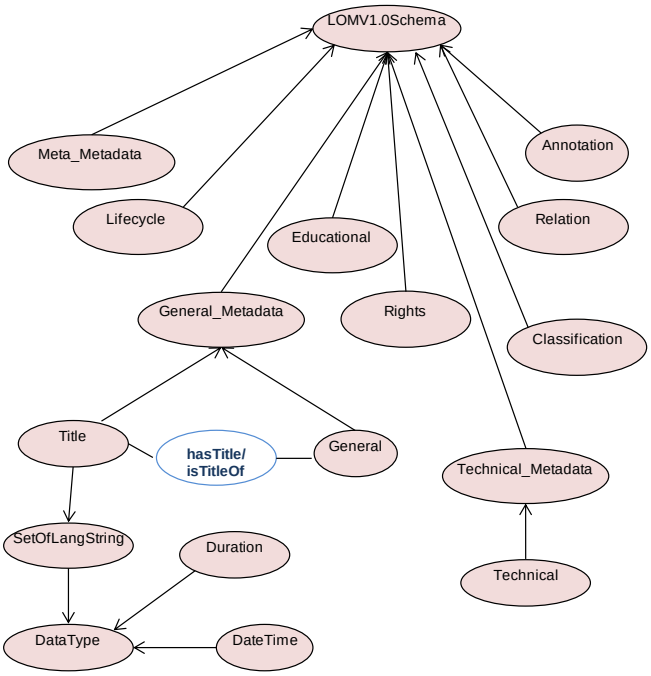

Fig. 3. An excerpt of the ontologies that compose the network.

C. AssessmentInstrument Ontology

The *Assessmentinstrument* ontology models different instruments that could be used in an assessment depending on the evaluation technique implemented. An assessment instrument is the physical support that is used to collect the information about the expected learning of students. This ontology is shown in Figure 4. The main concept is I*nstrument*. There are two types of instruments: *FormalInstrument* and S*emiformalInstrument* representing formal and semiformal techniques respectively. As *semiformalInstrument*, we have considered two type of it: *SimpleInstrument* such as *Exercises*, C*onceptualMap* and *Essays*, and *CompositeInstrument* as *portfolios* that consist of a collection of *SimpleInstrument* elements that help recording learning process and students' progress.

As *FormalInstrument* we considered two classifications: *EssayActivity*, where students have to elaborate the answer and *ObjectiveActivity*, where students have to identify the correct answer. *EssayActivity*, is specialized in two sub-concepts: *RestrictedEssay* and *UnrestrictedEssay*. *ObjectiveActivity* is one of the most used by professor because it eliminates the subjectivity in the rating, even

when it has an additional complexity to develop it. *Objective Activity* has three sub-concepts: *Choice, Correspondence* and *Completition*. *Choice* has *Option* associated. The concept *Option* is specialized in two sub-concepts: *Distractor* and *TrueOption*. *Distractor* are items that are not correct and *TrueOption* is the correct item. The concept *Choice* is specialized in: *SimpleChoice* contains only one correct option and *MultipleChoice* can have more than one correct option. In both cases, *Option* can only have Boolean answer associated. Finally the concept *Answer* can be of different types: *TrueFalse*, *Numeric*, *Text* and *Relation*.

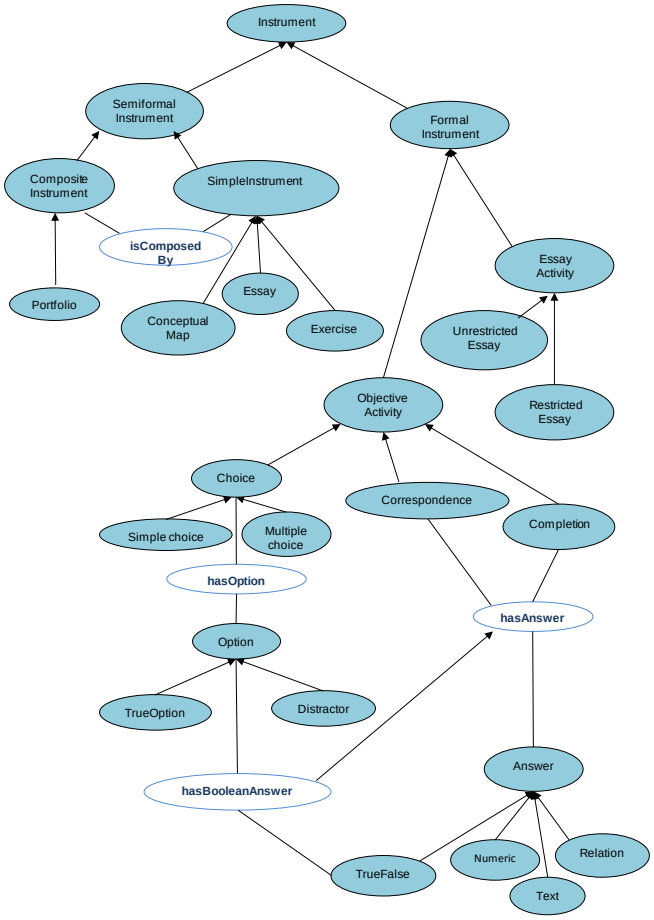

Fig. 4. Assessment Instrument Ontology

D.Rules for determining the assessment quality.

According with [19] there are some pedagogical recommendations that teachers need to take into account in the development of assessment. If these guides are followed by teachers, we can say that the assessment is valid in a pedagogical sense. In this work, these recommendations were used in order to define rules to express the restrictions in the generation of valid assessment.

Considering that Multiple and Simple Choice are the most used instruments, we use them in this paper to illustrate the rules. From a pedagogical perspective, it is recommended that there is always a right option. It is recommended also that this type of activities do not include options such as "none of them" or "all of them". In general, items should be belonging to the context of content area being assessed in a clear and simple way and preferably written in the affirmative mode. The *distractors* should appear as attractive as possible to the uninformed student.

Table I shows the pedagogical rules that have been taken into account. The first column describes the rule in a colloquial language. Second column shows the fist-order logic description of such rules. Note that in using First-order logic we consider reification of concepts such as:

Simple choice ∈ simpleChoices
Multiple choice ∈ multipleChoices
Option ∈ Options
trueOption ∈ TrueOptions
attribute ∈ attributes

TABLE I
PEDAGOGICAL RULES FOR SIMPLE AND MULTIPLE CHOICES EXPRESSED IN FIRST-ORDER LOGIC

Description	First-Order Logic
Simple choice	
1. A simple choice activity must have at least four options	$\Im \models \forall x \in simpleChoices\ (\exists\ y, z, w, r \in Options\ (hasOption(x,y) \wedge hasOption(x,z) \wedge hasOption(x,w) \wedge hasOption(x,r) \wedge y \neq z \neq w \neq r \wedge z \neq w \neq r \wedge w \neq r)$
2. A simple choice activity must have only one true option	$\Im \models \forall\ x \in simpleChoices\ (\exists! y \in TrueOptions\ hasOption(x,y))$
Multiple choice	
3. A multiple choice activity must have more than one true option.	$\Im \models \forall\ x \in multipleChoices\ (\exists\ y, z \in TrueOptions\ hasOption(x,y) \wedge hasOption(x,z) \wedge y \neq z)$
4. A multiple choice activity must have more than four options.	$\Im \models \forall x \in multipleChoices\ (\exists\ y, z, w, r \in Options\ (hasOption(x,y) \wedge hasOption(x,z) \wedge hasOption(x,w) \wedge hasOption(x,r) \wedge y \neq z \neq w \neq r \wedge z \neq w \neq r \wedge w \neq r)$
5. A multiple choice activity cannot have option like: "all of them" or "none of them"	$\Im \models \forall x \in multipleChoices\ (\exists\ y \in Options\ ((hasOption(x,y) \wedge\ \exists\ z \in attributes\ (hasAttribute(y, z) \wedge value(z,w) \wedge (w \neq$ "all of them" $\vee\ w \neq$ "none of them")))$

We have defined logical rules for representing each restriction above mentioned. Then, these rules were implemented in SWRL and SQWRL as shown next.

The first rule validates if a simple choice has the correct quantity of options (restriction 1) as follow:

$$SimpleChoice(?sc) \wedge hasOption(?sc, ?o) \wedge sqwrl:makeSet(?os, ?o) \wedge sqwrl:groupBy(?os, ?sc) \wedge sqwrl:size(?t,?os) \wedge sqwrl:greaterThanOrEqual(?t,4) \rightarrow optionQuantityValid(?sc) \quad (1)$$

In the same way, the restriction b) is validated with the following rule:

SimpleChoice(?sc) ∧ trueOption(?d) ∧ sqwrl:makeSet(?s1,?d) ∧ sqwrl:groupBy(?s1, ?sc) ∧ sqwrl:size(?t, ?s1) ∧ sqwrl:equal(?t,1) → answerQuantityValid(?sc) (2)

For multiple choices we have three restrictions (3, 4 and 5 from table I). Restriction 3 and 4 from table I are represented with rules (3), (4) respectively. Restriction 5 from table I is represented with rules (5) and (6):

MultipleChoice(?mc) ∧ hasOption(?mc, ?d) ∧ trueOption(?d) ∧ sqwrl:makeSet(?s1, ?d) ∧ sqwrl:groupBy(?s1, ?mc) ∧ sqwrl:greaterThan(?t,1) → answerQuantityValid(?mc) (3)

MultipleChoice(?mc) ∧ hasOption(?mc, ?o) ∧ sqwrl:makeSet(?os, ?o) ∧ sqwrl:groupBy(?os, ?mc) ∧ sqwrl:size(?t, ?os) ∧ sqwrl:greaterThanOrEqual(?t,4) → optionQuantityValid(?mc) (4)

MultipleChoice(?mc) ∧ hasOption(?mc, ?o) ∧ label(?o, ?l) ∧ sqwrl:normalizeSpace(?n,?l) ∧ sqwrl:stringEqualIgnoreCase(?n, "all of them") ∧ sqwrl:size(?t, ?n) ∧ sqwrl:Equal(?t,0) → whithoutAll(?mc) (5)

multipleChoice(?mc) ∧ hasOption(?mc, ?o) ∧ lavel(?o, ?l) ∧ sqwrl:normalizeSpace(?n,?l) ∧ sqwrl:stringEqualIgnoreCase(?n, "none of them") ∧ sqwrl:size(?t, ?n) ∧ sqwrl:Equal(?t,0) → withoutNon(?mc) (6)

Finally if a simple choice meets the restriction (1) and (2) we can say that this simple choice is valid. This statement is represented with the following rule:

SimpleChoice(?sc) ∧ optionQuantityValid(?sc) ∧ answerQuantityValid(?sc) → valid(?sc) (7)

In the same way, if a multiple choices meets the restriction (3), (4), (5) and (6) is a valid multiple choices:

multipleChoice(?mc) ∧ whithoutAll(?mc) ∧ whithoutNon(?mc) ∧ optionQuantityValid(?mc) ∧ answerQuantityValid(?mc) → valid(?mc) (8)

IV. EXPERIMENTS AND DISCUSSIONS

As an example we consider final exam related to an Artificial Intelligence course, shown in figure 5. This exam has two activities. The first activity is about search domain topic and has two reactive. The latter is about Machine learning domain topic and has one reactive corresponding to a multiple choice.

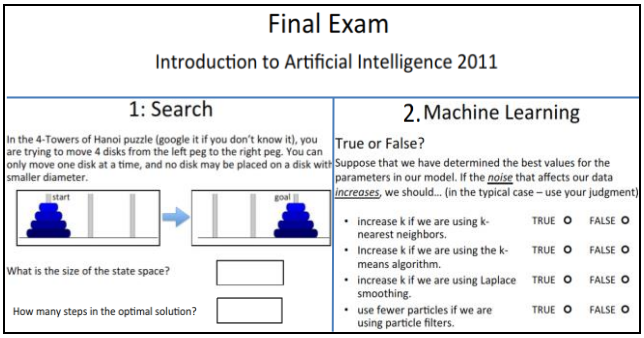

Fig. 5. The Artificial Intelligence Assessment. www.ai-class

Figure 6 shows the result to instantiate the ontology network in order to represent the artificial intelligence assessment. Note that instances have a prefix that identifies the ontology they belong. The asse:ExamIntroductionToAI instance represents the assessment, it has two activities: asse:SearchActivity and asse:MachingLearningActivity instances and it has lonto:IntroductionToAITitle instance associated by the isSchemaFor relationship. Each activity evaluate a domain topic as it is shown with the relations between asse:SearchActivity and dom:Search instances and between asse:MachingLearningActivity and dom:MatchinLearning instances.

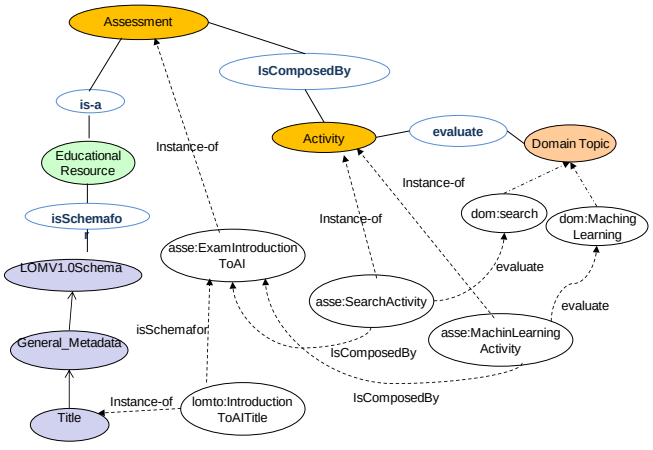

Fig. 6. Assessment instance

As can be seen in Figure 7, the *asse:SearchActivity* instance has in turn two instances of reactive associated

through the link *isComposedBy*: *asse:Item1*, and *asse:Item2* instances. Both reactive instances use instruments represented by the instances: *inst:StateSpace* and *inst:OptimalSolution*. Both instances of *Completion* have answers associated represented by the instances *inst:SpaceStateNum* and *inst:OptimalSolutionNum* respectively.

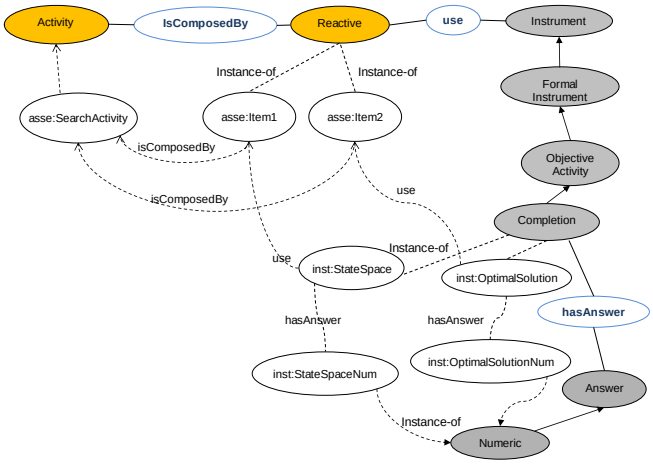

Fig. 7. Search activity decomposition

In the same way figure 8 shows the instantiation of Machine learning activity. The *asse:MachinLearningActivity* instance has *asse:Item1* instance associated. The *asse:Item1* uses as instrument the *inst:MultipleChoiceML*, which is an instance of *Multiple Choice* instrument. In turn it has two instances of *Distractor* associated: *inst:Op3* and *inst:Op4* and two instances of *TrueOption*: inst:O*p1* and *inst:Op2*. Both *inst:Op3* and *inst:Op4* have *inst:False* associated, which is in turn an instance of *TrueFalse*. Both *inst*:*Op1* and *inst:Op2* have *inst:True* instance associated as answer.

Taking into account the rules (3), (4), (5), (6) and (8) defined in Section III.C, it can be said that the multiple choice is well defined from a pedagogical point of view.

V. CONCLUSIONS AND FUTURE WORK

This work has shown a preliminary ontology network which purpose is to conceptualize the assessment domain in a TL process. The modularization that this network provides allows us concentrate the attention on a particular domain and incrementally build a more general model relating different ontologies. The concepts related with assessment domain were presented. Mainly, this work focused on describing the ontology network that models the different areas related to assessment in an educational context taking into account not only technical aspects but also pedagogical one.

The LOnto ontology conceptualizes not only the metadata proposed by IEEE standard but also the relations and restriction among metadata that are not present in the standard, giving as result an improvement in the use of such standard.

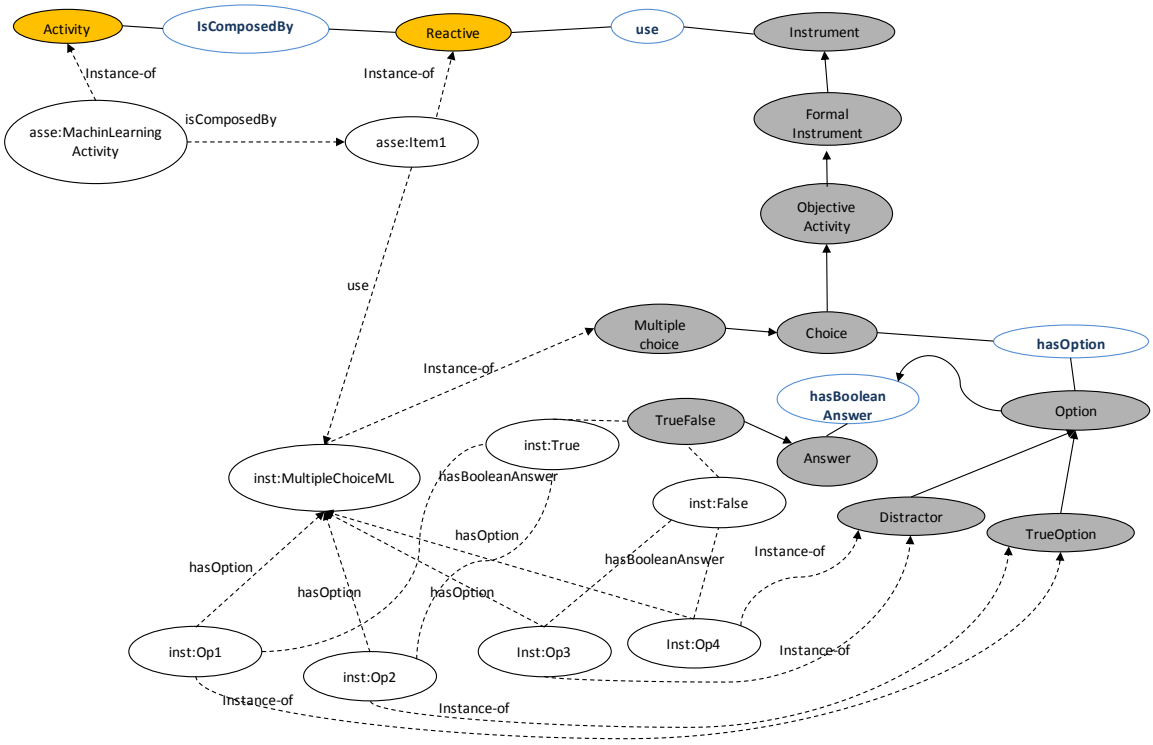

Fig. 8. Maching Learning activity instantiation

The *Assessment* ontology represents the main concepts found in an assessment domain, giving in a different ontology the instruments used to develop an assessment. In this way, we can consider on the one hand, the way in which to develop an assessment and on the other hand, the relation that this assessment has with students, teachers and educational program. Through ontology network it is possible to add new ontology and relates it with the existing one. The SWRL rules to determine the validity of a given assessment were presented. These rules are based on pedagogical criteria enabling assessment to be considered by educators in an e-learning process. In this first approach, we focus on multiple and simple choice activities due to they are the most popular activities used by educators in e-learning.

Finally, an example of the ontology network population by using an Artificial Intelligence assessment was discussed. In the future, we intend to acquire additional validation assessments for a broad evaluation and refinement of the ontology.

We are working on improvement of the ontology network adding new concepts and relation. In turn, we are developing test using different assessments provided from different knowledge domain. In addition, we are working on developing a tool for supporting an assessment generation by using the ontology network presented in this paper.

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O-ODM Framework for Object-Relational Databases

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***Abstract* —Object-Relational Databases introduce new features which allow manipulating objects in databases. At present, many DBMS offer resources to manipulate objects in database, but most application developers just map class to relations tables, failing to exploit the O-R model strength. The lack of tools that aid the database project contributes to this situation. This work presents O-ODM (Object-Object Database Mapping), a persistent framework that maps objects from OO applications to database objects. Persistent Frameworks have been used to aid developers, managing all access to DBMS. This kind of tool allows developers to persist objects without solid knowledge about DBMSs and specific languages, improving the developers' productivity, mainly when a different DBMS is used. The results of some experiments using O-ODM are shown.**

***Keywords* —Object-Relational Databases. Persistence Framework. Java Annotations. SQL:2008**

I. INTRODUCTION

Persistent frameworks, frequently called ORM (Object Relational Mapping) tool [6]-[7]-[8], have been used to aid database projects. This kind of tool maps objects from application to relation (relational databases - RD) [11]. Using ORM tools, developers have advantages; (1) they can persist data in RD without solid knowledge of Relational Database Management System (RDBMS). It allows developers to focus on application development (OO paradigm and language aspects); (2) all data access is made through the tool, since ORM tools are integrated in programming environment; developers can use a single environment to do this work; (3) generally, when more than one DBMS is used, only one instruction is modified. This instruction indicates the new DBMS; then, all the code produced by the tool to one DBMS is automatically changed to another. In case the instruction was not available, the developer would have to produce the new SQL code according to the characteristic of the DBMS chosen. All these aspects aid both: the point of view system maintenance and developers' productivity. Thus, the benefit of using persistent frameworks cannot be ignored. On the other hand, it is necessary to consider the new characteristics of Object-Relation Databases (ORDB).

ORDB allows manipulating objects in databases. Many DBMS offer new resources such as UDTs (User Data Types), composite types, REF types, inheritance and others that can be used to model objects in databases. Besides, using REF types to represent relationship between objects can result in improvement of performance given that no field needs to be created in an existing or new relation. This characteristic could be more suitable for new applications that have emerged and which present complex objects such as CAD/CAM (Computer Aided Design/ Computer Aided Manufacturing), GIS (Geographic Information System), Genetic, etc [9]. Adding to this, using ORDB, objects from an application must be mapped to objects from databases; thus the impedance mismatch, which has been reported in the literature and in real applications as a problem, can be avoided. Another ORDB advantage is the possibility to use only one conceptual model for both the application and the data tiers [1]. Generally, the entity-relationship model (ERM) and UML class model are built when the relational model is employed. This causes an overhead not only related to mapping class to relation, but also to elaborating the ERM and the need of specific knowledge to generate this model.

Since the strength of the Object-Relational Model might be more explored [4] together with the lack of tools to aid projects and maintenance of ORDB, this paper proposes an O-ODBM (Object- Object Database Mapping) tool, an object-relational persistence framework. O-ODBM maps an object from the application to the ORDB object [16].

However, not all DBMS implement all the resources of objects specified in the SQL standard. Therefore, some elements can be unavailable in some of them. Undoubtedly, this is another important aspect which contributes to ignoring object resources from DBMS and adds complexity to build CASE and Persistent framework tools to ORDB.

An example was used to evaluate the O-ODBM. We here present not only the O-ODBM characteristics, but also an example and the results.

To develop the O-ODBM, characteristics and operations were studied which are defined or implemented in JPA (Java Persistence API) and/or JDO (Java Data Object) standards and in Hibernate and Torque frameworks. Some of those characteristics, which provide benefits and /or facilities to developers, were implemented in our first version of O-ODBM Framework.

This article is organized as follows. In chapter 2, some characteristics of JPA (Java Persistence API) and JDO (Java Data Object), which were incorporated to O-ODBM, are introduced. Chapter 3 introduces the O-ODBM. Chapter 4 presents the example employed to evaluate the O-ODBM tool,

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and the results. Finally, chapter 5 concludes and presents future works.

II. JPA AND JDO STANDARDS – SOME CHARACTERISTICS

The O-ODBM *Framework* was developed in Java programming language. Some reasons pointed for this choice are (1) many ORM *Frameworks* available are based on Java language. (2) Java language facilitates the interoperability and (3) the number of the OO applications that developed in Java are increasing.

The JDO (*Java Data Object*) [7] e JPA (*Java Persistence API*) [8] standards define mapping from application object to relations of RDB. These standards also include a set of properties that simplify persistence and data access. Some of these properties were highlighted considering the scope of the O-ODBM project:

- all access to data is made only by the framework. As a result, it is no longer necessary to have a solid knowledge about the DB, SQL and DBMS used.
- offers a language for manipulating data that is closer to OO programming language than SQL.
- transaction manage, which allows the developer to define the beginning and end of transactions. The Framework is responsible for the interface with the DBMS used.
- mechanism for performance control to access, insert, delete and update objects. In OO applications, references between objects are very common. These references are mapped to tables and integrity rules, so that when a query is made, more than a table could be accessed. The use of annotations [12] is employed by the developer to indicate which objects must be persisted. Annotations allow adding information to java classes directly. The Framework uses this information to create the SQL code to generate tables, attributes, integrity rules in attributes and between tables, etc.

III. PROJECT OF O-ODBM FRAMEWORK

The rules of mapping defined for RDB are not suitable, since the new data types connected to the OO paradigm available in ORDBMS are not considered. The rules defined for the Framework proposed are summarized in Tables I and II. More details of these rules can be found in [1]-[2], which are a complementation of [4]-[9]-[14] from the point of view of real applications.

Requirements of O-ODBM Framework

A set of requirements, which are detailed as follows, was defined to guide the development of the Framework. In doing so, the characteristics of ORM Frameworks were considered, which are advantages for both application and developers. Then, JPA and JDO standards were studied, as well as Hibernate and torque implementations [6]-[7]-[8]. In view of the ORDBMS, SQL:2008 was also studied, along with Oracle 11g release 2 and BD2 9.7.5 version DBMS. To simplify the reference, the requirements were identified by the R letter and a sequential number, presented as follows.

R1 – to control the referential integrity rule connected to

TABLE I
MAPPING OF OBJECT FROM APPLICATIONS TO ORDBMS OBJECTS - ADAPTED FROM [1]

OO	ORDBMS	Justify
Class	Table UDT Typed table	Classes may be mapped to conventional tables. However, if the intention is to define methods and/or hierarchies, an UDT must be defined and, to store data, a typed table connected to UDT needs be created.
Abstract class	UDT	an UDT should be created whithout a typed table conected to it to represent an abstract class. In this case, the UDT would be used for defining other UDTs and as it does not have a typed table connected to it, instances will not be persisted.
Simple attribute	Build-in type	SQL:2008 presents many built-in types such as integer, real, etc. It is hence possible to find a corresponding type in SQL for each primitive type of Java.
multivalued attribute	Array or Multiset	multidimensional structures are suitable to store attributes of the same type (collections).
Methods	UDT methods	It is possible to define methods connected to UDTs. Thus, developers can choose to define methods in the database or in the application.

REF type. ORDB allows defining the relationship between objects using REF. However, if an object A, which is

TABLE II
MAPPING OF ASSOCIATIONS AND HIERARCHY IN ORDBMS – ADAPTED FROM [1]

Association		Corresponding in ORDBMS	
Bidiretional Association	Composition/ Aggregation/ Association	1..1	a cross reference is defined, i.e., each class maintains a reference (REF) to the other.
		1..*	a cross reference is also used, although the aggregated class will be an Array ou a Multiset of references.
Unidirectional Association		Similarly to the bidirectional associations above presented, though the reference will be only in table.	
Nth Association (three or more classes)		A table or a UDT is defined with the name of the association. The table or the UDT (and the typed table) must maintain references to the classes involved.	
Associative Class		a table or a UDT can be defined for the association class similarly to nth association.	
Generalization/ Specialization		a UDT is defined for each class of the hierarchy. Typed table would be defined later if data need to be persisted.	

referenced by object B, is removed, B gets a null reference.

Then, a rule, similar to the rule that controls foreign key in RDB, needs to be implemented to avoid a null reference.

R2 - Flexibility for multiple platforms of databases. This requirement means that the Framework gives a simple mechanism for a developer to change the DBMS and all SQL code for persistence and data access, which was generated by the framework for the first DBMS, will automatically be replaced by the code for the new DBMS. It is important to highlight, as explained before, there are differences among ORDBMS and some resources for database object can be not available; therefore, this may be the most difficult requirement to be achieved.

R3 – The developer does not need to know the SQL and DBMS employed. Thus, the framework has to present a language or a mechanism for object manipulation very similar to the OO programming language (if compared with the SQL). As a result, the learning process is facilitated, since the developer does not need to know SQL to use a DBMS.

R4 – Managing DBMS connections – including to open, to close and to verify the timeout of connections. If there are unfinished transactions, the Framework will keep the connection open until the commit or rollback of these transactions. The Framework would force itself to interrupt the transactions, despite keeping (ex. doing rollback) the data integrity in the database.

R5 – Managing the execution of transactions. For this, the Framework has to offer an interface for the developer to define his transactions.

R6 – Automatic code generation for object schema in DBMS, including codes for manipulating these objects.

R7 – the framework will be an access point to database; making the direct connection between application and database unnecessary.

R8 – use of annotations for defining which will be persisted in the database, facilitating the configuration of objects schema. The ORM Frameworks studied employs a similar mechanism; however, in the case of O-ODBM Framework, appropriated annotations have to be created.

R9 – Implementation of inheritance in database, according to OO.

R10 – Implementation of unidirectional, bidirectional and multivalued relationship, using reference (REF) to object when possible.

R11 – Application performance is not degraded.

R12 – Data could be retrieved on demand. In other words, according to what is defined by the developer, the Framework will postpone or will not retrieve related data to improve the performance of the data access [6]-[8]. This is an important aspect for performance because one object referenced by another can keep references for others and so on, which would certainly degrade the data access performance. Therefore, when there is no interest in referenced objects, the retrieval of object and its references would cause unnecessary performance degradation.

R13 – Data could be persisted on demand, which is defined as cascade property in JPA [8]. In this case, the Framework would do the persistence of the associated objects, preventing null references from being found, i.e., references for objects that do not exist

A. Architecture of O-ODBM Framework O-ODBM

The tool accepts input in two different formats: Java code, in which annotations are used to declare persistent classes, or XML files, which correspond to SQL code for the DBMS chosen. In the first case, the Framework presents a set of annotations, similarly to the ORM Frameworks. In the second case, the XML file, which represents the logical schema to ORDB, is generated by a case tool [1] for ORDB. The Framework should be part of the development integrated environment, in which from a conceptual model (ex. UML class model), or from a logical schema, the OR database can be automatically implemented in the DBMS chosen and accessed by the Framework.

A XSD (XML Schema Definition) was formalized to register the mapping from Java classes to ORDB objects. In this XSD, according to SQL:2008 [10] the ORDB data types are defined that define database objects, methods, inheritance, collections and other OO concepts. Therefore, in case the input of the Framework is a XML file produced by the modeling tool, the XSD would be used to verify it. In addition, XML documents are also used internally by the tool for describing the necessary information to mapping among different formats produced by the tool

Figure 1 introduces the architecture of the O-ODBM Framework and its components are described as follows.

Configuration Processor: reads the Java class annotated with the annotations introduced by the Framework. Once the Java classes have been interpreted, this module processes the annotations and generates the XML code with OR structure based on SQL:2008. It was decided to first generate the SQL code for SQL:2008 and then translate it to a dialect of specific DBMS. This decision was made due to the differences among DBMS regarding the object resources offered. Some DBMS implement part of these resources only; moreover, the implementation of the specific element can be different among these DBMS. On the other hand, the SQL:2008 not only has all the elements related to objects, but can also be easily

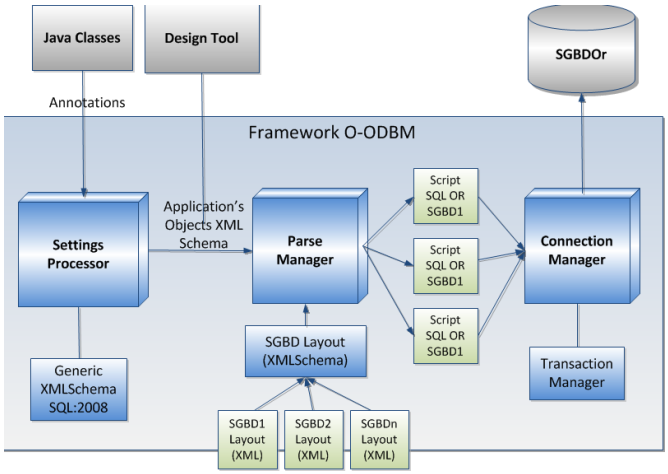

Fig. 1. Architecture of O-ODBM Framework.

translated into another SQL dialect. The XML-SQL schema that represents the database object schema is equivalent to the application object schema. The XML-SQL schema generated by the Configuration Processor is the input of the Conversion Manager Component.

Conversion Manager: generates the SQL scripts to be executed by the DBMS chosen. The Conversion Manager uses the DBMS layout file appropriated for translating the XML-SQL code into an adequate SQL dialect. For this, the Framework uses the XML file (DBMS Layout) that has the specific syntax for each DBMS. The output of this module is the SQL script, which is submitted to the DBMS by the Connection Manager Component.

Connection Manager: all the operations between the Framework and DBMS, for example, execution of SQL script to create structures, persistence and retrieval of objects are made by a connection. This component manages the connections with DBMS and this is transparent for the developer. Connections are automatically opened by the Framework whenever the operation is submitted.

Transaction Controller: manages all the transactions with the DBMS. When a transaction is opened, this component is activated and when the connection needs be closed, this component is consulted to verify/guarantee that there are no transactions open for that connection. In this process, a transaction can be finished (rollback or commit), or the connection is not closed. This component also manages the transaction inactive time and automatically finishes it if the transaction achieves the timeout.

DBMS Layout: Since a XML file, produced by the CASE tool, could be the input for the Framework; a XSD is also used by the Framework, similarly to the SQL schema, for validating this file.

B. Annotations

The API (*Application Programming Interface*) of the Framework is integrated with the programming environment. This way, the developer has the set of annotations, which were produced in this work, available for use and integrated with the development environment. The type of annotation will determine the map from Java class to ORDB element made by the tool. TABLE III introduces the set of annotations. TABLE IV and TABLE V show more annotations that are used for defining parameters and default values, respectively. Experienced developers in Framework and/or in ORDB could redefine default values.

IV. EXAMPLE USED FOR TESTINGTHE FRAMEWORK

An example, the persistent object schema of which is shown in Figure 2, was used for testing the applicability of the Framework. The main concern was to evaluate the behavior for queries involving objects in hierarchy and the use of reference (REF) for representing association between objects. However, this evaluation is not enough to draw conclusions about the performance of ORDBMS. Therefore, a more careful evaluation must be made in the future.

TABLE III
ANNOTATIONS.

Annotation	Description
@DbObject	indicates the class must be persisted.
@DbField	indicates the attribute must be persisted.
@DbMethod	indicates the object method must be created in DBMS.
@DbInhetitance	indicates the object is part of the hierarchy. Then, the hierarchy must be represented in DBMS. If the parent object has not been annotated with DbObject, only the derived objects would be part of a hierarchy in DBMS, although the characteristics inherited will be part of the derivated objects.
@DbRelation	indicates the attribute represents the association. The associations are represented by the inclusion of the attributes in associated classes. These attributes make references between themselves and, depending on the cardinality of association, this reference may be to an object or to a collection of objects..

In the example, only the annotations shown in Table III

TABLE IV
CONFIGURATIONS FOR @DBFIELD ANNOTATION.S.

PARAMETER	Default value	Description
size	255 for text and numbers.	defines the attribute max size.
isPK	none	indicates the attribute will be a primary key.
autoIncremet	none	indicates the attribute values will be generated by the DBMS.
type	keeps the equivalent data type in the DBMS.	defines the data types that will be used in DBMS

TABLE V
CONFIGURATIONS FOR @DBFIELD ANNOTATION.S.

PARAMETER	Default value	Description
size	255 for text and numbers.	defines the attribute max size.
isPK	none	indicates the attribute will be a primary key.
autoIncremet	none	indicates the attribute values will be generated by the DBMS.
type	keeps the equivalent data type in the DBMS.	defines the data types that will be used in DBMS

were used.

Since the class was annotated, a DAO class for each persistent class was generated. Then, using the O-ODBM Framework, the SQL script of the database schema was generated and executed in DBMS. After that, insert, update, delete and select operations were carried out. First, DB2 DBMS was used, and later Oracle DBMS. It is important to highlight that all these procedures were made by changing the directives of configurations only, i. e., neither class nor annotations were changed. TABLE VI introduces the results of each operation

V. EVALUATION

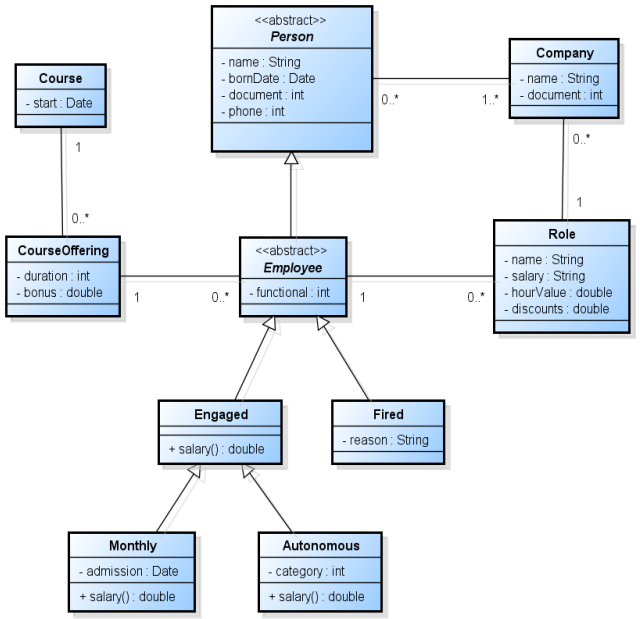

Fig. 2. Class Diagram used in the example to evaluate the Framework.

The set of requirements, defined in section III, and the result of the tests were used for evaluating the o-ODBM Framework.

A. Compliance with the requirements

R1 – the referential integrity rule will be implemented by the Framework if the Java code presenting the appropriate annotations (i.e., the attribute of the object has @DbRelation annotation). Therefore, the Framework will implement an operation to guarantee that null references do not exist.

R2 – the Framework only supports Oracle and DB2, although the modification of one into another is very simple for the developer, since he only declares what DBMS will used and the Framework generates the appropriate code. There are few DBMS that support OR characteristics and this limits the application of this requirement. However, it can be considered met with the use of these two DBMS.

R3 – the Framework has no data access language. However, the annotations can be used for persistence, queries and updating objects.

R4 – the Framework manages all the connections with the DBMS.

TABLE VI
TIME OF OPERATION.

	JDBC	O-ODBM
creation of schema	-----	2689 ms.
initialization	512 ms	734 ms
insert	129 ms	141 ms
update	198 ms	216 ms
Select	155 ms	173 ms

R5 – the Framework presents an interface that allows the developer to define the transaction beginning and end. In fact, the control of the transaction is made by the JDBC, which passes this control on to DBMS.

R6 – using the annotated class, the Framework generates the code to interact with the DBMS.

R7 – The Framework is a centralized data access point.

R8 – as stated before, a set of annotations is available and the developer can use it to indicate which must be persisted.

R9 – the Framework generates the code with the structures to represent inheritance as long as the correct annotation has been used. Then, UDTs hierarchy and typed tables are created in the database.

R10 – since there is the indication of the cardinality of association between the objects, the Framework, by default, creates a list of references in both objects for N:N cardinality. For 1:N, the reference can be to (1) only one object, (2) a list of objects, (3) the reference can be on both sides, in this case, on one side the reference is for an object and on other one, for a list of objects. This is similar to the OO application.

R11 – to evaluate if there is or not performance degradation, the decision was to compare the time spent for database access with and without using the Framework. For this, the OR schema was generated manually, using a JDBC. It was verified that the use of the Framework does not cause performance degradation.

R12 – the capacity of retrieving data on demand (lazy and eager strategy in JPA [6]-[8]) is implemented by the Framework. It allows having fewer unnecessary accesses to DBMS.

R13- cascade strategy (JPA) [6]-[8] is implemented by the Framework.

B. Analysis of Results

Three measures were used for assessing the results that are:

Productivity: here, the productivity is the amount of code the user needs to create to interact with the Framework, as compared with the amount that he has to generate without the Framework. It is worth highlighting that the code generated by the Framework will present a lower number of errors than the code generated by the developer. Another important issue is related to the necessary time for learning to use the Framework. This time will be less than that spent to learn

about SQL and ORDB.

Support to OR characteristics: it is the capacity of generating code with structures that allow implementing OO characteristics in DBMS such as object, inheritance, aggregation, composition, references, multivalued structures using the elements available in ORDB [14].

Performance: here, performance is the response time to execute the specific operation in ORDB with and without the use of Framework.

The use of annotations aims to increase productivity, since the use of the Framework is simpler and more intuitive from the developer's point of view. Learning was also considered facilitated by the use of annotations, since the set of annotations are integrated to the programming environment, which the developer interacts with more naturally, similarly to other Frameworks, such as Hibernate.

Another important issue, the use of annotations eliminates the need of more detailed knowledge about the local of persistence and objects there defined. In other words, it is transparent for the developer if UDTs, typed tables, REF types, etc were created in DBMS. This directly affects the developer's productivity, since there are less concepts he/she needs know.

Similarly to other ORM tools, such as Hibernate, an interface was available to allow developers to define transactions.

Without using Framework, it was necessary to generate all the database schema manually in each DBMS and JDBC was employed to make the connection and to access each database. It is not possible, therefore, to compare the performance for database schema generation between these two approaches (with and without the use of Framework). Conversely, the performance considering these two approaches for the insert, update and select operations were really closed, without significant differences. Concerning performance, i.e., response time in data access, few tests were performed with a simple example and with a small number of data. Then, specific work must be done for a real performance evaluation. In direct access (JDBC), the developer needs detailed knowledge about the ORDB, DBMS used and available data types, besides the access language.

As to OR characteristics, the O-ODBM Framework did the mapping using resources of DBMS objects and inheritance, aggregation, composition, references and multivalued structure were employed in this process, i.e., UDTs, REFs, ROWs, MULTSETs and ARRAYs were used. Although there are differences among Oracle, DB2 and SQL:2008, the Framework generated appropriate code to map and to access all of them.

VI. Comments and Conclusions

As the ORM Frameworks do not use the new available data type for ORDBM, this article introduced a proposal for a new Framework for ORDBMS, called O-ODBM. As the others, O-ODBM provides a transparent persistence mechanism. The advantage of the O-ODBM is the use of ORDB, so that the strength of object-relational model is not ignored [4] and its suitability for new applications can be more explored. For example, for scientific applications, it is necessary to deal with a large number of data, which can be related or gotten in groups to obtain information of interest. In this case, the use of RDB could achieve the high level of redundancy of data due to the kind of associations that will be necessary. Besides, to obtain statistic information, not only the existent functions (ex. average, some, etc.) could be necessary. The use of elements, such as UDTs from ORDBMS, allows new solutions to be more easily employed [15].

According to the evaluation made in this work, the O-ODBM was efficient. The advantages are: new concepts are not necessary to use it; the performance remains near the direct access (without Framework); automated generation of code for the persistence of objects; SQL and DBMS do not need be known by the developer; persistence mechanism is transparent for the developer.

Finally, the O-ODBM Framework is still a prototype and for the tool to be effectively used, functionalities need to be implemented or improved. However, the prototype was effective to demonstrate the viability of the proposal.

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Linked Data Methodologies for Managing Information about Television Content

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***Abstract* — OntoTV is a television information management system designed for improving the quality and quantity of the information available in the current television platforms. In order to achieve this objective, OntoTV (1) collects the information offered by the broadcasters, (2) integrates it into a ontology-based data structure, (3) extracts extra data from alternative television sources, and (4) makes possible for the user to perform queries over the stored information.**

This document shows the way Linked Data methodologies have been applied in OntoTV system, and the improvements in the data consumption and publication processes that have been obtained as result. On the one hand, the possibility of accessing to information available in the Web of Data has made possible to offer more complete descriptions about the programs, as well as more detailed guides than those obtained by using classic collection methods. On the other hand, as the information of the television programs and channels is published according to the Linked Data philosophy, it becomes available not only for OntoTV clients, but also for other agents able to access Linked Data resources, who could offer the viewer more fresh and innovative features.

***Keywords* — Linked Data, OntoTV, ontology, consuming, publishing.**

I. INTRODUCTION

NOWADAYS, the number of television platforms and channels number is growing significantly, so it is not easy for the viewer to decide what he want to watch in a certain moment of the day. Even when providers offer some descriptions about the programmes they broadcast, this information is not detailed enough and does not permit to perform advanced operations like content recommendations.

The creation of a management information system that gives solution to these problems could be very beneficial for the viewers as well as their television experience. This system aims to become a universal and easy-to-use television solution, able to offer more advanced features than those implemented in classic set-top-boxes. When information is scarce, it should access to external sources in order to complete the missing data, in a transparent and flexible fashion. This way the clients have access to a common television information service, no matter the particular device that is being used: a mobile phone, a decoder, or a personal computer. In previous researches in this same direction [1], OntoTV system was created in order to fulfil these requirements.

OntoTV collects information about television contents from various sources and represents all the data using knowledge engineering and ontologies. However, there are still some problems related to the way OntoTV manages the television information. First, the system uses a kind of software components called "Crawlers", which retrieve information from non-structured sources like HTML Web pages. These components consume many computational resources, and have to be customized to fit the particularities of every of the considered data sources. Secondly, only the clients who are compatible with the OntoTV's specifications can access the information stored in his knowledge base.

In this situation, the Linked Data consuming and publishing methodology [2] is gaining presence and importance in the Web. It consists of a set of principles for structuring and interlinking data that make information more useful and easy to reuse by others. As this methodology is built on the top of widely used standards in the Web, such as URI and HTTP, the information shared in this way becomes accessible to both humans and machines. At the end, this interlinked and easy accessible information obtained from different sources is what we commonly known as "Web of Data".

The main objective in this research is to apply the Linked Data methodology in OntoTV, in order to improve the data collection processes and the viewers' television experience. To to achieve that, some components for consuming television information from Linked Data sources have been designed. More specifically, OntoTV will retrieve extra information about movies, obtaining more complete electronic programming guides than before. Also, the data stored in the knowledge base will be now published according to Linked Data principles, so it will be available in the Web of Data for all these agents who are able to access to it.

II. ONTOTV SYSTEM

The OntoTV system (ONTOlogy-based management system for digital TeleVision) is a television content information management system that allows the viewers to access data about programs that have been or will be broadcasted in the various digital platforms. Due to the fact

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that this system incorporates appropriate mechanisms for data acquisition, it can provide the user detailed content descriptions and allows him to perform advanced search and recommendation operations. The system OntoTV was previously presented in [4], where the most important features were shown:

- To **integrate** all the possible information about television content by using different collection mechanisms for accessing the different existing sources.
- To **represent** the collected data by using ontologies, making possible to perform complex reasoning processes and inferences that generate new knowledge [5].
- To **execute** operations over the knowledge base that are interesting for the user. For example searches and recommendations, with a high degree of personalization.
- To allow the user to **interact** with the system in an easy and intuitive way. The client device sends requests for the execution of certain operations, receives the results from the server, and displays them to the user. The viewers can access the system, no matter which kind of implementation is running on their devices: MHP, Google TV, Media Centers, etc.

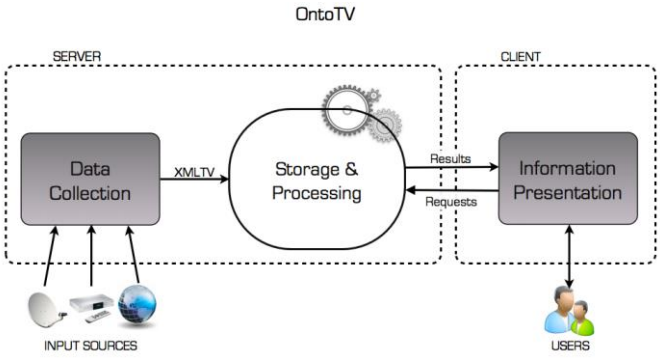

Fig. 1. Main modules inside OntoTV system.

Figure 1 shows a schema of the OntoTV system. The "Storage and Processing" module includes the television content ontology and the different search and recommendation algorithms that are executed over the knowledge base. "Data Collection" and "Information Presentation" modules will be described in more detail below, since they are the ones that will be modified for being compliant to Linked Data principles. This is done to improve the way OntoTV system consumes and publishes the data.

A. Data Collection module

This module directly reads the data from the sources supported by the system. The process consists of being able to interpret the format of a certain input source, and transform the extracted information to the XMLTV format, which is the one used in the system for representing the input files.

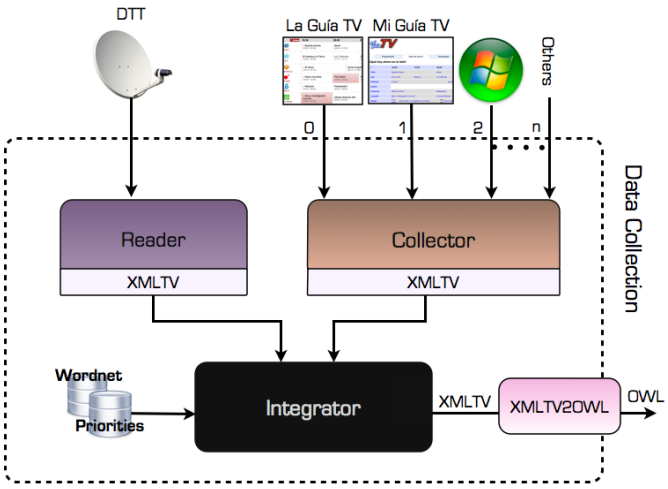

Fig. 2. "Data Collection" module in OntoTV

In Figure 2 the different components inside the "Data Collection" module can be seen. "Reader" components extract the data that television broadcasters offer in their platforms and channels. "Collector" components connect to external server, normally using the TCP/IP protocol, in order to obtain alternative programming guides. Finally, the component called "Integrator" includes in a single file all the information in XMLTV format that has been previously retrieved by the other two components.

Data Sources supported in OntoTV

According to the schema shown in Figure 2, "Reader" and "Collector" components access the following television data sources to feed OntoTV's knowledge base:

- Information included in the DTT data stream, accessed by performing the processes described in [1].
- Accessing to "La Guía TV", a Web page that contains information regarding to television contents broadcasted by the major television channels in Spain. It is necessary to perform translation processes from HTML to XMLTV.
- Accessing to "Mi Guía TV". It is a Web page with similar characteristics than the previous case.
- Accessing to "Windows Media Center" guide. Microsoft offers very complete programming guides for the main television channels in Spain. OntoTV extracts information from these guides and converts them into XMLTV format.

Figure 3 shows three fragments of XMLTV files related to the film "Blade Runner", broadcasted in Spain on the channel "Antena 3" on December 14, 2010. There are some differences in the level of detail provided by each source: for example the fragment corresponding to "Mi GuíaTV" is completely empty, while the "Windows Media Center" one contains precise information about the categories associated with that particular content.

```
<!-- DTT READER -->
<programme channel="15" start="20101214210940" stop="2
    <title>Blade Runner</title>
    <sub-title></sub-title>
    <desc></desc>
</programme>
<!-- LAGUIATV.COM -->
<programme start="20101214220000 +0100" channel="CLa
    <title lang="es">El cine de La 2: Blade Runner</
    <category lang="es">pelicula</category>
</programme>
<!-- MIGUIATV.COM -->
  <!--NO INFORMATION RETRIEVED -->

<!--WINDOWS MEDIA CENTER -->
<programme start="20101214220000 +0100" stop="2010121
    <title lang="es">El cine de La 2</title>
    <desc lang="es">Espacio que incluye la emisión de
    <date>20070427</date>
    <category lang="es">Otro</category>
    <category lang="es">Película</category>
    <length units="minutes">120</length>
</programme>
```

Fig. 3. XMLTV fragments collected from the various considered data sources.

Merging Duplicate Instances of Television Programs.
OntoTV is able to detect if descriptions from different sources refer to the same content. Duplicate descriptions about the same program are identified and resolved according to mechanisms described in [4]. Various criteria are taken into account in this process: *spatio-temporal similarity* of content (if two descriptions refer to the same channel, beginning and ending almost at the same time, then it is highly possible that both belong to the same program), *similarity in the titles*, (applying relative comparison string functions as the Levenshtein one [3]), or *global similarity* (given two descriptions, we look for words that appear in both description, regardless of the exact position in the text).

```
<!-- FUSION XMLTV -->
<programme start="20101214220000 +0100" stop="20101214235000 +01
    <title lang="es">El cine de La 2: Blade Runner</title>
    <desc lang="es">Espacio que incluye la emisión de una pelícu
    <date>20070427</date>
    <category lang="es">Otro</category>
    <category lang="es">Película</category>
        <category lang="es">pelicula</category>
    <length units="minutes">120</length>
</programme>
```

Fig. 4. XMLTV description obtained after merging the information from the considered data sources.

Once all the descriptions that belong to the same content have been identificated, it is neccesary to merge them into a single instance, as shown in Figure 4. If a description provides one attribute that is missing in the rest of sources, this field is taken immediately. However, if there is some overlapped parameters in the descriptions, the involved fields are concatenated if possible. If not, those who come from less important sources are discarded. At the end of this step for each content we obtain a unique description that is more complete and detailed than those extracted individually from each source.

Disadvantages of this Approach

As can be seen, all the considered sources provide information about television content. The problem is that the consuming data strategies used in each case are different: the access to DTT is done by interpreting DVB-SI tables, information from Web pages is extracted from certain HTML tags, etc. So each time a new data source needs to be incorporated to the system, is necessary to implement a new access method, as well as integrate it into the global data collection workflow. This process usually requires considerable engineering efforts, which makes more difficult for OntoTV to access new data stores where new television information can be found.

In addition to this lack of uniformity in the collection methods, the processes involved in them are usually very resource intensive because the information is not sufficiently structured.

B. Presentation of the Information

The client-server architecture that has been implemented in OntoTV makes possible that a great variety of television devices can access to the functionalities offered by this system regardless of their particular characteristics. This fact is especially important today, given the different options that are available on the market: MHP set-top-boxes, Google TV televisions, mobile devices with Android operating system, etc. For all these platforms it is possible to develop a client application, called "OntoTV-Client", which performs all the necessary functions to present the television information to the viewer. The premises are to have an Internet connection (for stablishing the client-server communication), as well as being able to use platform-specific libraries for tracking the user's actions, generate graphical interfaces, and interchange messages between client and server.

TABLE I
MESSAGE INTERCHANGING IN ONTOTV'S CLIENTS

Type of Message	Output	Input
Content Management	- Search request, taking into account various criteria.	List of contents that match the selected criteria.
	- Request for a detailed description of a particular content.	Description of a particular content.
	- Ask for a personalized electronic programming guide.	List of contents that match the user preferences.
User Data	- Sending of local events (like button presses, menu navigation, etc.) - Sending of information available on the explicit preferences menu.	User profile that is stored on the server.
Server Connection	- Open connection request.	Confirmation of successful connection.
	- Closing conncetion request.	Confirmation of successful disconnection.

However this information exchange is done by using certain

types of messages and a communication sequence that have been defined beforehand and are exclusive for OntoTV system. Then, for establishing a valid communication with the server, a client must implement this particular set of requests and responses.

Table 1 lists the most important messages the client sends and receives when communicating with OntoTV server. The HTTP protocol and the interchange of XMLTV files over TCP/IP are the basis for implementing those messages.

Disadvantages of this Approach

The problem with this approach is that, despite being independent of the platform used by the consumer, it is always necessary to implement this specific set of messages, even when the agent is not exactly a OntoTV client but another entity that eventually needs television information.

For example, a website that offers the user some miscellaneous information can access OntoTV for retrieving the broadcast times of different television programs, but it needs to incorporate all the communication logic that an OntoTV's client's is supposed to use.

III. Applying Linked Data Methodology

After analizing the way OntoTV operates when providing different features to the viewers, various problems have arised. On the one hand, traditional mechanisms for extracting information from television sources have been probed to be inefficient, due to the heterogeneity in the access methods and the accessing to non-structured information. On the other hand, only clients that are compliant with OntoTV specification can access its television information. This section aims to solve these problems by applying the Linked Data consuming and publishing principles [6], continuing the research line initiated by other television systems that also have used semantic technologies, as Notube [7], [8].

A. Linked Data Consumption

This section shows how to incorporate new Linked Data consumption strategies in the module "Data Collection", in order to increase the amount of television content information available in its knowledge base.

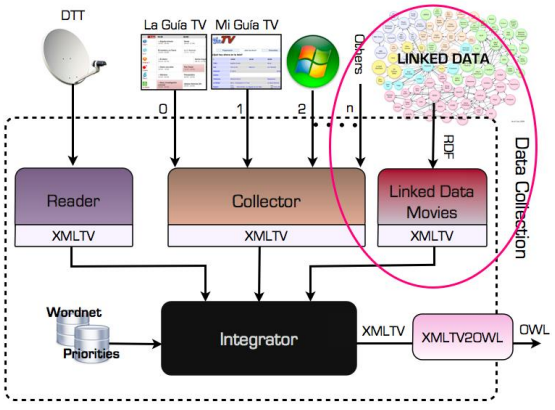

Fig. 5. Extended "Collection Data" module that accesses the Web of Data.

Specifically, the objective is to describe the way the new component called "LinkedData Movies" operates (see Figure 5). As summary, this component accesses Linked Data resources, identifies certain information about movies that is available on the Web of Data, and complete the missing parts of the XMLTV program guides that OntoTV has previously retrieved.

Alternatives for accessing the Web of Data

Several alternatives for accessing information about television content in the Web of Data have been studied. The most significant ones are shown below:

- Accessing to LinkedMDB dataset. It is possible to execute SPARQL queries over the entry point that this dataset provides, in order to obtain information about movies. However, although LinkedMDB is intended to be in the Web of Data the same than IMBD is today in Web of Documents, there are still a lot of films entries missing.
- To implement the method described in [6], which applies the "Crawling" consumption pattern. It consists of using Jena TDB[2] to create a local storage structure where the information collected by the Linked Data crawler DSpider[3] is continuously added. The disadvantage of this approach is that it has a high computational cost. In addition, the collection process is slow and must be repeated periodically to ensure that the information inside the local storage is not out-dated.
- Access the semantic mashup SIG.MA. The advantage of this alternative is that it is possible to access to relevant information from a great variety of semantic sources, without executing very intensive and slow collection processes. In addition, SIG.MA performs frequent updates in their data indexes so the obtained information about movies is updated enough.

The "LinkedData Movies" component

The component "LinkedData Movies" has been coded in Java and performs the following actions in order to extract information about movies from the Web of Data:

a) Getting the movie descriptions in RDF format. The basic mechanism to access Linked Data on the Web is to resolve HTTP URIs for retrieving a certain RDF data fragment. In the case of the SIG.MA mashup, it is necessary to perform an HTTP request to the following URL "http://sig.ma/search?q=moviename", where "moviename" is a string indicating the name of the movie we are looking for. Code 1 shows how to obtain RDF data from SIG.MA using the library "org.apache.commons.httpclient":

Code 1. Requesting RDF Data to the Server

2 http://openjena.org/TDB/
3 http://code.google.com/p/ldspider/

```
import org.apache.commons.httpclient.*;
   //Get Method
   HttpClient client = new HttpClient();
   HttpMethod method = new GetMethod(urlsigma + filmName);
   method.addRequestHeader("Accept",
   "application/rdf+xml");
   int responseCode = client.executeMethod(method);
   //Write RDF to FILE
   InputStream is = method.getResponseBodyAsStream();
   OutputStream os = new FileOutputStream(rdfFile);
   byte[] buffer = new byte[4096];
   for (int n; (n = is.read(buffer)) != -1;)
       os.write(buffer, 0, n);
```

b) Use SPARQL queries to extract the desired information from the previously obtained RDF file. The RDF file, which contains information about a particular film, is already available in the consumer side. So it is possible to extract the desired fragment of information by executing SPARQL queries over it. The "Jena ARQ" library has been used for this purpose, as shown below.

CODE 2. EXECUTING SPARQL QUERIES OVER THE RDF FILE

```
import com.hp.hpl.jena.query.*;
Model m;
m = ModelFactory.createMemModelMaker().createModel("");
model.read(in,null);
//Execute the Query
Query query = QueryFactory.create(stquery);
QueryExecution qe;
qe = QueryExecutionFactory.create(query, m);
ResultSet results = qe.execSelect();
```

Code 2 is able to execute the SPARQL query stored inside the variable "stquery". Figure 6 shows an example that extracts the name of the film's director by accessing the property "director", which is included on the SIG.MA vocabulary (http://sig.ma/property/).

```
PREFIX sigma: http://sig.ma/property/
PREFIX rdfs: http://www.w3.org/2000/01/rdf-schema#
SELECT ?director ?name
WHERE {
    ?film  sigma:director ?director.
    ?director rdfs:label ?name.
    }
-------------------------------------------------------------------
| director                                  | name               |
===================================================================
| <http://dbpedia.org/resource/Ridley_Scott> | "Sir Ridley Scott" |
-------------------------------------------------------------------
```

Fig. 6. SPARQL query for retrieving the name of the film's director.

In a similar way, it is possible to obtain also more film's attributes like the language, the country, the length, and others shown in Table 2. This way descriptions about movies that are available in OntoTV system become more detailed and complete than those obtained before accessing the Web of Data.

TABLE II
OTHER ITEMS ABOUT FILMS THAT CAN BE RETRIEVED FROM SIG.MA

Item	XMLTV Element	SIG.MA Property
Language	tv.programme.language	<sigma:language>
Length	tv.programme.length	<sigma:runtime>
Country	tv.programme.country	<sigma:country
Rating	tv.programme.rating	<sigma:ratings>
Director	tv.programme.credits.director	<sigma:director>
Actor	tv.programme.credits.actor	<sigma:starring>
Writer	tv.programme.credits.writer	<sigma:writer>
Producer	tv.programme.credits.producer	<sigma:producer>
Composer	tv.programme.credits.composer	<sigma:music_composer>
Image	tv.programme.icon	<sigma:picture>

c) Accessing to Other Datasets. The Linked Data philosophy is based on the idea of navigating through the global knowledge. For this reason, if the information that SIG.MA offers is insufficient, it is possible to retrieve alternative data by following the links available in the RDF triples. For example, in Figure 6, the URI for the director Ridley Scott refers to a document in the DBpedia dataset. Additional data can be obtained when URI is resolved with the same process described avobe, as seen in Figure 7:

```
PREFIX dbpedia-owl: <http://dbpedia.org/ontology/>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
SELECT ?date
WHERE {
    ?director  dbpedia-owl:birthDate ?date.
    }
Finding for more information in http://dbpedia.org/resource/Ridley_Scott
-----------------------------------------------------
| date                                              |
=====================================================
| "1937-11-30"^^<http://www.w3.org/2001/XMLSchema#date> |
-----------------------------------------------------
```

Fig. 7. SPARQL query for retrieving the director's birth date.

In the end, OntoTV stores much more information about the film on which the collection process has been applied. For example Figure 8 shows how the description of "Blade Runner" is much more detailed than before the access to the Web of Data (check again Figure 4 for a better comparison). All this extra information allows the system to offer the viewers more accurate results when executing operations, such as search and recommendations.

```
<!-- FINAL XMLTV -->
<programme start="20101214220000 +0100" stop="20101214235000 +0100"
    <title lang="es">El cine de La 2: Blade Runner</title>
    <desc lang="es">Espacio que incluye la emisión de una película.<
    <category lang="es">Otro</category> <category lang="es">Película
    <category lang="es">pelicula</category>
    <date>20070427</date>
    <language>English</language>
    <country>United States</country>
    <credits>
      <director>Ridley Scott, 1927-11-30, South Shields.</director>
      <actor>Harrison Ford</actor> <actor>Rutger Hauer</actor>
      <actor>Sean Young</actor> <actor>Edward James Olmos</actor>
      <actor>Daryl Hannah</actor> <actor>M. Emmet Walsh</actor>
      <writer>Philip K. Dick</writer> <producer>Michael Deeley</prod
      <composer>Vangelis</composer>
    </credits>
    <icon src="http://getmovielink.com/images/covers/BladeRunner.jpg
    <length units="minutes">120</length>
</programme>
```

Fig. 8. Description available in OntoTV system about the movie "Blade Runner", after accessing information in the Web of Data.

Analyzing the entire collection workflow, it is clear the benefits obtained when consuming information available on the Web of Data over traditional accesses to unstructured data sources. The use of URIs and the HTTP protocol provides a more uniform access to different datasets and makes easier to incorporate new sources in OntoTV system. Likewise, the fact that the data is represented in RDF format and structured according to certain vocabularies (such as SIG.MA), greatly facilitates the way the information is interpreted and processed.

B. Publishing Data according to Linked Data principles

As noted in paragraph 2.b, the only way to access the information stored in OntoTV's knowledge base is to implement a predefined and specific communication logic for the interchange of information between the client and the server. This section explains the changes made in OntoTV in order to publish television content descriptions by following Linked Data principles. This way any agent that is able to access the Web of Data can also take profit of them.

Television Domain Ontology

The first step in order to publish data using Linked Data principles is to choose a valid domain vocabulary that allows representation of television information. In previous works, OntoTV used the ontology proposed in AVATAR [9]. However, for the current research this ontology has been replaced by the one used by the BBC (British Broadcasting Corporation), called BBC Programmes. This organization has created this vocabulary by using its wide experience in the use of semantic technologies. This background knowledge has led to consider this alternative as the most suitable one for representing television programs and channels in a standard way, that is one of the main principles in the Linked Data philosophy.

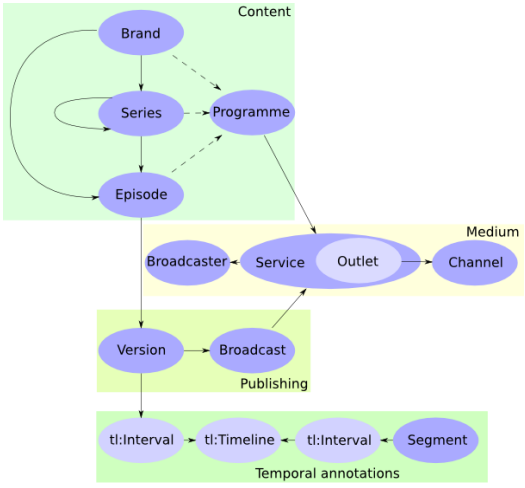

Fig. 9. BBC Programmes (www.bbc.co.uk/ontologies/programmes).

This ontology provides a simple vocabulary that includes multiple classes related to the television content and broadcasters domain. In the Figure 9, the box "Content" (Programme, Brand, Series, Episode) contains classes for representing different types of television content. Inside the "Medium" box we can find the class "Channel" for representing the different kinds of transmission mediums, as well as the class "Broadcaster " for modelling the television organization. The "Publishing" box includes the class "Version", which is very important for representing the different occurrences of a particular program in a certain channel, date and time. Classes inside the box "Temporal Annotations" have not been considered in this research.

Generating the RDF Data

This section describes the different steps to be performed in order to transform the XMLTV information about television channels and programs (previously extracted by the "Data Collection" module) into instances of the BBC Programes ontology.

The software component that performs this translation process is XMLTV2OWL. As seen in Figure 2, this component is included inside the "Data Collection" module. However, it plays an important role in the process of making this information available in the Web of Data, because it is the one who generates the instances that will conform the RDF code. The stages of this process are described in more detail below:

a) Step 1. Each element of type "<channel>" in the XMLTV file is transformed into an instance of the class "Service" in the BBC ontology. Before including this new individual in the knowledge base, it is necessary to check that there are no collisions with those instances that are already stored in OntoTV (because the channel has been previously inserted in the system). Also, an instance of the class "Broadcast" is created in order to relate the current instance of the program with the particular channel that broadcasts it. Figure 10 shows the RDF example code for the film "Blade Runner" in Turtle notation.

```
<http://data.ontotv.es/service/0a566f0d-27f4-9648-adf5-03a0cabf365a>
      a       po:Service
      po:broadcaster "RTVE"
      po:parent_service <http://data.ontotv.es/service/RTVE>
      po:channel <TDT>.

<http://data.ontotv.es/broadcast/f3dafbb0-8407-47c0-8267-8d87381b95ba>
      a       po:Broadcast ;
      po:broadcast_of <http://data.ontotv.es/version/2dfe2b07-1df3-4111-8
      po:broadcast_on <http://data.ontotv.es/service/0a566f0d-27f4-9648-a
```

Fig. 10. Instances of the classes "Service" and "Broadcast" in the BBC Programmes" ontology.

b) *Step 2*. For each "<programme>" XMLTV element:
An instance of the class "Programme" is created in the OntoTV's knowledge database, by transforming certain XMLTV fields into their corresponding properties in the BBC ontology. Before including that instance in the knowledge base, it is necessary to check if this particular program has not been previously added to the system. The Figure 11 shows the RDF example code for the movie "Blade Runner":

```
<http://data.ontotv.es/episode/7ffdb885-fcf4-44cd-80a7-7c137c8d457a>
      a       po:Episode ;
      dc:title "El cine de la 2: Blade Runner"" ;
      po:id   "7ffdb885-fcf4-44cd-80a7-7c137c8d457a" ;
      po:long_synopsis "Espacio que incluye la emision de una pelicula. Pa
      po:masterbrand "La 2" ;
      po:microsites <http://www.rtve.es/alacarta/tve/la2/> ;
      po:subject "Pelicula" , "pelicula" , "Otro" ;
      po:version <http://data.ontotv.es/version/2dfe2b07-1df3-4111-8f2d-70
      po:actor <http://data.ontotv.es/person/Harrison_Ford> <http://data.o
      po:director <http://data.ontotv.es/person/Ridley_Scott> ;
      po:duration "120"^^xsd:int ;
      po:executive_producer <http://data.ontotv.es/person/Michael_Deelay.
```

Fig.11. Instance of the class "Episode" for the movie "Blade Runner".

- An instance of class "Version" in the BBC ontology is created. This instance stores the attributes "start" and "stop" that are present in every "<programme>" XMLTV element. Also, this instance is associated with the one created in the previous step by using the property "po:version" in the class "Program". Before including it in the knowledge base, XMLTV2OWL looks again for possible collisions between individuals. If some duplicates are found, only the most recent instance is maintained. Figure 12 shows the corresponding RDF code for the "Blade Runner" example:

```
<http://data.ontotv.es/version/2dfe2b07-1df3-4111-8f2d-70adde8d2097>
      po:sound_format "urn:ard:tva:metadata:cs:ARDFormatCS:2008:3.2" ;
      po:subtitle_language "Spanish" ;
      po:aspect_ratio "urn:ard:tva:metadata:cs:ARDFormatCS:2008:1.24" ;
      po:time [ a       event:Interval ;
                event:end "2012-07-23T18:48:29.959Z"^^xsd:dateTime ;
                event:start "2011-11-15T20:45:00Z"^^xsd:dateTime
              ] .
```

Fig. 12. Instance of the class "Version" for the movie "Blade Runner".

Interlinking with other Linked Data Datasets

The Linked Data methodology put special emphasis on the need of establishing links between data fragments that are semantically related in some way [10]. This makes possible to browse the entire knowledge, jumping from one concept to another. For this reason, OntoTV executes some special processes that try to match the local instances available in the RDF base with other similar individuals from external datasets. This way it is possible to create links between OntoTV's triples and other resources in the Web of Data:

- Links to the DBpedia dataset: DPpedia is considered to be the core of the Web of Data cloud. It contains information about any domain, so it has become a reference dataset in the Linked Data research field. Here, the instance matching process has been performed by applying simple lexical similarity functions over the textual attributes in the classes "Service" and "Programme" (like for example, "producer "," director "," actor ", etc.) Figure 13 shows examples of such links:

```
<http://data.ontotv.es/person/Harrison_Ford>
     a       foaf:Person ;
      foaf:gender "m" ;
      foaf:nick "Harrison Ford" ;
      owl:sameAs <http://dbpedia.org/resource/Harrison_Ford>

<http://data.ontotv.es/person/Ridley_Scott>
     a       foaf:Person ;
      foaf:gender "m" ;
      foaf:nick "Ridley Scott" ;
      owl:sameAs <http://dbpedia.org/resource/Ridley_Scott> .
```

Fig. 13. Persons and their corresponding links to instances in DBpedia.

- Links to the "Geonames" dataset. Certain individuals in the knowledge base refer to geographical places. In these cases, OntoTV checks whether these instances are geographically equivalent to others in "Geonames" dataset, which contains over eight million names of places that are available for search.
- Links to "LinkedMDB" dataset. Although this dataset still contains only a few records of certain movies, it will become the reference dataset for information about films in the Web of Data. For this reason, OntoTV will try to identify possible alignments between the local instances and the ones stored in this dataset, especially for some attributes like "director", "actor" and "film". Again, string similarity functions on the titles will be applied.

The module "LD Publishing" (see Figure 14) is responsible of accessing to external datasets in order to execute all these the instance matching processes. As shown in Figure 13, the links found with this method are expressed in the form of <owl:sameas> triplets.

Finally, it is neccesary to mention the existence of some data publishing frameworks such as Openlink Virtuoso[4], which stores RDF triples, generates HTML pages containing the data (so they can be browsed online), and creates a SPARQL endpoint where this kind of queries can be executed. However, this possibility has not been addressed in this research.

C. OntoTV after applying Linked Data methodologies

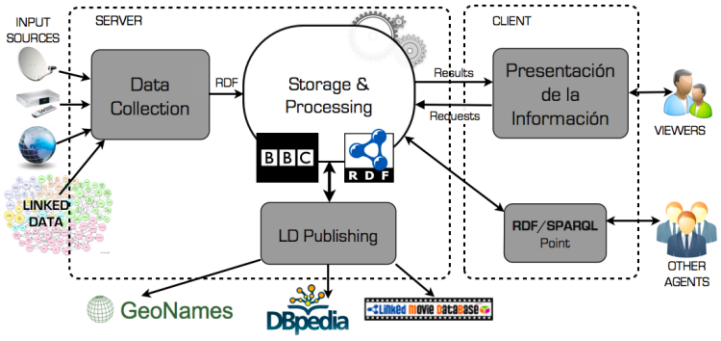

Fig. 14. OntoTV schema after applying Linked Data principles.

Figure 14 shows the changes occurred in OntoTV after the application of Linked Data methodologies. On the one hand, the "Collection Data" module adds a new source: The Web of Data cloud. Furthermore, the "Storage and Processing" module now contains the RDF information represented according to the BCC ontology and conveniently linked to other external dataset. Regarding the way the information is presented to the user, not only the OntoTV's clients have access to the data, but also all the agents who are able to access resources in the Linked Data cloud.

IV. CONCLUSIONS

Nowadays viewers have to do a considerable effort every time they want to find, access or compare television programs, due to the great variety of them available in the different platforms. OntoTV system has been designed for giving a solution to this problem. It uses advanced data collection techniques and ontology-based representation methods.

4 http://virtuoso.openlinksw.com/

However, the previous version of OntoTV accessed to non-structured data sources, so the collection mechanisms had to be fully customized for each considered resource. Furthermore, only the clients that were compatible with OntoTV's information interchange protocol could access the data stored in the system.

This paper describes how Linked Data principles have been applied in OntoTV system in order to solve these problems. On the one hand, Linked Data resources have been accessed to complete the information about movies available in the system; on the other hand, a mechanism for publishing information about television content and channels has been designed.

Regarding the *data consumption*, it has been probed that the data collected from Linked Data sources has been useful to enrich the scarce content descriptions originally sent by the providers. As the considered sources are compliant with Linked Data principles, the data extracted from them is well structured and includes semantic links between concepts that are not present in classic HTML links. In this situation it is straightforward to extract the desired information, not only in the case of film description, but also for other types of content. Furthermore, the decision of accessing a resource like SIG.MA, which automatically integrates many others Linked Data sources, has provided advantages over the crawling strategies and the execution of SPARQL queries. As the information comes from various sources, it is possible to find movie descriptions for almost any title.

Regarding the *data publishing*, information can now be accessed not only by OntoTV's clients, but also by any other agent able to consume Linked Data resources. And all of this without having to implement a specific logic for message interchange or interpret particular formats like XMLTV. Also, the decision of using the BBC's ontology, which is widely agreed in the television domain, has been very appropriate because the information collected by OntoTV system becomes available in the Web of Data in a more standard way.

Despite the improvements achieved, it is still necessary to continue enhancing the processes that transform the collected XMLTV data into instances of the BBC ontology. Other future research line is trying to incorporate better mechanisms for finding inconsistences in the data and detecting instance collisions, especially when adding instances of the programs. Finally, the algorithms for aligning information with LinkedMDB and DBpedia datasets can be also improved because until the moment they only use simple lexical comparisons.

In conclusion, the application of Linked Data methodologies has been very beneficial for improving the performance of systems that consume and publish data, like OntoTV does. With these information management strategies applied to the television domain, viewers will have access to a more accurate, complete and useful information.

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Comparative Study on Feature Selection and Fusion Schemes for Emotion Recognition from Speech

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***Abstract* — The automatic analysis of speech to detect affective states may improve the way users interact with electronic devices. However, the analysis only at the acoustic level could be not enough to determine the emotion of a user in a realistic scenario. In this paper we analyzed the spontaneous speech recordings of the FAU Aibo Corpus at the acoustic and linguistic levels to extract two sets of features. The acoustic set was reduced by a greedy procedure selecting the most relevant features to optimize the learning stage. We compared two versions of this greedy selection algorithm by performing the search of the relevant features forwards and backwards. We experimented with three classification approaches: Naïve-Bayes, a support vector machine and a logistic model tree, and two fusion schemes: decision-level fusion, merging the hard-decisions of the acoustic and linguistic classifiers by means of a decision tree; and feature-level fusion, concatenating both sets of features before the learning stage. Despite the low performance achieved by the linguistic data, a dramatic improvement was achieved after its combination with the acoustic information, improving the results achieved by this second modality on its own. The results achieved by the classifiers using the parameters merged at feature level outperformed the classification results of the decision-level fusion scheme, despite the simplicity of the scheme. Moreover, the extremely reduced set of acoustic features obtained by the greedy forward search selection algorithm improved the results provided by the full set.**

***Keywords* — Acoustic and linguistic features, decision-level and future-level fusion, emotion recognition, spontaneous speech**

I. Introduction

ONE of the goals of human-computer interaction (HCI) is the improvement of the user experience, trying to make this interaction closer to human-human communication. Inclusion of speech recognition was one of the key points to include "perception" to multimedia devices. This improved their user interfaces [1]. However, the analysis of affective states by the study of the implicit channel of communication (i.e. the recognition of not only what is said but also how it is said) may improve HCI making these applications more usable and friendly. This is because, in general, inclusion of skills of emotional intelligence to machine intelligence makes HCI more similar to human-human interaction [2]. There is a wide range of contexts where the analysis of speech and emotion in the input of the systems –and also the synthesis of emotional speech at the output– can be applied to, including automatic generation of audio-visual content, virtual meetings, automatic dialogue systems, tutoring, entertainment or serious games.

There are many studies related to emotion recognition based on different approaches. However, a big amount of these works are based on corpora consisting of utterances recorded by actors under supervised conditions. Nowadays this is not the current trend because of the lack of realism of these data [3].

The first study where authors attempted to work with a corpus of spontaneous speech seems to be [4], collecting utterances from infant directed speech. Many other works tried to deal with realistic data, such as [5] and [6]. Nevertheless, it is difficult to compare the results of these approaches when they are using different data and different evaluation methods. A framework to generalise the research on this topic was proposed by [7]. This framework was based on a corpus of spontaneous speech where two different subsets were defined in order to allow speaker-independence during the analysis. Speech was non-acted and, for this reason, utterances were characterised by being non-prototypical and having low emotional intensity. Results obtained within this framework [8] give an idea of the complexity of the task. The combination of 7 classification approaches considering different sets of features achieved 44.00% of unweighted average recall (UAR). We worked under the same naturalistic conditions in this article.

The task of emotion recognition from speech can be tackled from different perspectives [3]. We considered the analysis of two modalities: the acoustic (referred to the implicit message) and the linguistic (referred to the explicit message), extracting acoustic parameters from the speech signal and linguistic features from the transcriptions of the utterances of the corpus. Because in a realistic scenario the analysis of acoustic information could be not enough to carry out the task of emotion recognition from speech [9] the linguistic modality could improve an only-acoustic study. In this article, both modalities were combined at the decision level and at the feature level to compare the performance of different classification approaches using both procedures. To improve

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the performance of the classifiers and optimize the experiment we reduced the acoustic set of features (the largest one) by selecting the most relevant parameters by a greedy algorithm before starting the learning stage. Also, for this feature selection stage, we compared two search methods (forwards and backwards) through the space of feature subsets.

This paper is structured as follows: Section II describes the corpus and details its acoustic and linguistic parameterization. Section III defines the methodology of the experiment, describes the feature selection algorithms used to optimize the acoustic set of data and details the two fusion schemes proposed. Section IV summarises the results. Conclusions are detailed in Section V.

II. CORPUS

This work was based on the FAU Aibo Corpus [10] as it was defined in [7]. In this Section we describe this corpus and its acoustic and linguistic parameterization.

A. Corpus Description

The FAU Aibo Corpus consisted of 8.9 hours of audio recordings of German speech from the interaction of children from two schools playing with the Sony's Aibo robot in a *Wizard of Oz* (WOZ) scenario. These audio recordings were divided into 18,216 chunks. A chunk is each one of the segmentations of the audio recordings of the corpus into syntactically and semantically meaningful small parts. These parts were defined manually following syntactic and prosodic criteria [10]. The chunks of the two schools were divided into two independent folds (fold 1 and fold 2) to guarantee speaker-independence. Thus, each fold contained speech recordings from different children. Each chunk, after parameterization, was considered an instance of the datasets used to train and test the classification schemes. The number of resulting instances was 9,959 for the fold 1 and 8,257 instances for the fold 2. The emotions considered to label the corpus were defined by these five category labels: Anger (A), including angry (annoyed), touchy (irritated as a previous step of anger) and reprimanding (reproachful); Emphatic (E) (accentuated and often hyper-articulated speech but without sentiment); Neutral (N); Positive (P), which included motherese (similar to infant-directed speech but from the child to the robot) and joyful states; and Rest (R), a garbage class collecting three affective states: surprise (in a positive sense), boredom (with a lack of interest in the interaction with the robot) and helpless (doubtful, speaking using disfluencies and pauses).

Because of the use of a WOZ scenario to record the affective states of the children, the corpus collected spontaneous utterances of naturalistic emotional speech in a real application environment. For this reason, it included non-prototypical emotions of low intensity. Moreover, the distribution of the emotion labels was very unbalanced. For example, the majority class (N) consists of 10,967 utterances (60.21% of the whole corpus) while the minority class (P) consists of only 889 utterances (4.88% of the whole corpus). For a full description of this corpus cf. [7].

B. Acoustic Parameterization

The acoustic analysis of the corpus consisted on calculating 16 low-level descriptors (LLDs). These LLDs were: the zero-crossing rate (ZCR) analysed in the time signal, the root mean square (RMS) frame energy, the fundamental frequency (F0) normalised to 500 Hz, the harmonics-to-noise ratio (HNR) and 12 mel-frequency cepstral coefficients (MFCC). We also computed the derivative of these LLDs.

We calculated 12 functionals from these LLDs and, also, from their derivatives. These functionals were: the mean, the standard deviation, the kurtosis and the skewness, the value and range and position of the extremes, and the range and two linear regression coefficients with their mean square errors (MSE).

To perform this parameterization we used the openSMILE software included in the openEAR toolkit release [11], obtaining $16 \times 2 \times 12 = 384$ features per instance.

C. Linguistic Parameterization

The linguistic parameterization was based on the transcriptions of the corpus. These transcriptions defined the words that children used to communicate with the robot Aibo. We used the concept of emotional salience proposed by [12] to translate the words of a chunk into 5 emotion-related features. Assuming independence between the words of a chunk, the salience of a word is defined as the mutual information between a specific word and an emotion class. Therefore, an emotionally salient word is a word that appears more often in that emotion than in the other categories. Considering this definition, let $W = \{v_1, v_2, ..., v_n\}$ be the n words of a chunk and let $E = \{e_1, e_2, ..., e_k\}$ be the emotional space defined by a set of k emotion classes. Mutual information between the word v_m and the emotion class e_j is defined by (1).

$$i(v_m, e_j) = \log \frac{P(e_j \mid v_m)}{P(e_j)} \tag{1}$$

where $P(e_j|v_m)$ is the posterior probability that a chunk containing the word v_m implies the emotion class e_j and $P(e_j)$ is the a priori probability of the emotion e_j.

The emotional salience of the word v_m related to the emotional space E is defined by (2).

$$sal(v_m) = \sum_{j=1}^{k} P(e_j \mid v_m) i(v_m, e_j) \tag{2}$$

We calculated the emotional salience of all the words of the training dataset retaining only those with a value greater than a threshold empirically chosen at 0.3. This resulted in a list of emotionally salient words. Next, we calculated 5 linguistic features for each chunk. These features, called activations and

denoted by a_j, were calculated following (3) [12].

$$a_j = \sum_{m=1}^{n} I_m i(v_m, e_j) + \log P(e_j) \quad (3)$$

where I_m is 1 if the word matches the list of salient words or 0 otherwise.

To guarantee the independence of the two folds during the parameterization stage, the list of emotionally salient words was created considering only the fold used for training. Next, we calculated the activation features for both folds but using only the emotional salience values and the a priori probabilities from the training fold. By following this procedure the test data remained unseen during the analysis of the training data to extract the information about the emotional salience of the words of the corpus.

III. EXPERIMENTATION

In this Section we explain the methodology of the experiment, the feature selection algorithms used to reduce the acoustic set of features and the two procedures to fusion the acoustic and linguistic modalities.

A. Methodology

The acoustic feature vector contained a big amount of information (384 features), being much larger than the vector of linguistic parameters (5 features). The inclusion of irrelevant features in the space of parameters could deteriorate the performance of the classifiers used in the learning stage [13]. Moreover, if these data were merged with the linguistic features without any previous processing then the resulting vectors would be very unbalanced because they would contain many more features related to the acoustic information than features related to the linguistic information.

Feature selection techniques are designed to create subsets of features without redundant data by discarding irrelevant input variables with little predictive information. These reduced subsets could improve the performance of the classifiers and obtain a more generalizable classification model [14]. We used a wrapper method [15] to evaluate the candidate subsets created by a search algorithm and two ways of searching the feature space to create these subsets, as it is explained in detail in Section III.B.

In the classification stage, we considered two procedures to fusion the acoustic and the linguistic data. On the one hand, we performed a decision-level fusion of these modalities classifying the acoustic and the linguistic data independently and merging the classification results by a third classifier. On the other hand, we used a feature-level fusion procedure merging the acoustic and the linguistic parameters before the classification stage. These procedures are detailed in Section III.D and Section III.E, respectively.

We evaluated the classifier schemes in a 2-fold cross-validation manner. We used one fold for training and the other fold for testing and vice versa. This allowed us to guarantee speaker-independence in the experiment. The mean value of the performances of both folds was also calculated.

We considered three learning algorithms in this experiment using the implementations provided by the WEKA data mining toolkit [13]. The first learning algorithm was a Naïve-Bayes (NB) classifier. This algorithm was found to be the most relevant in [16] despite its simplicity. For this reason it was used as the baseline in this experiment. To improve the performance of this classifier we applied, prior to the training stage, a supervised discretisation process based on the Fayyad and Irani's Minimum Description Length (MDL) method [17]. The second classification approach was a support vector machine (SVM) classifier. For this work, we chose a SVM with a linear kernel using sequential minimal optimisation learning [18]. To allow the algorithm to deal with a problem of five classes we used pairwise multi-class discrimination [19]. Finally, the third classifier was a logistic model tree as described in [20]. This is a model tree using logistic regression at the leaves instead of linear regression. This is named Simple Logistic (SL) in WEKA.

We used the UAR measure to compare the performances of the classification approaches because the distribution of the classes in the FAU Aibo Corpus was very unbalanced. Comparing the UAR of the classifiers, instead of the weighted-average recall (WAR) measure, the most even class-wise performance was intended. Thus, the same importance was given to the majority and the minority classes of the corpus because we considered the detection of the interactions with emotional content as important as the detection of the neutral interactions. However, in most of other studies of emotion recognition the WAR measure was used because the distribution of the classes of their corpora was usually quite balanced. Equation (4) shows that the recall for one class *c* is calculated as the proportion of correctly classified cases (True Positives) with respect to the corresponding number of instances (True Positives and False Negatives) of this class. Equation (5) shows the computation of UAR performance of a classifier considering the recalls of each class *c*.

$$recall_c = \frac{TP_c}{TP_c + FN_c} \quad (4)$$

$$UAR = \frac{\sum_{c=1}^{|C|} recall_c}{|C|} \quad (5)$$

where *TP* stands for True Positives, *FN* stands for False Negatives and |*C*| represents the number of classes.

B. Feature Selection Process

To reduce the set of acoustic features we chose a wrapper method. A wrapper method uses a learning algorithm to evaluate the subsets created by a search algorithm. These subsets are the candidates to be the optimal ones. We considered the Naïve-Bayes classifier to assess the goodness-

of-fit of the candidate subsets. We searched the space of features by means of two greedy procedures to automatically create these subsets:

- Greedy forward (FW) search. This algorithm carried out an iterative exhaustive search through the feature space creating subsets starting with no features and adding one parameter at each iteration.
- Greedy backward (BW) search. In this case, the iterative exhaustive search consisted on creating subsets starting with all the features and discarding one at each iteration.

Before starting the feature selection stage we resampled the fold 1 reducing it by half to speed up the process and biased it to a uniform distribution. To guarantee independence between both datasets, we used only the fold 1 to select the candidate subsets of features and evaluated them on all the instances of this fold.

In the case of the FW search, the acoustic dataset was reduced from 384 features to 28 features: 21 related to the MFCC parameters, 3 related to the RMS frame energy, 2 related to the F0, 1 related to the HNR and 1 related to the ZCR. The BW search was a more conservative approach and created a set of 305 features.

A comparison of the performances of the classifiers using the full set of acoustic features and the reduced sets is shown in Fig. 1. For each algorithm we show three results: the Fold 1 column indicates the results obtained when training the classifiers with the fold 1 and testing with the fold 2, the Fold 2 column is the opposite and the Mean column is the mean of the previous results. As it can be observed, focusing on the mean values of the Fold 1 and Fold 2 experiments and except the case of the Naïve-Bayes classifier, UAR values were slightly better for the reduced sets than for the full set of features. In the case of the Naïve-Bayes classifier, the dataset created by the FW search degraded dramatically the performance of this classifier. Nevertheless, the performance was slightly improved using the dataset created by the BW search. Thus, we chose the reduced sets for this experiment decreasing the computational cost of the classification algorithms.

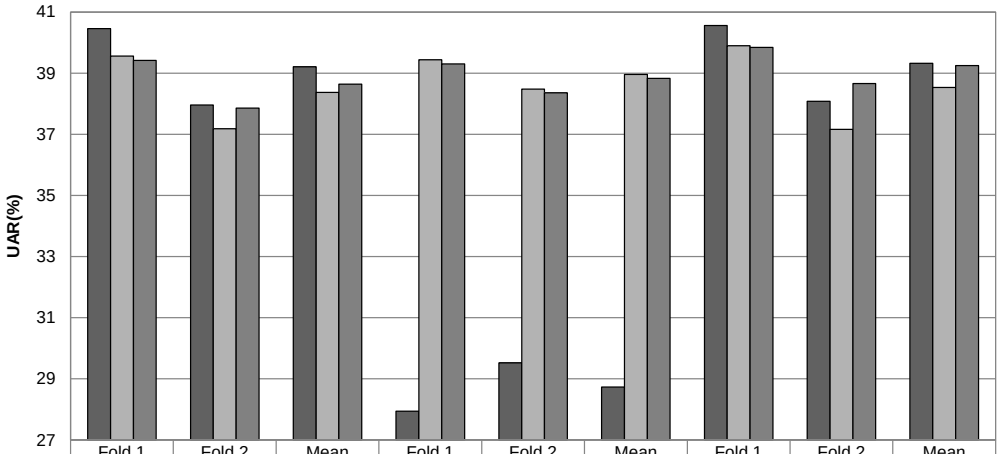
C. Dataset Pre-processing

To optimize the performance of the classifiers we pre-processed the datasets used to train them. Datasets were biased to a uniform class distribution by means of a resampling with replacement technique and duplicating the total number of instances. We did not bias the distribution of classes in the case of the Naïve-Bayes algorithm because this process degraded its performance. In the case of the SVM, data was also normalised by the Euclidean norm.

D. Decision-Level Fusion

Decision-level fusion is based on the processing of the classification results of prior classification stages. The main goal of this procedure is to take advantage of the redundancy of a set of independent classifiers to achieve higher robustness by combining their results [21].

In this experiment, decision-level fusion was performed by combining hard decisions from the classifiers that were trained and tested by the acoustic and linguistic features independently. Although soft decisions could also be used, hard decision classifiers provide the least amount of information to make their combinations [22]. We followed the stacked generalization strategy introduced by [23] and used a decision tree to merge the classifications obtained by the two classifiers. This stacking approach proved to be useful in the field of emotion recognition in previous works like those by [24] and [25]. The decision tree used to merge the hard decisions of the classifiers was a J4.8 classifier. This is the WEKA implementation of the C4.5 Revision 8 algorithm [13], a slightly improved version of the C4.5, based on entropy



	All acoustic features (384)			FW Selected acoustic features (28)			BW Selected acoustic features (305)		
	Fold 1	Fold 2	Mean	Fold 1	Fold 2	Mean	Fold 1	Fold 2	Mean
NB	40.46	37.96	39.21	27.94	29.52	28.73	40.56	38.08	39.32
SVM	39.56	37.18	38.37	39.44	38.48	38.96	39.90	37.16	38.53
SL	39.42	37.86	38.64	39.30	38.36	38.83	39.84	38.66	39.25

Fig. 1. Unweighted average recall of the classifiers using the full dataset of 384 acoustic features and using the reduced sets of the 28 and 305 acoustic features selected by the greedy forward search and greedy backward search selection algorithms, respectively. NB stands for Naïve-Bayes, SVM stands for Suport Vector Machine and SL stands for Simple Logistic. FW and BW stands for the greedy forward search and greedy backward search selection algorithms, respectively.

information [26].

To train the J4.8 algorithm we trained and tested each one of the three classifiers with the full training sets, both the acoustic and the linguistic. Next, we created a dataset merging the hard decisions of each classifier for both sets of features. This dataset was used to train the J4.8 learning scheme after biasing it to a uniform distribution and duplicating the number of instances. Once more, and as in other stages of this experiment, test data remained unseen during the training process. When the J4.8 classifier was trained, we evaluated the hard decisions of the classifiers tested with the test data, measuring the performance of the full scheme at the end.

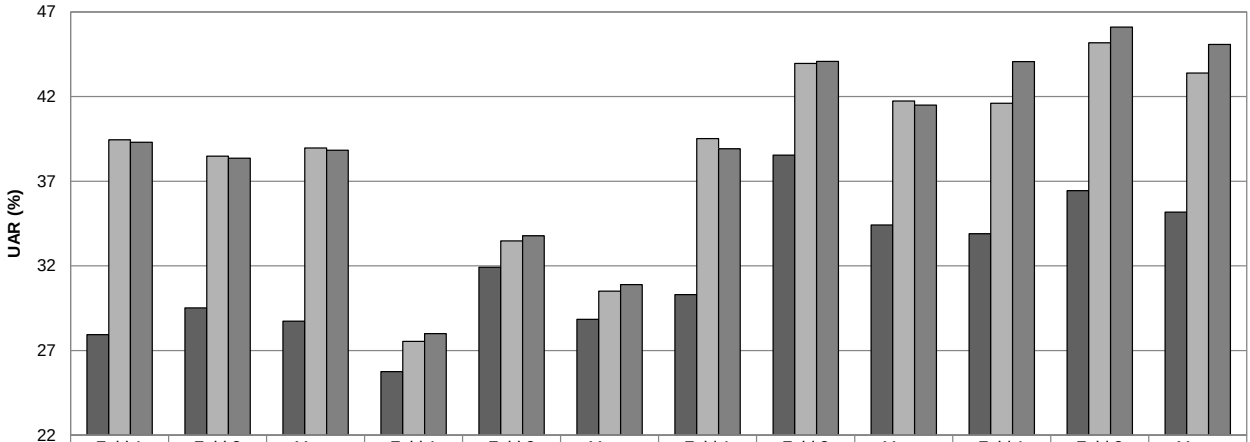
E. Feature-Level Fusion

A feature-level fusion scheme integrates unimodal features before learning concepts, as it is described in [27]. The main advantage of a feature-level fusion scheme is the use of only one learning stage. Moreover, this fusion scheme allows taking advantage of mutual information from data. We used concatenation of the reduced set of acoustic features and the linguistic set to create a multimodal representation of each instance. Thus, the amount of features for the merged dataset was of 33 elements per instance.

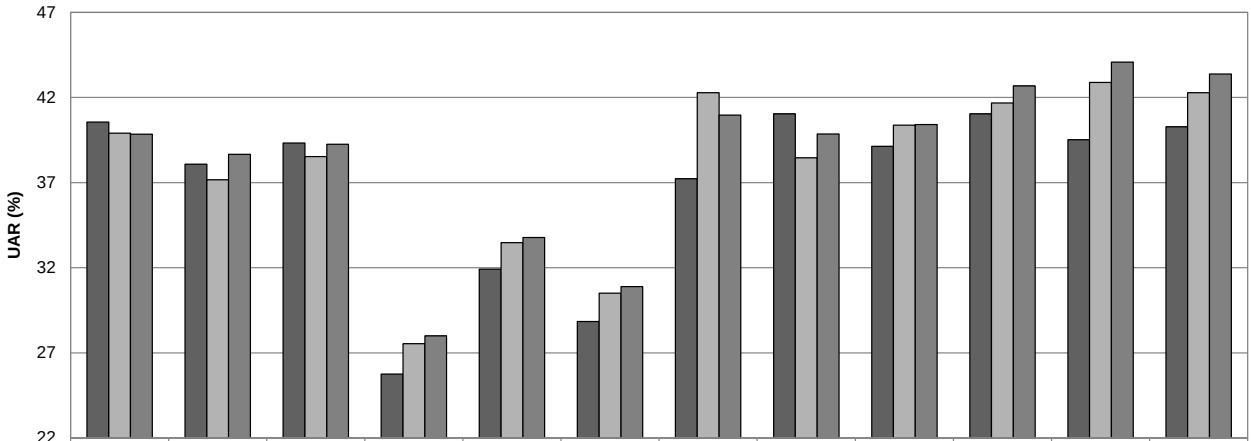
IV. RESULTS

Results of this experiment are shown in Fig. 2. Like in Fig. 1, for each algorithm we show three results: the Fold 1 column indicates the results obtained when training the classifiers with the fold 1 and testing with the fold 2, the Fold 2 column is the opposite and the third result is the mean of the previous results. The results obtained by the dataset created by the FW search procedure are shown at the top and the results achieved by the BW search dataset are shown at the bottom.

Focusing on the mean value of the two folds, it can be observed that the performance of the classifiers that only used



	FW Selected acoustic features (28)			Linguistic features (5)			Decision-level fusion (FW)			Feature-level fusion (FW)		
	Fold 1	Fold 2	Mean	Fold 1	Fold 2	Mean	Fold 1	Fold 2	Mean	Fold 1	Fold 2	Mean
NB	27.94	29.52	28.73	25.76	31.92	28.84	30.30	38.54	34.42	33.90	36.44	35.17
SVM	39.44	38.48	38.96	27.54	33.48	30.51	39.52	43.96	41.74	41.60	45.18	43.39
SL	39.30	38.36	38.83	28.00	33.78	30.89	38.92	44.08	41.50	44.06	46.10	45.08



	BW Selected acoustic features (305)			Linguistic features (5)			Decision-level fusion (BW)			Feature-level fusion (BW)		
	Fold 1	Fold 2	Mean	Fold 1	Fold 2	Mean	Fold 1	Fold 2	Mean	Fold 1	Fold 2	Mean
NB	40.56	38.08	39.32	25.76	31.92	28.84	37.22	41.04	39.13	41.04	39.52	40.28
SVM	39.90	37.16	38.53	27.54	33.48	30.51	42.28	38.46	40.37	41.68	42.88	42.28
SL	39.84	38.66	39.25	28.00	33.78	30.89	40.96	39.86	40.41	42.68	44.08	43.38

Fig. 2. Unweighted average recall of the classifiers using the selected set of acoustic features (28 features selected by the greedy forward search selection algorithm (top) and 305 features selected by the greedy backward search selection algorithm (bottom)), the set of 5 linguistic features, the decision-level fusion scheme and the feature-level fusion scheme.

the 28 acoustic features selected by the FW search was better, in general, than the performance of the classifiers that only used the 5 linguistic parameters. In the case of the SVM classifier, the use of the acoustic features improved the performance of the linguistic parameters by 8.45% absolute (27.70% relative). In the case of the Simple Logistic performance was improved by 7.94% absolute (25.70% relative). Only the Naïve-Bayes got its performance improved (by only 0.11% absolute, 0.38% relative) using the linguistic features instead of the acoustic parameters. In the case of the set of features selected by the BW search, the performance of the classifiers using the 305 features was better, in all cases, than using the 5 linguistic parameters. The improvement in the case of the Naïve-Bayes, the SVM and the Simple Logistic classifiers was 10.48% absolute (36.34% relative), 8.02% absolute (26.29% relative) and 8.36% absolute (27.06% relative), respectively.

However, the combination of the linguistic and the acoustic features at the decision and at the feature levels improved the performance of the classifiers that considered both modalities independently. For the FW search, the decision-level fusion results improved the mean of the performances achieved by the acoustic and the linguistic sets in the case of the Naïve-Bayes, the SVM and the Simple Logistic classifiers by 5.63% absolute (19.56% relative), 7.00% absolute (20.15% relative) and 6.64% absolute (19.05% relative), respectively. The improvement in the case of the feature-level fusion scheme was 6.38% absolute (22.16% relative), 8.65% absolute (24.90% relative) and 10.22% absolute (29.32% relative), respectively. Considering the BW search, the decision-level fusion results improved the mean of the performances achieved by the acoustic and the linguistic sets in the case of the Naïve-Bayes, the SVM and the Simple Logistic classifiers by 5.85% absolute (16.95% relative) and 5.34% absolute (15.23% relative), respectively. In the case of the Naïve-Bayes classifier, performance was slightly degraded. The improvement in the case of the feature-level fusion scheme was 6.20% absolute (18.19% relative) for the Naïve-Bayes, 7.76% absolute (22.48% relative) for the SVM and 8.31% absolute (23.70% relative) for the Simple Logistic classifier. As it can be observed, the improvement achieved by the fusion of the acoustic and the linguistic parameters (regardless the classifier considered) is more significant in the case of the acoustic FW search selected features than in the case of the acoustic BW search selected features.

In all the cases, the fusion of both modalities at the feature level outperformed the results of the fusion at the decision level. Considering the FW search selected features, for the Naïve-Bayes, the SVM and the Simple Logistic classifiers, the feature-level fusion scheme improved the performance of the decision-level scheme by 0.75% absolute (2.18% relative), 1.65% absolute (3.95% relative) and 3.58% absolute (8.63% relative), respectively. In the case of the BW search selected features, the feature-level fusion scheme considering the Naïve-Bayes, the SVM and the Simple Logistic improved the performance of the decision-level scheme by 1.15% absolute (2.94% relative), 1.91% absolute (4.73% relative) and 2.97% absolute (7.35% relative), respectively.

Although the Naïve-Bayes classifier performed well in a prior study [16], in the case of the FW search selected features its performance was below the other two classifiers. The main reason can be found in the fact that the feature selection algorithm used in Section III.B was not designed to avoid dependencies among the chosen parameters, being independence of features one of the requirements of this classification algorithm [28]. This degradation was not observed analysing the features selected by the BW search because it contains a larger number of parameters.

Only the Fold 1 columns of Fig. 2 must be taken into account to compare these results with the experiments carried out by other authors in the same scenario. This column shows the performance of the classification algorithms when using fold 1 for training and fold 2 for testing, i.e. the two different schools independently, as detailed in [7]. Reference [8] compiled a list of results achieved by several authors working in the same conditions and their fusion by a majority voting scheme. The fusion of the best 7 results achieved a performance of 44.00% UAR, considering different learning schemes and datasets. The best result obtained in this paper by means of the Simple Logistic classifier and the feature-level fusion scheme considering the acoustic FW search selected features (i.e. using 33 features) improved this result by 0.06% absolute (0.14% relative). Although both results were quite similar, it is noteworthy that the number of features involved in our study was dramatically lower and also the complexity of the learning scheme.

V. Conclusion

In this paper we presented a comparison between decision-level and feature-level fusion to merge the acoustic and the linguistic modalities in a real-life non-prototypical emotion recognition from speech scenario. Also, we compared two procedures to select the most relevant features from the large set of acoustic parameters.

We parameterized the audio recordings of a naturalistic speech corpus obtaining 384 acoustic and 5 linguistic features. To reduce the amount of acoustic features we compared two greedy search procedures for feature selection analysing the full set of features forwards and backwards, obtaining 28 and 305 relevant parameters, respectively. The performance of the classifiers with these reduced datasets was, except for the case of the Naïve-Bayes algorithm with the FW search selected features, slightly better than using the full dataset. Using fewer features we were able to speed up the emotion recognition process because we simplified the parameterization stage and the small datasets reduced the computational cost of the classification stage.

Linguistic information, by themselves, did not create a good dataset for the classifiers of this experiment and their performance was even below the performance achieved by

using only the acoustic dataset. However, the combination of these modalities by means of any of the two fusion procedures outperformed the results achieved by both modalities on their own. It is remarkable, then, the importance of analysing the acoustic modality (how things are said) and the linguistic modality (what things are said) to achieve the best results in an automatic emotion recognition experiment, in a similar way as we do in the human communication. This outperformance is more significant in the case of the fusion of the linguistic parameters and the acoustic FW search selected features than in the case of the fusion of the linguistic parameters and the acoustic BW search selected features. Moreover, in general, results from the FW scheme are better than in the BW scheme, except for the case of the Naïve-Bayes algorithm.

Feature-level fusion revealed as the best scheme to merge the acoustic and the linguistic information. Moreover, this kind of fusion is simpler than decision-level fusion, which reduces the complexity of the analysis of the speech recordings. In this feature-level fusion scheme we used only one classifier to analyse a reduced set of acoustic and linguistic parameters merged by simple concatenation of vectors. The performance of this scheme was better than the decision-level scheme consisting of three classifiers: two for each modality and one to merge their results.

The best classifier in this experiment was the Simple Logistic algorithm. Although the Naïve-Bayes is a simple classifier able to achieve good results, its performance was degraded when working with the smallest set of acoustic features (those selected by the FW search procedure). One of the requirements of this classifier is the use of independent parameters but our feature selection procedure was not intended to achieve it. For this reason, in future work, we will experiment with other methods to select relevant feature subsets but also eliminating the redundancy of the data, like [29].

Future work will be related to the enhancement of the linguistic parameterization by considering not only individual words but also groups of them in the form of n-grams. With these n-grams we will be able to study the relation of more complex linguistic structures and the relations between words. Also, we will include an automatic speech recogniser module to work in a more real scenario.

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DEVELOP-FPS: a First Person Shooter Development Tool for Rule-based Scripts

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***Abstract* —We present DEVELOP-FPS, a software tool specially designed for the development of First Person Shooter (FPS) players controlled by Rule Based Scripts. DEVELOP-FPS may be used by FPS developers to create, debug, maintain and compare rule base player behaviours, providing a set of useful functionalities: i) for an easy preparation of the right scenarios for game debugging and testing; ii) for controlling the game execution: users can stop and resume the game execution at any instant, monitoring and controlling every player in the game, monitoring the state of each player, their rule base activation, being able to issue commands to control their behaviour; and iii) to automatically run a certain number of game executions and collect data in order to evaluate and compare the players performance along a sufficient number of similar experiments.**

***Keywords* —Intelligent Game Characters, Behaviour Control and Monitoring, Rule Based Scripts, Development Software Tool.**

I. INTRODUCTION

IN the recent years artificial intelligence become a key feature to the success of a computer game. The hard-core gamer no longer accepts "space invaders" kind of behaviour with easily identifiable patterns, he expects the game to deliver a convincing challenge always different and interesting. To the game publisher the increase of a game lifespan is also a strategic decision to make; the player capability of defining new scenarios and adversaries allows him to define his own challenges and opponents expanding the longevity of the game.

The development of game oriented platforms, consoles or special tuned computers, provided new spaces to developed and apply new AI technics in commercial games. Game development toolkits are starting to provide support to design of non-player characters' behaviour (NPCs), mainly through the use of copyrighted languages (UnrealScript on UnrealEngine [1]), open-source or free languages (Lua on World of Warcraft [2]) or libraries of behaviours (PandAI on Panda3D engine [3]). Although some commercial games include game editors, these are usually centred on terrain or level construction, giving a limited support to the artificial intelligence aspects. The high-end game developments of tools support the design and deploy intelligent NPC through limited and proprietary solutions. Most of the game companies had its own tools and development kits, which are not made available to the game community. The low-cost, open source and shareware alternatives put most of their effort in supporting the game engine and graphical design, solving problems like physical simulation, collisions detection and character

animation, the tools to assist the design and development of NPCs' behaviour are usually omitted.

The existence of a debugging tool to validate the behaviour of a NPC is still a dream in the designer's mind. As the behaviour complexity of NPCs increases, also growths the need for a tool that provides a set of functionalities like: breakpoints that can stop a behaviour script at any point; recreate situations to test snippets of code; monitor variables, functions and NPCs knowledge; force the behaviour or remotely control a character. Most of the scripting languages used in the development of AI components are interpreted (directly or in byte-code), and the common tool available to construct those scripts is a text editor with colour syntax (although some languages provide plugins for standards IDE only for write the code). When some execution bug occurs, the common procedure is stopping the script, in some situations the interpreter will also crash. Some better interpreters will provide an error message identifying the type of error and its location in the code. With no tools to deploy, test and monitor the components, it is up to the programmer to perform the debug and test cycle of his own code. For instance, the Unity game development tool [4,5] provides a debug mechanism based on log messages produced in the script. The existence of mature tools providing a professional environment to support all the development process would dramatically reduce the time spend in this cycle, liberating the programmer to produce better code.

If we want that a game became a professional product, we have to provide tools that allow extensive and professional test of the code, guaranteeing the quality of the final delivery. Scripting languages without tool support can rapidly degenerate in spaghetti code with lots of tweaks and artifices that disallow any future changes or reuse of the program.

We propose a generic architecture to support the process of development and test of autonomous characters behaviour in a computer game environment. Based on this architecture we create a software tool (DEVELOP-FPS), which support the development, debug and execution of NPCs behaviours in a FPS like game. The tool is supported on the Unreal Tourment 2004 engine and uses the Pogamut API library [6] to access the environment sensor information and control of the avatar. Our tool provides the developer with a set of functionalities

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that allow monitor and control an individual character, define and deploy specific scenario situations, gather data and statistics of running experiments, and get different perspectives of the scenario.

In the next section we detail our generic architecture in a global perspective. In section 3 we present our application and the options made. Finally in section 4 we make some conclusions and provide future development directions.

II. GENERIC ARCHITECTURE

Our generic architecture is composed by four main components: The NPC behaviour definition script; the individual control console; the global control console; and the game engine server. These components were substantiated using the Jess Rule Based Language [7] to define the characters behaviour and the Unreal Engine as the game server. This architecture is outlined in figure 1.

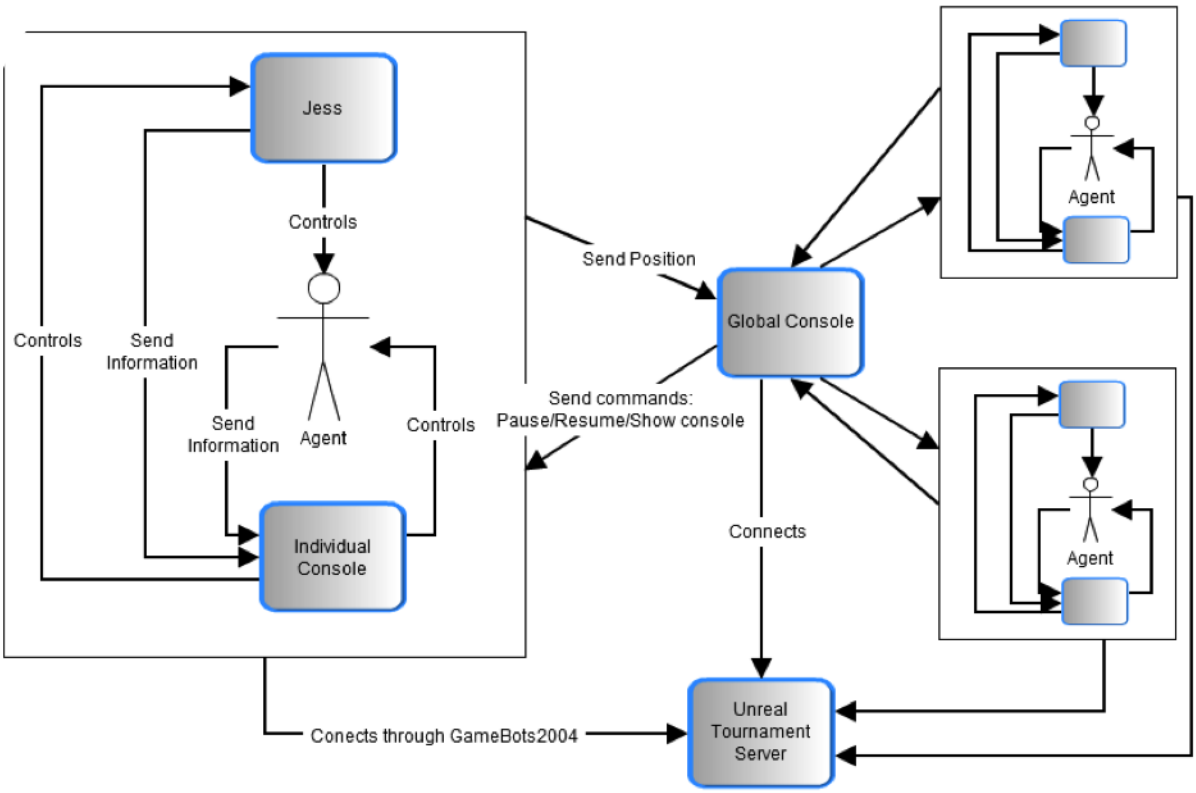

Fig. 1. Generic architecture: the Unreal Tournament Server, The Global Console and the individual Non Player Character Agents with the Jess scripts.

We can split this architecture in two main component classes: individual character management, and global management. The first group comprise the tools to access, monitor and control and individual character. Through those tools the developer can issue commands to the agents, using the individual console, which can cause a wide range of effects, from alterations in the character internal representations to consequences in the game environment. In order to maintain a certain degree on independence from the specific game environment, all the control of the NPC avatar in the environment is actuated through a middleware interface (Pogamut), that provide an intermediate abstraction over the game engine. The NPC behaviour script can be debugged and executed using the console, the developer can directly control the interpreter, issuing commands, stopping execution, testing alternatives, and monitoring execution.

The second group comprise the simulated environment where all the characters actuate, and a global management tool. The simulated environment provides a game world with a physical engine, graphical representations of the environment from different points of view, and functionalities to interact with the scenario – actions an NPC can perform and information it can perceive. As stated before the actions and perceptions are made available through the middleware interface.

The global console offers a set of functionalities to manage the characters as group, issuing commands that all of then must accomplish.

One of our objectives with this generic architecture was to provide a relative independence between what are the tools made available to the development, debugging and execution of characters behaviour and the specifics of the game engine. This architecture is an evolution of earlier work presented originally in [8].

III. THE SOFTWARE TOOL DEVELOP-FPS

DEVELOP-FPS is a software tool written in JAVA, specially designed for the development of First Person Shooter (FPS) players controlled by Rule Based Scripts in Jess. DEVELOP-FPS may be very powerful if used by FPS developers to create, debug, maintain and compare rule base player behaviours along a number of repeated experiments. It was designed for developing scripts for the *Game Unreal Tournament* but it can easily be adapted to other game platforms.

In figure 2 we may see an example of DEVELOP-FPS in action: In the centre two NPCs are fighting, on the right the Global Console is displayed and on the top and left we can see the individual console of one the players and the 2D-map as seen from the that player perspective.

Fig. 2. A screenshot of the game control with four windows displaying a graphical view of the environment, two 2D maps representing a global situation an individual position, an individual control console.

We will now proceed to detail the tool architecture and their main components and respective functionalities.

A. Global Terminal

The global console role functions are: 1) to offer a bird eye view of the world, providing a 2D map of the game world and displaying the waypoints and character positions; 2) launching an individual console for each character giving the user the possibility to monitor and control each NPC; 3) the possibility to stop and resume the game execution; and 4) to automatically run a certain number of game executions and collect data in order to evaluate and compare the characters performance along a sufficient number of similar experiments. In Figure 3, we see a snapshot of the global console in a game played by 2 NPCs with IDs 218 and 219.

AS we said above, the global console 2D map will represent an updated bird eye view of the NPCs positions (large circular icons), with a different colour for each NPC, and also the waypoints: the reference locations in the environment defined by the user, for navigation purposes. The information is obtained from each NPC trough Sockets: each NPC sends its position to the Global Console every 0.5 seconds.

In the top of the console we see the IDs of the connected clients (the individual identification of each game character), and the one selected will have its respective console displayed, the others will be hidden—only one of the individual consoles can be displayed at any moment. In the bottom we may see two buttons that are used to stop the game execution of every character ("Stop All") and to resume their execution ("Resume All"). This is an important feature for developing behaviours for game characters, due to the frequent necessity to stop the game execution for debugging and testing behaviours.

There are three parameters for the repetition of a set of similar experiments: 1) The duration of each run; 2) the number of experiments and 3) the number of agents. Note that each game can end because there is only one player left or because the duration has reached the defined limit.

The Global Console is responsible for start up the NPCs, run the game until it finishes, collect the game reports and destroy the NPCs, repeating this procedure the right number of runs.

Fig. 3. The display of the Global Console: the 2D world map where we see a set of waypoints and two characters. In the bottom of the console we see the Pause All and Resume All buttons and the three important parameters to repeat a set of experiments.

At the moment, we do not provide an interface for specifying which settings the user wants varied, and what values he wants them to take for, neither for specifying what data to collect from each run. It is up to the NPC developer to program all this information directly in the JAVA code. For example, he may want to vary the set of world maps to use and he may want the report of the NPC winner, the number of survivors, the energy of NPCs in the end of the game. The repeated experiments report will be written on a file (in csv format).

B. NPC Terminals

Each Non Player Character (NPC) has its own private console (Fig. 4), which may be hided or visible and when is displayed it can be used for monitoring and controlling the game character. It displays the NPC position, orientation coordinates and sensory information, along with information regarding the rule base execution. There is the possibility to display a world map with an icon representing the Terminal Player, which can be used to tell the NPC to go to a certain position on the map. Below there is a mini-command center. The jess code entered in this command center is executed only by this NPC and the output can be visualized above the command center in a window. This jess code can be used for additional NPC behaviour monitoring and controlling. On the left, we find three manual buttons for controlling the NPC movements and on the bottom a line of buttons useful for stopping and resuming execution besides other functionalities.

In the presence of the Global Terminal only one NPC is allowed for display, as we do not want to fill the screen with terminal windows. If we want to monitor or control different agents, we have to activate the display of one after another sequentially. In order to choose to be displayed a different NPC filling a specific slot in the Global Terminal with the NPC ID.

In case the Global Console is switched off, something different happens: every time a created NPC does not detect the Global Terminal, it launches its individual terminal. Therefore, if there are 10 NPCs created from the same computer, there will be 10 individual terminals displayed in the computer monitor, visually overcharging it.

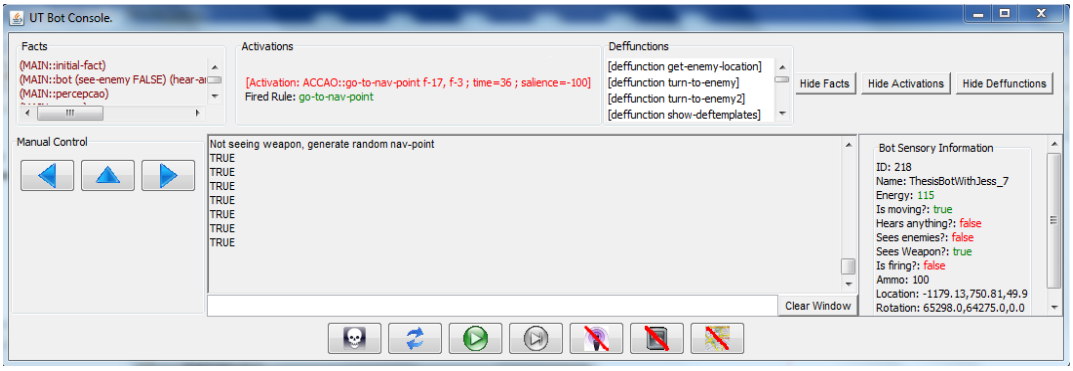

Fig. 4. Example of a NPC terminal. On the top section the Jess data, which can be totally or partially hiden. On the left, three manual movement and orientation button controls. On the right, the agent state may be displayed, and on the center, we see the command window.

1) Control Buttons Line

In the bottom of the NPC terminal we see a line of control buttons (see Fig. 5).

Fig. 5. The NPC control interface. From left to right, Kill agent, Reload logic, Play/Pause agent, Show/Hide agent state,

Show/Hide Jess state, Show/Hide map. In the Figure, the agent state is hided and the same happens with the Jess state.

We will describe each button function from left to right.

Kill agent button: The NPC is killed and disappears from the game.

Reload Logic: If we change the NPC script, by activating this button, the agent behaviour will be controlled by the most recent script version. It will be updated in the agent without being forced to close the application and reinitialize the game.

Play/Pause: The NPC execution is paused and can be resumed. This way we can stop a certain player in order to monitor its behaviour with more detail. We can resume the behaviour at any time.

Step: Behaviour is executed one step forward. Time is divided in steps and behaviour can be followed step by step.

Show/Hide Agent State: The agent state, which appears on the right section of the terminal window, may be hided or displayed.

Show/Hide Jess State: The agent information regarding the Jess rule based script execution may be hided or displayed.

Show/Hide Map: The NPC map can be hided or displayed.

2) NPC Sensory Information

In order to monitor the behaviour execution of an NPC, it is useful to access to its most important internal data, like the energy level, the position and rotation and also other relevant information like if it is moving or if it is seeing or hearing anything. What about the enemies? Is it seeing any of them? It is seeing any weapon and what about the number of ammunition that it is currently possessing? All that information can be displayed on the individual terminal window, along with the NPC ID and name (see Fig. 6).

At this point, we have considered the referred data as the most important to be displayed. As we will explain later there are other ways to monitor other aspects of the agent, by using the powerful command window tool.

3) Manual Controls

On the left we may see three manual control buttons that allow us to control manually the movement of an NPC. By clicking the right or left arrow buttons, the NPC will make a respectively clockwise or anti-clockwise 45º rotation; by clicking the north arrow, it will advance forward a certain small distance, if possible. This buttons can be very useful if we want to manually position the NPC so that it will end with a certain position and orientation.

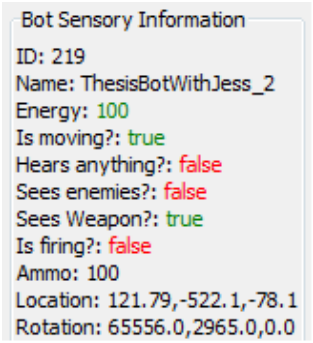

Fig. 6. The displayed sensory information in a NPC console.

4) Individual 2D Map

We can visualize a world map with the position of every NPC in the game but where the position of the currently monitored NPC is highlighted (see Fig. 7).

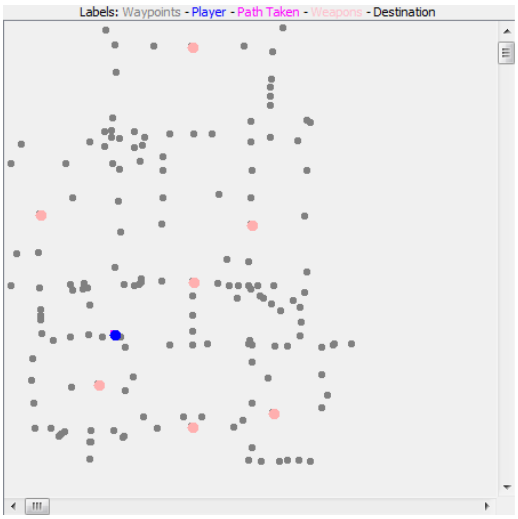

Fig. 7. 2D Map. It allows the visualization of the monitored agent in relation to the others and the world. On the top we see information regarding the colour legends.

The map may be used as an interface for controlling the position of the NPC. The user can click in any waypoint on the map, and if it is possible, the NPC goes directly to the chosen waypoint.

5) Jess Monitoring

In order to develop and maintain a rule based script it is very useful to be able to monitor the list of facts from the Jess working memory, the agenda or rule activations, the selected and fired rule and also the available user defined Jess functions along with some useful built-in ones (see Fig. 8). All this information may be displayed in the individual terminal window.

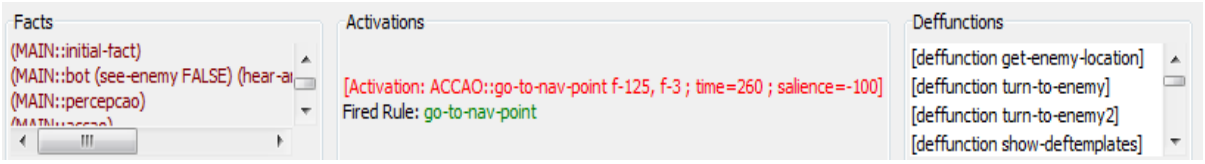

Fig. 8. Jess monitoring information: the working memory facts list, the rule activations and fired rule and also the user defined functions along with other useful built-in functions.

After stopping a NPC, it will be easy to test the script rules, monitoring their activation in a certain situation. We can follow the rule-based behaviour of a NPC using the step control button and observing the Jess information on the individual terminal window.

The user defined functions visualization was introduced with the goal of helping the user just in case he wants to execute a particular function using the command window. It will certainly be useful for him to look up for the right function name.

On the right of the terminal window, depicted in Fig. 5, we see three buttons that allow us to hide any of these three Jess information types.

6) Command Window

For a full agent monitoring and control, in the individual terminal is offered a command window, which is an interface where the game developer has the possibility to execute any Jess command and behaviour or perception functions and observe their output. This is an important tool for script exploration and debugging besides being very useful for setting up test situations.

The user can fire rules step by step tracing the NPC behaviour, following the evolution of the NPC state and facts list as well as the rules activation and selection. Or he can execute some specific Jess function that extends the NPC state besides the standard information given on the right and referred on III.B.2. The user can even create a function in real-time and execute it, and as Jess is written in Java, he can have full access to the Java API.

As an example, consider that we want to test the script when the user is facing the enemy. We would run the game until our NPC sees its enemy and that after pausing the game, we would pick up the right user defined Jess function: *(turn-to- enemy)*, and execute it in the command prompt. Afterwards we would see the ordered list of rule activations in the window terminal by executing the *(agenda)* command, so that we could check if the rules script were behaving as expected.

C. The Execution Step: the interface between JAVA and JESS

The game execution is divided in steps, but the script developer is responsible for the definition of what is a step, although there are some restrictions. The JAVA NPC controller will always put two special Jess modules in the focus stack: the PERCEPTION and BEHAVIOR, and will issue a (run) command for execution of the PERCEPTION rules followed by the BEHAVIOR ones.

Thus, it is convenient that the script developer separates the Jess rules in two modules: one specialized in gathering information like, for example, the nearest enemy location, and the other specialized in actions, like moving or shooting. In each module more than one rule can fire—each module is executed only when no more rules fire. Therefore, the script must carefully manage the return of the control to JAVA so that Jess rules in any of the two modules do not fire forever.

TABLE I
A JESS SCRIPT TO ILLUSTRATE A SIMPLE NPC BEHAVIOUR DEFINITION USING A PERCEPTION/ACTION CYCLE.

```
;An example of Deftemplate
;to store all about the agent

(deftemplate bot
  (slot see-enemy)
  (slot hear-anything)
  (slot moving)
  (slot nav-target)
  (slot enemy-target))

;Setup
(deffacts SETUP
  (perception)
  (action)
  (bot (see-enemy FALSE)
       (nav-target nil)))

(defmodule PERCEPTION)

;Rule to collect info about the agent
(defrule perception
  ?f <- (perception)
  ?x <- (bot (nav-target ?target))
  =>
   (retract ?f)
   (assert (perception))
   (modify ?x (see-enemy
               (see-enemy-func))
               (enemy-target
                (get-enemy-location)))
   (return))

(defmodule ACTION)

;Rule to pursuit and fire at the enemy he sees
(defrule fires-and-pursuit-enemy
  (declare (salience 100))
  ?a <- (action)
  ?bot <- (bot  (see-enemy TRUE)
  (enemy-target ?t&~nil))
  =>
  (retract ?a)
  (assert (accao))
  (go-to-enemy ?t)
  (shoot ?t)
  (return))
```

We show in Table I an example of a toy Jess script, only for illustration. The (return) command assures that control no

more rules are executed inside the respective module: after a (return) in a PERCEPTION rule, control is given to the ACTION module, and after a (return) in an ACTION rule, control is given back to JAVA, putting an ending in the step. We can see several perception and action functions: *(see-enemy-func)* returns a boolean and *(get-enemy-location)* returns the enemy position coordinates; *(goto-enemy)* means that the MPC goes towards a position near the enemy and *(shoot)* means the NPC turns towards the enemy position and shoots.

Note that while in the JESS command window we can execute a rule after another monitoring behaviour in a thinner scale than a step. In the example given there is only one rule in each module and so a step execution will fire 2 rules in case they are both activated.

At table II we present another short example of the Jess code to control the character movement in a formation controlled by the group leader. As the previous example the behavior is controlled by a cycle of perception/action activated be a message from the squad leader. This message indicates to the character is new position on the formation and the direction it should be facing. When a new message is received, the PERCEPTION module stores the information of the character new objectives. This information is used to activate the module ACTION and execute the appropriated actions to achieve those goals.

TABLE II
AN EXEMPLE OF A PICE OF CODE THAT CONTROL THE MOVEMENT OF A CHARACTER IN A FORMATION

```
(defmodule PERCEPTION)

(defrule perception
   ?f <- (perception)
   ?x <- (bot) ; representation of BOT current attributes
   =>
   (retract ?f)
   ;If received a message to move in formation (id 9)
   (if (and (eq (get-receiver-team-id-from-message) 9))
      then  (bind ?var  (select-place-on-diamond-formation
                  (get-location-from-message)
                  (get-rotation-from-message)))
            ;setup destination
            (modify ?x (nav-target ?var))
            ;setup bot rotation
            (modify ?x (rot-target
               (select-rotation-on-diamond-formation ?var)))
   )
   (assert (perception))
   (store RuleFired perception)
   (return)
)

...

(defmodule ACTION)

(defrule go-to-destination
   ?a <- (action)
   ;If there is a destination and a rotation
   (bot (nav-target ?target&~nil)(rot-target ?rot))
   =>
   (retract ?a)
   (assert (action))
   ;move bot
   (go-to-target ?target ?rot))
   (store "RuleFired" go-to-destination)
   (return)
)
...
```

This rules and modules can be combined in more complex behaviours, taking advantage of the capability of the tool environment to make extensive tests to each component. Although the integration of different pieces of code is not entirely error free, these characteristics provide us with a significant enhancement over the current accessible tools.

IV. CONCLUSIONS AND FUTURE WORK

In this paper we presented a generic architecture to support the development of tools to assist the design, debug and execution of artificial intelligent non-player characters in a game simulated environment. We build the application DEVELOP-FPS as a concrete example of the implementation of the architecture, and introduce some of its core functionalities and capabilities. This tool allows the management of the NPCs from different levels, individually monitoring and controlling their behavior or act in a global perspective.

We have designed several experiments using this tool, from simple behaviours that only follow a fixed path to advanced cooperative team behavior which include collision avoidance and split and regroup capabilities. Our tool was fundamental in the debugging process and testing of the developed behaviours. The advantages of forcing situations when a specific behavior characteristic was triggered and follow the execution trace of the agent rules were an improvement in the character creation.

We believe that this kind of tools is fundamental in the process of constructing and deploying artificial intelligence components. Although commercial games companies had their own proprietary tools, these are not made available to the general public. The use of a text editor and a trial and error approach hardly is viable when the project grows beyond a certain dimension. The development of these tools is a something that in a close future had to taken into account when a new game project is initiated.

By now we are already extending the game developer tool in order to have different agent teams controlled by the Global Console. Another useful extension can be the addition of a command window into the Global Console so that we can broadcast Jess commands and functions to every Non Character Player or just to a specific team, which may help setting up test scenarios. The definition of teams and the definition of coordinated actions and group tactics is currently work in progress. We expect that our tool will improve and facilitate the designer tasks.

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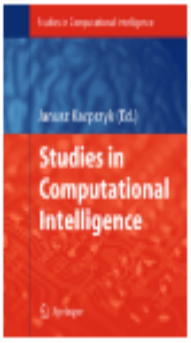

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