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In activities other than purely logical thought, our minds function much faster than any computer yet devised

DANIEL CREVIER

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EDITORIAL TEAM

Editor's Note

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.

The research works presented in this issue are based on various topics of interest, among wich are included: Mobile services, gesture recognition, physics simulation, management decision support, business intelligence, Internet, remote executables, scientific computing, university-industry links, Sony AIBO, Aperios, toolchain, MAS, data fusion, tracks, merge, inference, Homeland Security, european projects, research trends, emerging technologies and desk research.

Almulhim et al. proposes a fuzzy group prioritization method for deriving group priorities/weights from fuzzy pairwise comparison matrices. The proposed method extends the Fuzzy Preferences Programming Method (FPP) by considering the different importance weights of multiple DMs. Detailed numerical examples are used to illustrate the proposed approach [1].

Klein et al. introduces the Behaviour Assessment Model (BAM), which is designed to gaining insights about how well services enable, enhance and replace human activities. More specifically, the basic columns of the evaluation framework concentrate on service actuation in relation to the current user context, the balance between service usage effort and benefit, and the degree to which community knowledge can be exploited. The evaluation is guided by a process model that specifies individual steps of data capturing, aggregation, and final assessment [2].

Costa et al. presents SketchyDynamics, a library that intends to facilitate the creation of applications by rapidly providing them a sketch-based interface and physics simulation capabilities. SketchyDynamics was designed to be versatile and customizable but also simple. In fact, a simple application where the user draws objects and they are immediately simulated, colliding with each other and reacting to the specified physical forces, can be created with only 3 lines of code. In order to validate SketchyDynamics design choices, they also present some details of the usability evaluation that was conducted with a proof-of-concept prototype [3].

Skyrius et al. defines relations between simple and complex informing intended to satisfy different sets of needs and provided by different sets of support tools. The paper attempts to put together decision support and business intelligence technologies, based on common goals of sense-making and use of advanced analytical tools. A model of two interconnected cycles has been developed to relate the activities of decision support and business intelligence. Empirical data from earlier research is used to direct possible further insights into this area [4].

Ferreira et al. present a study, largely based on academic practice, a simple illustrative example in Geometry is implemented on a distributed system that outsources the computing-intensive tasks to remote servers that may be located in other universities or companies, linked to grids and clusters and so on. The software stack and software developed to support the communication is explained in detail. The architecture developed stresses the interoperability of the software, and a suitable high degree of decoupling between components hosted in various locations. The results of this study motivate further work and serve a practical purpose that may be useful to everyone doing scientific computing [5].

Castillo et al. presents an agent-based solution for data fusion in Homeland Security. The research is focused on obtaining a Multi-agent system able to inference future enemy's actions or behaviors from data received from heterogeneous sensors.presents a revision and an analysis of the Open Data initiative situation in Spain. The analysis looks at origins and concepts, the legal framework, current Initiatives and challenges that must be addressed for the effective reuse of public information industry [6].

Kertész shows an improvements of the native software development environment (Open-R SDK) provided to program AIBO are presented in the paper. More enhancements are implemented in the core components, some software methodologies are applied to solve a number of restrictions and the achievements are summarized in the contribution [7].

De La Fuente et al. presents a desk research that analysed available recent studies in the field of Technology Enhanced Learning. This research will be used as a basis to better understand the evolution of the sector, and to focus future research efforts on these sectors and their application to education [8].

Dr. Rubén González Crespo

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WELCOME TO NEW MEMBERS

Monique Janneck Ph.D. is professor at the Lübeck University of Applied Science, Germany. She studied psychology and earned a doctorate in informatics with a thesis on the design of cooperative systems from a communication psychology perspective. Her research focus is on the interplay between human behavior, social structures and technological development: She is interested in the way humans interact with technology, the way theories and findings on human behavior can inform the design of information technology, and the way technology impacts individual, organizational, and social behavior and structures.

Daniel Burgos works as Vice-chancellor for Research & Technology, and Director of Engineering at the International University of La Rioja (www.unir.net, http://research.unir.net). He also holds the Technology Innovation Chair at the same university. Previously he worked as Director of Education Sector and Head of User Experience Lab in the Research & Innovation Department of Atos, Spain, since 2007; and as an Assistant Professor at Open Universiteit Nederland before that.

His research interests are mainly focused on Adaptive and Informal eLearning, Learning & Social Networks, eGames, and eLearning Specifications. He is or has been involved in a number of European funded R&D projects like, i.e. Intuitel, Hotel, Edumotion, Inspiring Science Education Stellar, Gala, IntelLEO, Go-MyLife, Grapple, Unfold, ProLearn, TenCompetence, EU4ALL, NiHao, Kaleidoscope, Sister, ComeIn, et cetera.

Prof. Dr. Burgos holds degrees in Communication (PhD), Computer Science, Education, and Business Administration. Furthermore, he is member of a number of Executive Boards of associations and professional clusters focused on educational technology and eLearning innovation like, i.e. Telearc, Telspain, Menon Network, Adie, and others

JOURNAL COVER

We want to thanks the cover of this issue to Rubén González Crespo, Editor In Chief of the Journal.

TABLE OF CONTENTS

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A Fuzzy Group Prioritization Method for Deriving Weights and its Software Implementation

Tarifa Almulhim, Ludmil Mikhailov and Dong-Ling Xu
Manchester Business School, University of Manchester, Booth Street East, Manchester

***Abstract* — Several Multi-Criteria Decision Making (MCDM) methods involve pairwise comparisons to obtain the preferences of decision makers (DMs). This paper proposes a fuzzy group prioritization method for deriving group priorities/weights from fuzzy pairwise comparison matrices. The proposed method extends the Fuzzy Preferences Programming Method (FPP) by considering the different importance weights of multiple DMs. The elements of the group pairwise comparison matrices are presented as fuzzy numbers rather than exact numerical values, in order to model the uncertainty and imprecision in the DMs' judgments. Unlike the known fuzzy prioritization techniques, the proposed method is able to derive crisp weights from incomplete and fuzzy set of comparison judgments and does not require additional aggregation procedures. A prototype of a decision tool is developed to assist DMs to implement the proposed method for solving fuzzy group prioritization problems in MATLAB. Detailed numerical examples are used to illustrate the proposed approach.**

***Keywords* — Fuzzy Non-linear Programming, Fuzzy Preferences Programming Method, Multiple Criteria Decision Making, Triangular Fuzzy Numbers.**

I. Introduction

THERE are various techniques for deriving priorities/weights for decision elements (e.g. attributes/criteria) from a decision maker (DM) or group of DMs, some of which are reviewed by Choo and Wedley [1] and Ittersum et al. [2]. Most techniques are based on either direct weighting or on pairwise comparison. In direct weighting, the DM is directly asked to give values between 0 and 1 to each decision element to assign their importance. Some methods for deriving attributes/criteria weights by direct assigning techniques are: the Simple Multi-Attribute Rating Technique (SMART) [3], SWING weighting methods [4], and SMART Exploiting Ranks (SMARTER) [5].

When the DM or the group of DMs are unable to directly assign decision elements' weights, the Pairwise Comparison (PC) method proposed in [6] can be used.

Psychological experiments have shown that weight derivation from PC is much more accurate than direct weighting [7]. Therefore, the PC methods are often used as an intermediate step in many MCDM methods, as Analytic Hierarchy Process (AHP) [7], Analytic Network Process (ANP) [8], PROMETHEE [9], and Evidential Reasoning (ER) [10].

The PC methods require construction of Pairwise Comparisons Judgment Matrices (PCJMs). In order to construct a PCJM, the DM is asked to compare pairwisely any two decision elements and provide a numerical/linguistic judgment for their relative importance. Thus, the DM gives a set of ratio judgments to indicate the strength of his/her preferences, which are structured in a reciprocal PCJM. Then, the weights or priority vectors of the decision elements can be derived from the PCJM by applying some prioritization methods.

There are numerous Pairwise Comparisons Prioritization Methods (PCPMs), such as the Eigenvector Method [7], the Direct Least Squares Method [11], the rank-ordering method [7], the Logarithmic Least Square Method [12], and the Fuzzy Programming Method [13]. Choo and Wedley [1] summarised and analysed 18 PCPMs for deriving a priority vector from PCJMs. They discussed that no method performs best in all situations and no method dominates the other methods.

However, in many practical cases, in the process of prioritization the DMs are unable to provide crisp values for comparison ratios. A natural way to deal with the uncertainty and imprecision in the DMs' judgments is to apply the fuzzy set theory [14] and to represent the uncertain DMs' judgments as fuzzy numbers. Thus, Fuzzy PCJMs can be constructed and used to derive the priority vectors by applying some Fuzzy PCPMs. Such methods are proposed by Laarhoven and Pedrycz's [15], Buckley [14], Chang [16] and Mikhailov [17], and applied for group decision making.

The existing fuzzy PCPMs have some drawbacks. They require an additional defuzzification procedure to convert fuzzy weights into crisp (non-fuzzy) weights. However, different defuzzification procedures will often give different solutions [17].

The linear and non-linear versions of the Fuzzy Preference Programming (FPP) method [17] do not require such defuzzification procedures, but their modifications for group decision making situations assume that all the DMs have the same weight of importance. However, in real group decision making problems, sometimes some experts are more

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experienced than others [18-19]. Therefore, the final results should be influenced by the degree of importance of each DM.

In order to overcome some of the limitations of the group FPP method, a new group version of the FPP method is proposed by introducing importance weights of DMs in order to derive weights for decision elements in group decision problems. The proposed method has some attractive features. It does not require any aggregation procedures. It does not require a defuzzification procedure. It derives crisp priorities/weights from an incomplete set of fuzzy judgments and incomplete fuzzy PCJMs. Moreover, the proposed method considers the DMs weights.

For applying the proposed method and solving prioritisation problems, a Non-Linear FPP Solver is developed based on the Optimization Toolbox of MATLAB, in order to overcome the complexity of programming. This decision tool is demonstrated by solving a few numerical examples.

The remainder of this paper is organised as follows. In Section II, representation of the fuzzy group prioritization problem is briefly explained. Then, the proposed method is presented in Section III and illustrated by numerical examples in section IV. The developed Non-Linear FPP Solver is presented in section V, followed by conclusions.

II. Representation of the Fuzzy Group Prioritization Problem

Consider a group of K DMs ($DM_k, k=1,2,...,K$) that evaluate n elements $E_1,..E_n$ (in MCDM, these elements could be clusters, criteria, sub-criteria or alternatives). With respect to some fixed preference scales, each DM assesses the relative importance of any two elements (E_i, E_j) $(i, j=1,2,..,n)$ by providing a ratio judgment a_{ijk}, specifying by how much E_i is preferred/not preferred to E_j.

In a fuzzy environment, suppose that each DM provides a set of y fuzzy comparison judgements $A^k=\{\tilde{a}_{ijk}\}$, $y \le n(n-1)/2$, where $i=1,2,..,n-1$, $j \succ i$, $j=2,3,.....n$, $k=1,2,..,K$ and those judgments are represented as Triangular Fuzzy Numbers (TFNs) $\tilde{a}_{ijk}=(l_{ijk}, m_{ijk}, u_{ijk})$, where l_{ijk}, m_{ijk} and u_{ijk} are the lower bound, the mode and the upper bound, respectively. Fig. 1 shows the TFN $\tilde{a}_{ijk}=(l_{ijk}, m_{ijk}, u_{ijk})$.

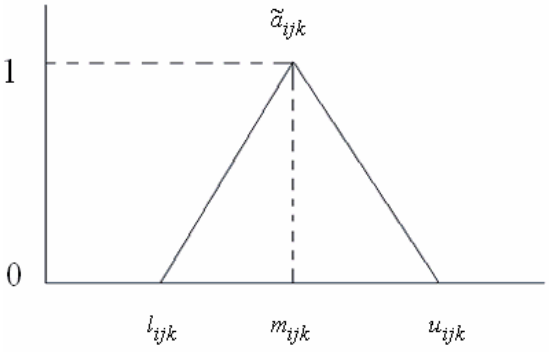

Fig. 1. Triangular Fuzzy Number $\tilde{a}_{ijk}=(l_{ijk}, m_{ijk}, u_{ijk})$

The set A^k can be used to form a Fuzzy PCJM of the form (1):

$$A^k=\begin{bmatrix} (1,1,1) & (l_{12k},m_{12k},u_{12k}) & .... & (l_{1jk},m_{1jk},u_{1jk}) \\ (l_{21k},m_{21k},u_{21k}) & (1,1,1) & .... & (l_{2jk},m_{2jk},u_{2jk}) \\ ... & ... & .... & ... \\ (l_{i1k},m_{i1k},u_{i1k}) & (l_{i2k},m_{i2k},u_{i2k}) & .... & (1,1,1) \end{bmatrix} \quad (1)$$

Then, the fuzzy group prioritisation problem is to determine a crisp priority vector (crisp weights) $w=(w_1, w_2,..., w_n)^T$ from all A^k, $k=1,2,...,K$, which represents the relative importance of the n elements.

III. Group Fuzzy Preference Programming Method

The non-linear FPP method [17] derives a priority vector $w=(w_1, w_2,..., w_n)^T$, which satisfies:

$$l_{ij} \tilde{\le} w_i/w_j \tilde{\le} u_{ij} \quad (2)$$

where $\tilde{\le}$ denotes 'fuzzy less or equal to'. If M is the overall number of fuzzy group comparison judgments, then $2M$ fuzzy constraints of the type (3) are obtained.

$$\begin{aligned} -w_i + w_j l_{ij} &\tilde{\le} 0 \\ w_i - w_j u_{ij} &\tilde{\le} 0 \end{aligned} \quad (3)$$

For each fuzzy judgment, a membership function, which represents the DMs' satisfaction with different crisp solution ratios, is introduced:

$$\mu_{ij}(w_i/w_j)=\begin{cases} \dfrac{(w_i/w_j)-l_{ij}}{m_{ij}-l_{ij}}, & w_i/w_j \le m_{ij} \\ \dfrac{u_{ij}-(w_i/w_j)}{u_{ij}-m_{ij}}, & w_i/w_j \ge m_{ij} \end{cases} \quad (4)$$

The solution to the prioritization problem by the FPP method is based on two assumptions. The first, requires the existence of a *non-empty fuzzy feasible area* $\tilde{P}$ on the $(n-1)$ dimensional simplex Q^{n-1},

$$Q^{n-1}=\{(w_1, w_2,..., w_n), w_i \succ 0, \sum_{i=1}^{n} w_i = 1\} \quad (5)$$

The fuzzy feasible area $\tilde{P}$ is defined as an intersection of the membership functions (4). The membership function of the fuzzy feasible area $\tilde{P}$ is given by:

$$\mu_{\tilde{P}}(w) = [Min\{\mu_1(w), \mu_2(w), ...\mu_{2M}(w)\} \setminus \sum_{i=1}^{n} w_i = 1] \quad (6)$$

The second assumption identifies a selection rule, which determines a priority vector, having the highest degree of membership in the aggregated membership function (6). Thus, there is *a maximizing solution* w^* (a crisp priority vector) that has a maximum degree of membership λ^* in $\tilde{P}$, such that :

$$\lambda^* = \mu_{\tilde{P}}(w^*) = Max[Min\{\mu_1(w), ..., \mu_{2M}(w)\} \setminus \sum_{i=1}^{n} w_i = 1] \quad (7)$$

A new decision variable λ is introduced which measures the maximum degree of membership in the fuzzy feasible area $\tilde{P}$. Then, the optimization problem (7) is represented as

$$\begin{aligned} &Max \ \ \lambda \\ &s.t. \\ &\lambda \le \mu_{ij}(w) \\ &\sum_{i=1}^{n} w_i = 1, \quad w_i \succ 0, \\ &i = 1,2,..., n, \quad j = 1,2,..n, \quad j \succ i \end{aligned} \quad (8)$$

The above max-min optimization problem (8) is transformed into the following non-linear optimization problem:

$$\begin{aligned} &Max \ \ \lambda \\ &s.t. \\ &(m_{ij} - l_{ij})\lambda w_j - w_i + l_{ij} w_j \le 0 \\ &(u_{ij} - m_{ij})\lambda w_j + w_i - u_{ij} w_j \le 0 \\ &i = 1,2,...n-1; \ \ j = 2,3,..n \ \ ; \ j \succ i \ ; \\ &\sum_{i=1}^{n} w_i = 1 \ ; \quad w_i \succ 0; \quad i = 1,2,..., n \end{aligned} \quad (9)$$

The non-linear FPP method can be extended for solving group prioritization problems. Mikhailov *et al.* [20] proposed a Weighted FPP method to the fuzzy group prioritization problem by introducing the importance weights of DMs. However, the Weighted FPP method requires an additional aggregation technique to obtain the priority vector at different α - thresholds. Consequently, this process is time consuming, due to several computation steps needed for applying the α - threshold concept. Therefore, this paper modified the non-linear FPP method [17], which can derive crisp weights without using α - threshold and by introducing the DMs' importance weights.

When we have a group of K DMs, the problem is to derive a crisp priority vector, such that priority ratios w_i / w_j are approximately within the scope of the initial fuzzy judgments a_{ijk} provided by those DMs, i.e.

$$l_{ijk} \lesssim w_i / w_j \lesssim u_{ijk} \quad (10)$$

The ratios w_i / w_j can also express the satisfaction of the DMs, as the ratios explain how similar the crisp solutions are close to the initial judgments from the DMs.

The inequality (10) can be represented as two single-side fuzzy constraints of the type (3):

$$\begin{aligned} &R_q{}^k W \lesssim 0, \\ &k = 1,.., K \ , \ q = 1,2,..2M_k \end{aligned} \quad (11)$$

The degree of the DMs' satisfaction can be measured by a membership function with respect to the unknown ratio w_i / w_j :

$$\mu_q{}^k(R_q{}^k W) = \begin{cases} \dfrac{\left(w_i^k / w_j^k\right) - l_{ijk}}{m_{ijk} - l_{ijk}} \ , w_i^k / w_j^k \le m_{ijk} \\ \dfrac{u_{ijk} - \left(w_i^k / w_j^k\right)}{u_{ijk} - m_{ijk}} \ , w_i^k / w_j^k \ge m_{ijk} \end{cases} \quad (12)$$

We can define K fuzzy feasible areas, $\tilde{P}_k$, as an intersection of the membership functions (12) corresponding to the k -th DMs' fuzzy judgments and define the group fuzzy feasible area $\tilde{P} = \bigcap \tilde{P}_k$.

By introducing a new decision variable λ_k , which measures the maximum degree of membership of a given priority vector in the fuzzy feasible area $\tilde{P}_k$, we can formulate a max-min optimisation problem of the type (8), which can be represented into:

$$\begin{aligned} &Max \ \ \lambda_k \\ &s.t. \\ &\lambda_k \le \mu_q{}^k(R_q{}^k W) \\ &\sum_{i=1}^{n} w_i = 1; \quad w_i \succ 0, \\ &i = 1,2,...,n; \quad k = 1,.., K; \quad q = 1,2,..2M_k \end{aligned} \quad (13)$$

For introducing the DMs' importance weights, let us define I_k as the importance weight of the $DM_k; k = 1,2,..., K$. For aggregating all individual models of type (13) into a single group model, a weighted additive goal-programming (WAGP) model [21] is applied.

The WAGP model transforms the multi-objective decision making problem to a single objective problem. Therefore, it can be used to combine all individual models (13) into a new single model by taking into account the DMs' importance weights.

The WAGP model considers the different importance weights of goals and constraints and is formulated as:

$$\begin{aligned} &\mu_D(x) = \sum_{s=1}^{p} \alpha_s \mu_{z_s}(x) + \sum_{r=1}^{h} \beta_r \mu_{g_r}(x) \\ &\sum_{s=1}^{p} \alpha_s + \sum_{r=1}^{h} \beta_r = 1 \end{aligned} \quad (14)$$

Where:

μ_{z_S} are membership functions for the p–th fuzzy goal $z_S, s = 1,2,... p$;

μ_{g_r} are membership functions of the h-th fuzzy constraints $g_r, r = 1,2,..h$;

x is the vector of decision variables;

α_s are weighting coefficients that show the relative important of the fuzzy goals;

β_r are weighting coefficients that show the relative important of the fuzzy constraints.

A single objective model in WAGP is the maximisation of the weighted sum of the membership functions μ_{z_S} and μ_{g_r}. By introducing new decision variables λ_s and γ_r, the model (14) can be transformed into a crisp single objective model, as follows:

$$
\begin{aligned}
&Max \ \ \textstyle\sum_{s=1}^{p} \alpha_s \lambda_s + \sum_{r=1}^{h} \beta_r \gamma_r \\
&s.t. \\
&\lambda_s \le \mu_{z_s}(x), \qquad s = 1,2,... p \\
&\gamma_r \le \mu_{g_r}(x), \qquad r = 1,2,...h \\
&\textstyle\sum_{s=1}^{p} \alpha_s + \sum_{r=1}^{h} \beta_r = 1 \\
&\lambda_s, \gamma_r \in [0,1]; \qquad \alpha_s, \beta_r \ge 0
\end{aligned}
\tag{15}
$$

In order to derive a group model, where the DMs have different importance weights, we exploit the similarity between the models (13) and (15). However, the non-linear FPP model (13) does not deal with fuzzy goals; it just represents the non-linear fuzzy constraints. Thus, by taking into account the specific form of $R_q^{\,k} W \tilde{\le} 0$ and introducing the importance weights of the DMs, the problem can be further presented into a non-linear program by utilising the WAGP model as:

$$
\begin{aligned}
&Max \ \ Z = \textstyle\sum_{k=1}^{K} I_k \lambda_k \\
&s.t. \\
&(m_{ijk} - l_{ijk})\lambda_k w_j - w_i + l_{ijk} w_j \le 0 \\
&(u_{ijk} - m_{ijk})\lambda_k w_j + w_i - u_{ijk} w_j \le 0 \\
&i = 1,2,...n-1; \quad j = 2,3,..n \ ; \\
&j \succ i \ ; \ k = 1,2,...K; \\
&\textstyle\sum_{i=1}^{n} w_i = 1 \ ; \quad w_i \succ 0; \qquad i = 1,2,..., n
\end{aligned}
\tag{16}
$$

Where the decision variable λ_k measures the degree of the DM's satisfaction with the final priority vector $w = (w_1, w_2, ..., w_n)^T$; I_k denotes the importance weight of the k-th DM, $k = 1,2,..K$.

In (16), the value of Z can be considered as a consistency index, as it measures the overall consistency of the initial set of fuzzy judgments. When the set of fuzzy judgments is consistent, the optimal value of Z is greater or equal to one. For the inconsistent fuzzy judgments, the maximum value of Z takes a value less than one.

For solving the non-linear optimization problem (16), an appropriate numerical method should be employed. In this paper, the solution is obtained by using MATLAB Optimization Toolbox and a Non-linear FPP solver is developed to solve the prioritization problem.

IV. Illustrative Examples

The first example illustrates the solution to the fuzzy group prioritization problem for obtaining a priority vector and a final group ranking. The second example demonstrates how the importance weights of DMs influence the final group ranking.

A. Example 1

This example is given to illustrate the proposed method and also the solution by using the Non-linear FPP Solver.

We consider the example in [20], where three DMs ($K = 3$) assess three elements ($n = 3$) and the importance weights of DMs are given as: $I_1 = 0.3$; $I_2 = 0.2$; $I_3 = 0.5$.

The DMs provide an incomplete set of five fuzzy judgments, presented as TFNs:

DM 1: $a_{121} = (1,2,3)$; $a_{131} = (2,3,4)$.

DM 2: $a_{122} = (1.5,2.5,3.5)$; $a_{132} = (3,4,5)$.

DM 3: $a_{123} = (2,3,4)$.

The group fuzzy prioritization problem is to derive a crisp priority vector $w = (w_1, w_2, w_3)^T$ that approximately satisfies the following fuzzy constraints:

For DM 1: $1 \tilde{\le} w_1/w_2 \tilde{\le} 3$; $2 \tilde{\le} w_1/w_3 \tilde{\le} 4$.

For DM 2: $1.5 \tilde{\le} w_1/w_2 \tilde{\le} 3.5$; $3 \tilde{\le} w_1/w_3 \tilde{\le} 5$.

For DM 3: $2 \tilde{\le} w_1/w_2 \tilde{\le} 4$.

Using the above data and the non-linear model (16), the following formulation is obtained:

$$
\begin{aligned}
&Max\ Z = 0.3\lambda_1 + 0.2\lambda_2 + 0.5\lambda_3 \\
&s.t. \\
&\lambda_1 w_2 - w_1 + w_2 \le 0 \\
&\lambda_1 w_2 + w_1 - 3w_2 \le 0 \\
&\lambda_1 w_3 - w_1 + 2w_3 \le 0 \\
&\lambda_1 w_3 + w_1 - 4w_3 \le 0 \\
&\lambda_2 w_2 - w_1 + 1.5w_2 \le 0 \\
&\lambda_2 w_2 + w_1 - 3.5w_2 \le 0 \\
&\lambda_2 w_3 - w_1 + 3w_3 \le 0 \\
&\lambda_2 w_3 + w_1 - 5w_3 \le 0 \\
&\lambda_3 w_2 - w_1 + 2w_2 \le 0 \\
&\lambda_3 w_2 + w_1 - 4w_2 \le 0 \\
&w_1 + w_2 + w_3 = 1 \\
&w_1 \ge 0, \quad w_2 \ge 0, \quad w_3 \ge 0
\end{aligned}
\tag{17}
$$

Regarding the judgments of this example, the results have been conducted by the Non-Linear FFP Solver. The solution to the non-linear problem (17) is:

$w_1 = 0.621$, $w_2 = 0.212, w_3 = 0.167$.

This solution can be compared with the crisp results from the example in [20] as shown in Table I. We may observe that we have the same final ranking $w_1 \succ w_2 \succ w_3$, from applying the two different prioritization methods. However, the Weighted FPP method [20] applies an aggregation procedure for obtaining the crisp vector from different values of priorities at different α - threshold. While, the proposed non-linear group FPP method does not require an additional aggregation procedure.

If the third DM, who has the highest important weight, provides a new fuzzy comparison judgment $a_{323} = (1,2,3)$, which means that the third element is about two times more important than the second element, the weights obtained by using the proposed Non-Linear FFP method are: $w_1 = 0.538$, $w_2 = 0.170$, $w_3 = 0.292$ and the final ranking is $w_1 \succ w_3 \succ w_2$. Consequently, it can be observed that the third DM's judgments strongly influence the final ranking.

However, if the importance weight of the third DM is lower than the first two DMs' weights, then the new fuzzy comparison judgment does not change the final ranking. Thus, we can notice the significance of introducing importance weights of the DMs to the fuzzy group prioritization problem.

TABLE I
RESULTS FROM THE TWO PRIORITIZATION METHODS

Methods	w_1	w_2	w_3
Weighted FPP method [a]	0.615	0.205	0.179
Non-linear FPP method [b]	0.623	0.216	0.161

[a] The method proposed in [16] with applying α - threshold.
[b] The method proposed in this paper without applying α - threshold.

The computation time of the proposed method has been investigated by using the Non-Linear FFP Solver. It was found that the group non-linear FFP method performs significantly faster compared to the Weighted FPP [20] with different α - thresholds ($\alpha = 0, 0.2, 0.5, 0.8, 1$), as seen in Fig. 2.

We can conclude that the average computation time (Minutes) for the Weighted FPP method highly increases as the number of decision elements n increases, compared with the proposed method. Hence, these results showed that the method proposed in this paper is more efficient, with respect to the computation time. Therefore, the proposed method in this paper demands less computation time than the Weighted FPP method [20].

B. Example 2

This example shows that the importance weights of the DMs influence the final group ranking.

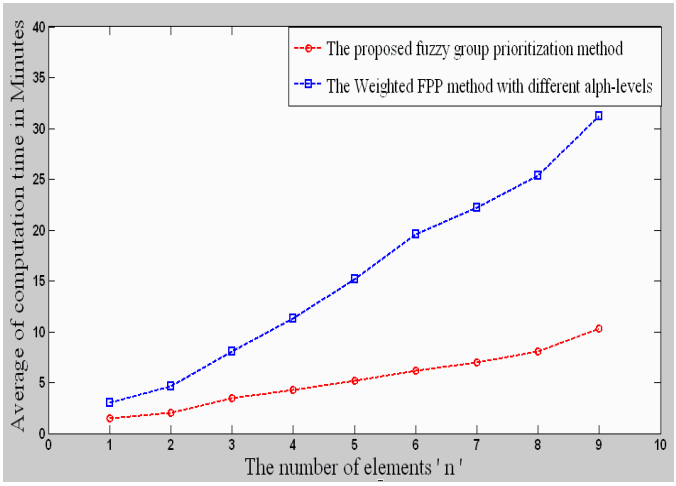

Fig. 2. Average Computation Time (Minutes)

Consider that two DMs ($K = 2$) assess three criteria ($n = 3$). The DMs provide an incomplete set of four fuzzy judgments ($m = 4$) presented as TFN:

DM 1: $a_{121} = (1,2,3); a_{131} = (2,3,4).$

DM 2: $a_{212} = (3,4,5); a_{312} = (2,3,4).$

Two situations are investigated when both DMs have the following different weights:

1. $I_1 = 0.2$, $I_2 = 0.8$
2. $I_1 = 0.8$, $I_2 = 0.2$

For both situations, the final rankings for both individual DMs are shown in Tables II and III respectively. The final group rankings are also shown in Tables II and III (the third row of each table). The results are obtained by using the Non-Linear FFP Solver. Each final group ranking is obtained by solving a non-linear program of type (15), which includes eight non-linear inequality constraints corresponding to the given DMs' fuzzy comparison judgements.

It can be observed from Tables II and III that the final group ranking tends to be the individual ranking of the DM who has the highest importance weights. In more detail, it can be seen

from Table II that the judgements of the second DM with the highest importance weight ($I_2 = 0.8$) influence, more strongly, the final group ranking. On the other hand, the final group ranking in Table III is dependent on the first DM, who has the highest importance weight ($I_1 = 0.8$).

From examples 1 and 2, we can observe the importance of introducing importance weights of the DMs to the fuzzy group prioritisation problem. It is seen that the final group ranking depends on the DMs' importance weights.

V. Software Implementation Using MATLAB

MATLAB is a numerical computing environment, which allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including

TABLE II

INDIVIDUAL AND GROUP RESULTS ($I_1 = 0.2$, $I_2 = 0.8$)

DMs	w_1	w_2	w_3	Final ranking
DM 1	0.545	0.273	0.182	$w_1 \succ w_2 \succ w_3$
DM 2	0.117	0.530	0.353	$w_2 \succ w_3 \succ w_1$
Group	0.117	0.529	0.354	$w_2 \succ w_3 \succ w_1$

TABLE III

INDIVIDUAL AND GROUP RESULTS ($I_1 = 0.8$, $I_2 = 0.2$)

DMs	w_1	w_2	w_3	Final ranking
DM 1	0.545	0.272	0.181	$w_1 \succ w_2 \succ w_3$
DM 2	0.117	0.530	0.353	$w_2 \succ w_3 \succ w_1$
Group	0.402	0.397	0.201	$w_1 \succ w_2 \succ w_3$

C, C++, Java, etc. [22]. This development environment includes many functions for statistics, optimization, and numeric data integration and filtering [23].

In this paper, we use the Optimization Toolbox and the Graphical User Interface (GUI) of MATLAB as the development tools for implementing the proposed group non-linear FPP method, because these tools provide powerful numerical functions, optimisation procedures, good visualisation capabilities and programming interfaces.

Essentially, there are three steps for programming and developing the Non-Linear FFP solver:

Step 1: Coding the model into the system. A number of functions are available in the Optimization Toolbox-MATLAB to solve the non-linear programming problem. In our prototype, the optimisation problem is solved using the sequential quadratic programming procedure [19].

Step 2: Creating a basic user interface. In this step, the interface is designed, so that it can run in the MATLAB command window. The aim of this user interface is to obtain the input information from the DMs.

Step 3: Developing the system based on the GUI functions. In this step, the MATLAB GUI functions are employed to develop a more user-friendly system.

Regarding the given data in example 1, the input information which should be acquired includes the total number of decision elements, the names of these elements and the total number of DMs, as shown in Fig.3. Then, the pairwise judgments for each DM can be entered by the user, as illustrated in Fig. 4. According to example 1, the fuzzy judgments for the DM 1 are illustrated in Fig. 4. Thus, the main feature in the developed interface is that the user can input the fuzzy judgments into the system directly and easily.

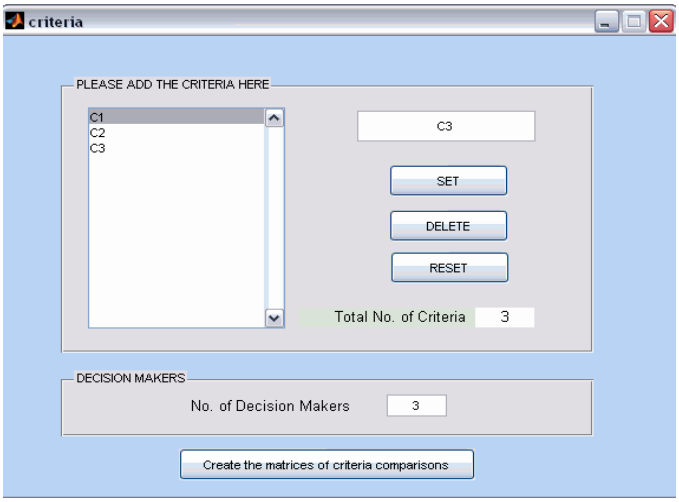

Fig. 3. The criteria setting window

Fig. 4. The fuzzy comparison judgments window for the DM 1

However, if the user is unable to provide fuzzy comparison judgments between two elements, then he/she can click on the **'Missing Data'** button and the system temporarily puts -1 for this comparison. The negative value is not a true judgment in the real world; it just indicates that those elements should not be included in the further calculations. For instance, in the given example, the judgment a_{231} is missing for DM1 and it is

recorded as (−1,−1,−1) in Fig. 4.

After entering the fuzzy judgments from all DMs, the user can set the DMs' importance weights into the system. According to the given data in example 1, the importance weights of the three DMs are entered, as shown in Fig. 5.

Finally, the Solver finds the optimal solution and visualises it graphically – Fig. 6.

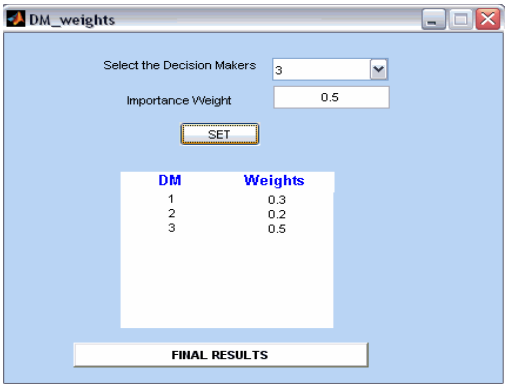

Fig. 5. The DMs' importance weights window

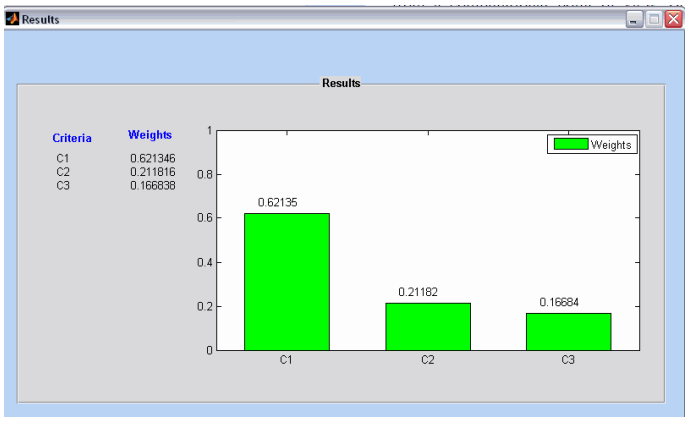

Fig. 6. The results from the Non-Linear FFP Solver

VI. Conclusions

This paper proposes a new method for solving fuzzy group prioritisation problems. The non-linear FPP is modified for group decision making by introducing DMs' importance weights. The proposed method derives crisp priorities/weights from a set of fuzzy judgements and it does not require defuzzification procedures. Moreover, the proposed method is capable of deriving crisp priorities from an incomplete set of DMs' fuzzy pairwise comparison judgments. Comparing with the Weighted FPP method, the proposed method is efficient from a computational point of view. Hence, the proposed method is a promising and attractive alternative method to existing fuzzy group prioritisation methods.

Another contribution of this study is the development of a Non-Linear FPP Solver for solving group prioritisation problems, which provides a user-friendly and efficient way to obtain the group priorities.

Future work includes presenting the importance weights for the DMs as fuzzy numbers, not just as crisp numbers, in order to model the uncertain importance weights of DMs. Moreover, we would like to incorporate the proposed method into other MCDM methods such as the Fuzzy Analytic Hierarchy Process, the Fuzzy Analytic Network Process and the Evidential Reasoning approach for complex decision problem analysis.

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Tarifa Almulhim received a bachelor degree in mathematics from King Faisal University, Alhassa, Saudi Arabia in 2005, and a M.Sc. degree in operational research and applied statistics from the University of Salford, Salford, UK, in 2010.
She has worked as a lecturer at King Faisal University and has tutored in various subjects, including Operational Research, Applied Statistics as well as the use of SPSS software on behalf of the Statistics and Quantitative Methods Department. Currently, she is working towards her Ph.D. in business and management at the University of Manchester, UK. Her current research interests include studying the health insurance market in developing countries, multi-criteria decision methods and analytical decision processes.

Ludmil Mikhailov obtained a first class BSc (1974) and MSc (1976) degree in Automatic Control from the Technical University in Sofia, Bulgaria and a PhD degree in Technical Cybernetics and Robotics from the Bulgarian Higher Certifying Commission (1981).
He is a Senior Lecturer at the Manchester Business School, the University of Manchester.
He worked as an Associated Professor at the Institute of Control and System Research of the Bulgarian Academy of Sciences (BAS) until 1996, where he was a head of a research group. During his work at BAS, he participated in many industrial projects on the development of various software systems for control, monitoring and technical diagnosis.
After joining the Decision Technologies Group at the Computation Department, UMIST in January 1997, Ludmil started to investigate new methods for multiple criteria decision making. He is the author of about 90 technical papers in peer-reviewed journals and international conferences, and holds two patents in the area of systems and control. His current research interests include multiple criteria decision analysis, fuzzy logic systems, decision making under uncertainty and intelligent decision support systems.

Dong-Ling Xu (PhD, MBA, MEng, BEng) received her BSc degree in electrical engineering, Master degree in Business Administration (MBA), and MSc and PhD degrees in system control engineering.
She is Professor of decision sciences and systems in Manchester Business School, the University of Manchester.
Prior to her current appointment, she worked as lecturer and associate professor in China, principal engineer in industry and research fellow in universities in the UK. She has published over 150 papers in journals and conferences, such as European Journal of Operational Research and IEEE Transactions on Systems, Man, and Cybernetics.
As a co-designer, she developed a Windows based decision support tool called IDS (Intelligent Decision Systems). The tool is now tested and used by researchers and decision analysts from over 50 countries, including organisations such as NASA, PricewaterhouseCoopers and General Motors. Her current research interests are in the areas of multiple criteria decision analysis under uncertainties, decision theory, utility theory, optimisation and their applications in performance assessment for decision making, including supplier selection, policy impact assessment, environmental impact assessment, sustainability management and consumer preference identification.

Analysis of Log File Data to Understand Mobile Service Context and Usage Patterns

Bernhard Klein, Ivan Pretel, Sacha Vanhecke, Ana B. Lago and Diego Lopez-de-Ipiña,
DeustoTech –Deusto Institute of Technology, University of Deusto, Bilbao, Spain
Department of Electronics and Information Systems, Ghent University, Belgium

***Abstract* — Several mobile acceptance models exist today that focus on user interface handling and usage frequency evaluation. Since mobile applications reach much deeper into everyday life, it is however important to better consider user behaviour for the service evaluation. In this paper we introduce the Behaviour Assessment Model (BAM), which is designed to gaining insights about how well services enable, enhance and replace human activities. More specifically, the basic columns of the evaluation framework concentrate on (1) service actuation in relation to the current user context, (2) the balance between service usage effort and benefit, and (3) the degree to which community knowledge can be exploited. The evaluation is guided by a process model that specifies individual steps of data capturing, aggregation, and final assessment. The BAM helps to gain stronger insights regarding characteristic usage hotspots, frequent usage patterns, and leveraging of networking effects showing more realistically the strengths and weaknesses of mobile services.**

***Keywords* — Mobile services, technical acceptance model, log-data analysis, human-computer interaction**

I. Introduction

USER acceptance in field trials is still mostly evaluated through questionnaires and focus interviews. Mobile applications are, however, much stronger related to real mobile behaviour as people carry their devices with them. Because of the dependency of mobile applications' functionalities on the user situation answers to general questions about the application can often not easily be given.

A relative new approach for mobile services is the observation of application usage through data loggers. A data logger records application events or errors jointly with other usage or system related metadata. To support daily activities successfully, mobile applications should not interrupt the activities, provide a reasonable interaction/benefit ratio to the user, and provide community leveraging beyond exploitation of personal experience. Analysing usage hotspots, usage frequency and usage type allow researchers to speculate about potential strengths, weaknesses or even problems for the surveyed service.

In this work, we present a behaviour assessment framework that describes the systematic collection of behaviour data and guides researchers in their log data analysis. With such an analysis approach researchers can gain more insights about first and long term service impressions, acceptances issues correlated with the user experience and the success of subsequent product evolvement steps.

The article is structured as follows. The next section discusses related works. Section 3 describes the method how to capture, aggregate, and represent data. In Section 4 the behaviour assessment model is defined. A preliminary case study is given in Section 5. Section 6 concludes the article.

II. Related Work

In order to perform a study focused on mobile services the first step is to compare, analyse and find the differences and connections between existing data loggers, concepts and conclusions related to the mobile services evaluation field.

Lab-based evaluation frameworks log information in a controlled environment using specific devices and specific users. The main advantages of the lab-based frameworks are the highly controllable environment and the collection of data, which is cheap and easy. However, the context, which is the most influential factor in the mobile services field, is not considered and it can hardly be simulated. Many simulation tools produce highly inaccurate results because of the context. Furthermore, several agents also alter the results of user experiments. The experts who lead the experiment and the tasks performed by the users can not only alter the execution of experiments but also evoke situations that would never happen in real environments. The users may also add biased results during the execution of the experiments [1] because they suffer several problems such as test-anxiety [1]: during the task performance the highly test-anxious person divides his attention between self-relevant and task-relevant variables; due to the self-focussed attention the user of the mobile service may not show real behaviour. Further, in many tasks such as phone calls, it would be subjectively annoying for many users to be in a room with observing researchers.

On the other hand the field-based evaluation frameworks (see Table 1) capture information in real environments. They commonly use added cameras and human observers to capture

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information from the interactions. Furthermore, this kind of framework tries to bring the lab to the field. For example, the Usertesting platform [2] not only brings methods like the think-aloud verbal protocol but also records the user's feedback with a webcam; finally it reproduces the interaction again enabling the annotations during it. Using this kind of techniques means that although the task is performed in real environment, it is changed and consequently, the interaction altered. Another tool related to Usertesting is the Morae Observer [3] tool. It captures all the interaction data and indexes it to one master timeline for instant retrieval and analysis; it generates graphs of usability metrics. Both tools are focused on the interaction because they are centred on capture of screen interaction and the user's feedback through filming the face or recording comments. Another group of tools such as ContextPhone [4] and RECON [5] are focused on the context capture. They capture the surrounding environment through mobile sensors. This capturing technique retrieves a lot of real data without influencing the interaction but the user's feedback is lost. In order to fill the lack of the user's feedback other tools like MyExperience [6] and SocioXensor [7] use techniques like self-reports, surveys and interviews mixed with the context capture. These tools are quite powerful and flexible because the user has at any time the complete control about when participate in an application acceptance survey. In case, he has been interrupted in the survey he can resume it to a later point of time.

To sum up, to acquire valid interaction data about mobile services, it is essential to capture objective information to solve questions like when, where, how long, etc. users are really interacting with a service. These questions can hardly be determined with a lab-based framework. The field-based evaluation frameworks can provide deeper and more objective information, but the added agents such as cameras and invasive evaluation methods (e.g. think-aloud verbal protocols) have to be removed. In order to do so, the best way to capture interaction data is by registering information through a mobile device using a tiny capture tool. This tool should log the context via the built-in mobile sensors and logging the key interaction events.

III. Mobile Service Assessment through Behavior Analysis

A framework for automatically logging and processing data for evaluation has been developed. In the following we briefly explain the different behaviour capturing and aggregation phases and the architectural requirements.

A. Data Logging and Aggregation Overview

As can be seen in Fig. 1 the framework distinguishes four main phases:

1. Data Capture: A data logger component installed separately on the mobile device records event and error data triggered by the mobile service. Examples for logging data are: service start and stop times, UI events e.g. buttons pressed, screen transitions, any changes in settings and erroneous data entries, exceptions and any unexpected system behaviour. These data are complemented with additional user contexts (e.g. provider and subscriber data), service information (e.g. queries/results, content data, screen stay duration) and device contexts (e.g. location data) for further evaluation.

2. Transfer Protocol: Logging data is periodically (e.g. daily) transferred to an analysis component hosted on the Internet. To minimize the influence on mobile service performance the transfer process is only started if the mobile device remains in an idle execution state.

3. Data Aggregation: The analysis component parses the incoming logging data and interprets the raw data log format with a parser. A filter process removes out-of-bound values, spatio-temporal inconsistencies, and entries that do not conform to preset criteria. Following this filtering step the log data are aggregated through clustering analysis.

TABLE I
PROPERTIES FOR THE LOGGING TOOLS

Tool	Capture Techniques	Data	Report
Usertesting	Screen, webcam and microphone	Interaction, user information and user's feedback	Reproduce the screen interaction
Morae Observer	Screen, webcam and microphone, observer	Interaction, user information and user's feedback	Reproduce the interactions and calculate graphs
ContextPhone	Mobile sensing and interaction event logging	Interaction, device status and environment	Mobility patterns detection
RECON	Interaction event logging and mobile sensing	Interaction, device status, user information, user's feedback, and environment	Trace Data analysis Engine
MyExperience	Wearable hardware sensing, mobile sensing, audio recording and user surveys	Interaction, device status and environment	Performance analysis, SMS usage and mobility analysis
SocioXensor	Interaction event logging, survey, interview	Interaction, user, device status and environment	SQL database

4. Data Visualization: From the results tables, graphs and diagrams are generated for the researcher. Furthermore, the entire log is automatically annotated so that each entry is written out for human readability and annotated to get basic derived information such as duration and transitions.

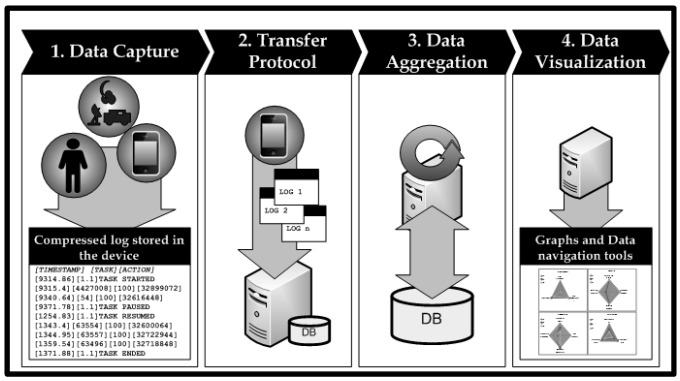

Fig. 1. Graphical description of the data logging, visualization and aggregation process.

B. System Architecture

The Neurona evaluation framework [8] was extended to meet the BAM requirements. This platform shown in Fig. 2 is based on three main components: the mobile device component, the connector component, and the analysis server component.

The Mobile Device component is software installed in the user's mobile and logs user interactions; it is formed by the Logger/App interface, Logger Module and Context Information Module. The Logger/App interface is a tiny software library used to send interaction events to the logger module. The logger module stores the interaction data and shows brief questionnaires about the interaction experience to capture the user's feedback; these questionnaires are shown at the end of the interaction to not disturb the experience. Another element is the context information module, which provides context information acquired from the built-in mobile sensors and the mobile Operative System.

The Analysis Server component is hosted in a web server; this component is formed by the Data Aggregation Module, the Visualization Module, the Applications Manager and the Usergroup Administration. The Data Aggregation Module receives logged data and calculates normalized information to store it in the system database. The expert who wants to check the normalized information can do it using the Visualization Module; which shows advanced graphs. The Applications Manager enables the expert to register into the system, update and remotely configure prototype applications. The Usergroup Administration module registers users and devices, assigns applications and exposes several administration options related to the relations between users, applications and experts.

Finally, the connector between the explained elements transfers the logged information generated by the Mobile Device component to the Analysis Server component. It is divided in two main elements: the mobile interface and the server web service. Basically the mobile interface checks the state of the device and if the user is not interacting with the device it sends logged data to the web service hosted in the Analysis server. To minimize the required transfer bandwidth logging data is encoded in memory saving format and decoded later to a human readable format when the logging data has been received by the Analysis Server.

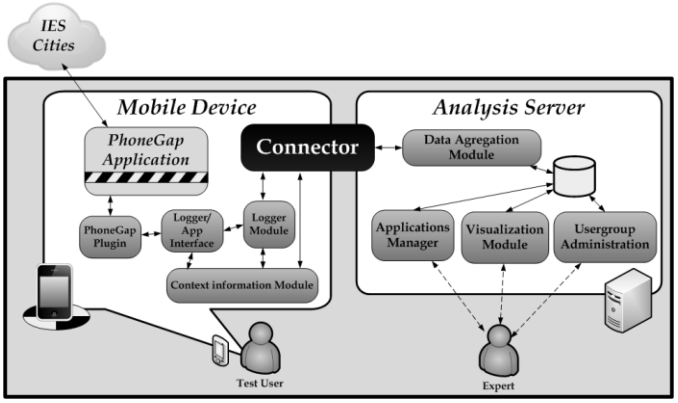

Fig. 2. System architecture of Neurona Tool.

C. Integration with IES Cities through PhoneGAP

For the IES Cities project the Neurona framework has been extended with an additional integration plugin using the PhoneGap tool. The IES Cities mobile applications are developed using the PhoneGap technology. PhoneGap is a framework for building cross-platform mobile apps with standards-based Web technologies. Developers who use PhoneGap may only use HTML, CSS, and JavaScript to implement several applications to remotely access existing backend and cloud processes while the device is connected to the Internet. In particular, thought this framework the developed applications which can access to the IES Cities services.

Among the variables which are relevant to the model presented by this work several sources for completing the model information should be studied as well as the different kind of information sources which can be found inside a mobile device (in particular, in Android OS operating system devices). It is important to mention that this model captures and handles sensitive information (e.g. location of the user). Consequently, applications which use BAM model should ask for several Android permissions: The *INTERNET* permission to open network sockets, check the weather and upload the logged information to the main server. The *ACCESS_FINE_LOCATION* permission to access precise location from location sources such as GPS, cell towers, and Wi-Fi. The *RECORD_AUDIO* permission is used to measure the noise level. With *ACCESS_NETWORK_STATE* our capturer accesses detailed information about networks. Finally, the *ACCESS_WIFI_STATE* permission is used to retrieve information about Wi-Fi networks.

PhoneGap applications cannot access sensors, in order to solve so; a PhoneGap plugin has been developed. PhoneGap

Plugins need to be implemented for each platform, to validate the system the data capture in focused on Android platforms. The developed plugin is made up by a JavaScript file which contains functions to call from the IES Cities mobile application and log interaction events, including the current context. There are two main steps to including the developed plugin in IES Cities mobile application: referencing the explained JavaScript file and importing the native code (the extended Neurona evaluation framework library) that will be called through the JavaScript file.

This plugin has only 6 main functions: *log_start_task, log_pause_task, log_resume_task, log_end_task, log_interaction* and *log_error*. These functions capture the timestamp of the interaction, the current context and the object with witch user is interacting. They only require three parameters: the event type, which will be explained bellow, the identification of the visual structure for a user interface and last but not least, the object (i.e. buttons, textboxes…) the user is interacting with.

A task can pass through four main states: When a task is not started yet (NOT STARTED), when a task is started and its user is interacting to achieve the goal of the task (STARTED), when a task is started but its user is not interacting to achieve it (PAUSED) and when the task is finally terminated (END). After seeing the main states we will see several events which can be triggered to change the state of a task, these events should be generated by the mobile applications using the plugin functions. During a task performance a user can trigger two main events: START_TASK (at the beginning of the task: *log_start_task*) and END_TASK (at the end of the task: *log_end_task*). Additionally but not compulsory there exist two others: if user leaves the task (e.g. because of an incoming phone call) PAUSE_TASK event (*log_pause_task*) is produced. Where user decides to continue the task RESUME_TASK event (*log_resume_task*) is triggered. When a task is started two events related to the interaction of the user can be triggered. The INTERACTION event (*log_interaction*) means that a user is interacting in the right way. This event should be triggered when a user is achieving little microchallenges inside the goal of the task. The ERROR event (*log_error*) means that a user has made a mistake during the interaction process.

IV. The Behaviour Assessment Model

A proven performance assessment method considering concurrent aspects has been the Balanced Scoreboard (BSC) approach. Aligning each of the dimensions systematically helps get a better impression about different influencing factors.

A. Dimensions of the Behaviour Assessment Model

This leads to following six different dimensions illustrated in Fig. 3:

1. Remote service search: This dimension is based on the categories Planned Execution Scenario and Service Actuation. In order to fulfill end-users need to plan activities ahead of a trip; users require the capability to explore the service offer according to given properties. The retrieval quality depends on the query power e.g. different search concepts and the query success rate. An example is a map based discovery tool, which retrieves services according to locations selected on a map.

2. Nearby service discovery: The dimension founds on the categories Spontaneous Execution and Service Actuation. As mobile services are much stronger correlated with the daily life of end-users an important requirement is to raise their attention to an adequate service offer in a seamingless manner. A successful implementation depends on the reasoning power (that compare the current users' context and the intended service context) and the number of directly consumed services (reasoning success).

3. Service creation/provision: The categories Planned Execution and Service Interaction define this dimension. Complex mobile services require often too much knowledge from the user to execute them easily on the spot. Therefore, services should offer any type of service creation, personalization or reservation functionality so that they can be consumed better in time constrained situations. The editing complexity and the service content quality are important indicator examples to determine this dimension.

4. On-the-spot service consumption: The dimension is constructed through the categories Spontaneous Execution and Service Interaction. Since users on the move often follow other real-world activities it is important that the attention needed to execute the service is kept to an absolute minimum. The navigation complexity (effort) and the quality of the content provided by the service are important indicator examples.

5. General platform activity services: This dimension stems from the categories Planned Execution and Central Provision. All general service aspects influencing the provision quality e.g. power consumption and error handling account for this dimension.

6. Community services: This dimension is founded on the category Spontaneous Execution and Community Networking. Tools that consider community behaviour can help in structuring the knowledge space further and lead to more transparency in the community. Examples are best-of ranking lists, member reputation lists and content recommender systems. For instance car sharing opportunities can be more easily evaluated by users and improve their selection. Suitable example indicators are the lurker ratio (active community participation) and the degree of community transparency achieved with previously mentioned community services.

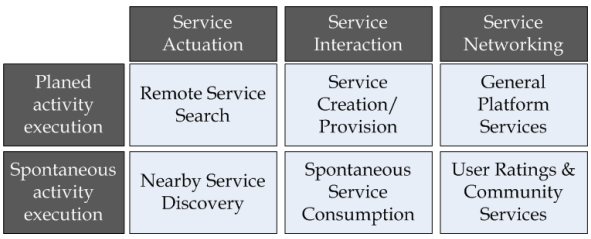

Fig. 3. Dimensions of Behavior Assessment Model.

B. The Balanced Scoreboard Assessment Approach

These six dimensions focus on realistic service usage. This emphasises the valuation of a service by the way how end-users apply services to solve given problems. Such behaviour patterns have the potential to tell us about underlying reasons why specific service fail or become well accepted. Recording such behaviourally relevant data also allow the emulation of service usage in respect to given user´s context. Both aspects are important for developers to continuously improve the service. According to the BSC approach, the intention is to find a few aggregated indicators that quantify a given dimension. The indicator must meet the requirements of reasonability and measurability. A general problem of social surveys is to translate the indicators into precise measures. The abstract classes of measurement types, correspond hereby with different event and error logging data types. To achieve comparability between different numerical scales of measurements e.g. an event/error frequency scale, a function has to be defined which maps selected scale areas on specific quality rating values. Since humans perceive the influence of various indicators for a given dimension differently, weight coefficients are used to balance the influence of individual indicators. Both mapping function properties and weight coefficients can be obtained through a profiling questionnaire prior to the field trials.

Finally, the results of an analysis and evaluation are typically held in a spreadsheet for detailed analysis and visualised by a radar chart for a summarised representation (see Fig. 4). For visualization by a radar chart, the six dimensions are equally arranged. The scaling is adapted appropriately according to the distribution of the measurement results with its positive orientation towards the origin. For a better visualisation of the consequences of the results, each scale can be subdivided in fulfilled (positive centre areas), and not fulfilled (negative edge areas).

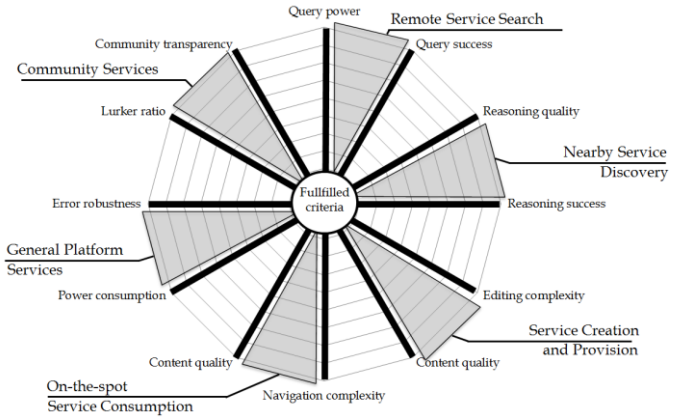

Fig. 4. Visualization of the behavior model with six dimensions (grey color) and example indicators (black color).

V. The IES Cities Project

The IES Cities project aims at providing an open platform so that users are able to use, produce and provide information for internet-based services improving their knowledge about the cities they live. The project represents an extension of other European projects (see m:ciudad, MUGGES, and uService) focusing on service creation, mobile peer-to-peer services, and the integration of open linked data sources. Open linked data refers here to a concept of publishing structured data e.g. pollution data provided by the local government so that it can be interlinked and become more useful. City services, created and provided through the platform enable citizens to wrap this type of data. They adapt to the current context of a citizen through smartphone embedded sensors. End-users may not only to receive information from the city but also generate real-time content which complements, enriches and updates the data available through the open data model associated to the municipality. These services are intelligent as they come with business logic to automate the management of parking spaces, public transport, pollution, health states and many other aspects of urban life, user interactions are eased and automated. In order to facilitate its usage the platform will be provided as mobile and web-based platform. It is assumed that sensor networks are already deployed in the cities and become integrated as part of the project.

In the following the screen interaction model for the *IES-Improve Your Neighbourhood* service is exemplarily explained (see Fig. 6). This screen model includes screen sequences for querying the appropriate IES services (dashed box), creating and consumption of IES services and the service/report rating. In order to create or view *IES-Improve Your Neighbourhood* reports users first have to query for adequate IES service. After selecting the *IES-Improve Your Neighbourhood* service, users can decide a) to create a new report, b) look for and c) rate existing reports. The IES service obtains user data through the screen, retrieve sensor data to personalize IES service and open linked data to provide up to date content.

VI. Case Study of the IES Cities Prototype

A. The Assessment Process

Applying the BAM analysis technique requires specific preparation steps. These include the definition of indicators for each dimension, correlating them with available logging data, appropriate balancing of these measurements with weight factors, the execution of field trials and representing the results. Fig. 5 gives a complete overview about the evaluation process.

In the following specific modifications to the BAM model in respect to the IES Cities project are presented:

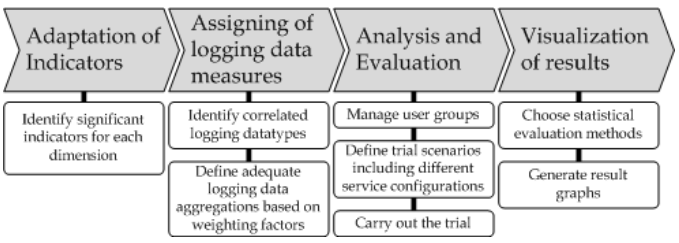

Fig. 5. Different phases of the assessment process and correlated activities.

Fig. 6. Screen flow graph of IES – Improve Your Neighbourhood

- Adaptation of indicator structure. First, adequate indicators have to be identified which align with the specific dimension of the BAM model. The IES service interaction model considers six different behavior dimensions in accordance with the BAM model. These include activites to trigger city services through seach and discovery functions, activites for the service creation, provision and consumption and finally rating functions to exploit further networking effects on the service and report level.
- Assignment of logging data types. In this phase, logging data types are correlated with the indicators. During the prospective field trial, the Neurona Framework will obtain application and sensor data by plugging into the IES player through the PhoneGAP tools.
- For the dimension service remote search and nearby service discovery, the query success rate and the average result quality are relevant indicators. Therefore the number of queries issued before a service is consumed (query success rate) is counted. The result quality can be measured by the average distance between the current user location and the location to which the report has been assigned. Hereby it is assumed that reports related to a given issue closer to the user a more relevant. The dimension service creation/provision and consumption is determined by the indicators editing/viewing complexity and service quality. The editing/viewing complexity is closely correlated with the time a user spends to create/provide and consume services. Therefore, the logger obtains timestamps when ever an editing and consumption screen flow is started and ended. The average duration of the editing/viewing process can later be correlated the process complexity and even reveal if a given process has been interrupted. The dimension General Platform Services is defined by the indicators power consumption (measured as consumed energy units per day) and error recovery quality (reciprocal number of occurred errors per day). And finally, the dimension community services are defined by the lurker ratio (measured as provider-consumer ratio of a consumed service) and the consumed service quality (measured through average rating of consumed services).
- Analysis and evaluation. Generally an iterative evaluation approach is recommended starting from early prototypes up to the final mobile service. In order to compare the development progress it is important not to vary the measurement criteria. It is assumed that the explanatory power of the BAM model increases with a stronger concretization of the mobile service during the development cycle. All these logging data types have different value ranges. For future evaluation it is important to translate these into an given grading scheme. This is usually achieved through mapping functions which assign chosen value ranges to specific grade value. A series of experiments will therefore be conducted in the laboratory as soon as the IES platform has been completed. Parameterized aggregation services at the Neurona framework will then automatically convert the cleaned logging data to the adequate grading format. Since the previously specified indicators contribute to the successful execution of service with varying degree it is important to specify adequate weighting factors. It is therefore mandatory to learn more about the characteristic service behaviour.
- Preparing the result visualisation. The results of the test group are analysed and evaluated with statistical methods and visualised according to the radar graph approach. First, goals for every single indicator should be determined before the actual start of the field trials, in order to compare these to the empirical results. Then, initial and long-term service usage should be compared in order to identify entry barriers. Correlated with this

analysis, is the grouping of logging data according to the technical technical experience (see technical adoption model described by Rogers [12]). By comparing innovators, early adopters, early majority, late majority and laggards a reasonable priority list of future service modifications can be determined. Finally it is also important to analyse logging data from different trials in order to see to what extend applied service modifications have led to an acceptance improvement.

B. Visual Evaluation of IES Cities

We emulate the advantages of the IES Cities project based on logging data obtained during the field trial executed for the MUGGES project. In this field trial logging data from 30 potential end-users have been collected during a two week period. Each study participant was given a mobile phone with the previously developed MUGGES software installed. The users were given specific tasks e.g. to describe preferred pathways by providing reports for favorite point of interests. The connector component transfers periodically event data to the analysis server for further evaluation.

Applying the BAM approach (with a rating range from 0 – very good till 3 very bad) a service provider can come, for example, to the following simplified conclusions concerning the explained dimensions in Section 4:

- Remote activity discovery: With increasingly more created services users applied more sophisticated search approaches (keyword-based and map-based search) to compensate the small screen size. The discovery function seems to work well for the majority of the trial users (rating 1.5).
- Situation-aware activity recommendation: The overall distance between the location assigned for a selected service and the trial user has been quite far (up to 1 km). Besides the sparse distribution of the provided services another reason has been the bad performance of the location technology. Provider could conclude that the recommendation service is not sufficient (rating 2.5) for the current spontaneous usage scenario.
- Mobile activity preparation: The service creation process took a lot of time, not short enough to create mugglets on-the-go. People compensated this by distributing the creation process in several phases. The mobile activity preparation is not sufficient (rating 3.0) in the current development stage.
- On-the-spot activity support: The services in general have high information quality for the user, as they come with a environment map, text descriptions, comments and photos. Above that, the real-time notification feature helped people to stay up-to-date. Provided services thus have been very useful (rating 1).
- General provider services: The peer-to-peer service sharing approach has lead to an high power consumption and the error rate has been quite high. Service provider may conclude that the execution of shared services in the Internet cloud may be a better option.
- User-created services: Platform usage has been high since users could create their own personal service based on the offered service templates. Especially in later stages during the project service ratings have been found very useful (rating 1) to identify popular services or confirm reports.

The radar graph shows some important weaknesses. Recommender systems, the mugglet creation process and the provider infrastructure still make an everyday usage difficult (see Fig. 7). Comparing these logging data results with the questionnaires conducted after the trial backs these findings. But more importantly, user perceptions were not always clear enough to pinpoint the exact problems with the platform infrastructure. The evaluation with the BAM is more differentiated and considers some critical aspects that influence the acceptance of this mobile service significantly.

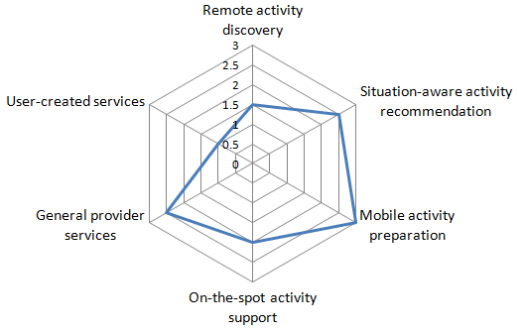

Fig. 7. Evolution of the IES Cities based on MUGGES logging data.

VII. Conclusions and Future Work

We introduced the BAM as an instrument for the analysis and evaluation of the user acceptance for mobile services. The BAM is characterised by a structure that helps to identify systematically a balanced set of important, individually measurable and independent acceptance criteria. The application of the BAM is guided by a process model that supports all phases from the development of acceptance criteria over the measurement of relevant indicators to the evaluation and visualisation of the derived results. Using the BAM reveals several insights:

- *First and permanent usage patterns*. Analyzing the radar graph at the beginning of the trial and later phases of the trial shows can show entry barriers of the mobile service. Results obtained in later stages show how people exploit mobile service strengths but also compensate potential weaknesses of the service.
- *Usage patterns for different technical adoption groups*. According to Rogers technical diffusion model user groups are divided in innovators, early adopters, early majority, late majority and laggards. Clustering logging data according to these groups may reveal interesting insights how the technical experience influences service usage. These observations are especially valuable to define a priority of feature improvements for the mobile service.

- *Behaviour changes in different product development stages*. As the development of the mobile service evolves comparing results with earlier trials can help to confirm if the applied feature modifications fulfil the intended improvements.

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Bernhard Klein received his diploma degree in Computer Science from the Technical University of Munich and the Ph.D. degree from the University of Vienna. During his doctoral studies he has worked as research assistant and lecturer at the Institute of Distributed and Multimedia Systems at the University of Vienna. Prior to the University of Vienna he has worked with Siemens Corporate Research, where he participated in several research projects for multimedia and video collaboration, annotation and archiving. In June 2009, he joined the Mobility Research Lab (MoreLab) at the University of Deusto, where he participated in several European projects and projects supported by the Spanish government. He has published several articles in various conferences and workshops in the field of mobile peer-to-peer systems and groupware systems.

Ivan Pretel was born in Arrigorriaga, Spain.He received the Bachelors degree in computer engineering, the Masters degree in development and integration software solutions from the University of Deusto, Bilbao, Spain, where he is currently pursuing the Ph.D., focusing his research on fields related to human-computer interaction, quality in use, advanced mobile services and 2.0 services. His engineering studies he complemented his knowledge by working in the Architecture Department of a software company, responsible for managing the internal software platform of a well-known savings bank. After completing his engineering studies, he received the Best End-Term Project Award. He began his research career in the Deusto Foundation where he started as a research intern in the mobile services area, participating in various projects related to system architecture and Human Computer Interaction. He is currently a Researcher with the DeustoTech - Deusto Institute of Technology.

Sacha Vanhecke is master student in Computer Science with a specialization on Software Engineering at the Ghent University. Since 2011 he holds Bachelor degree in Informatics. Based on his experience in semantic web technologies, mobile web applications and computer vision, he is finishing his diploma thesis at the University of Deusto, where he participates in an Erasmus Exchange Program. Based on the prototype platform developed in the MUGGES project he ported and enhanced the first version of the IES Cities platform.

Ana B. Lago was born in Bilbao, Spain. He received the Ph.D. degree in computer science and engineering from the University of Deusto. She is currently a Professor with the Department of Telecommunications, as a member of the Faculty of Engineering of the University of Deusto. She is a Researcher with the MoreLab Research Group, Deusto Institute of Technology – DeustoTech Deusto University. She is the Director of the Ikertia classroom, consequence of an agreement between the University of Deusto and the Ikertia Foundation. She manages and coordinates several multidisciplinary research and development projects in software engineering and mobile services areas. Her current research interests where she has managed and coordinated at different levels numerous national and European projects, are e-learning technologies, Mobile Web, Social Mobile Services and Social Networks. She has participated in national and international conferences.

Diego López-de-Ipiña is an Associate Professor/Reader at the University of Deusto, where he is the Principal Researcher at MORElab "Envisioning Future Internet" Research Group, DeustoTech-INTERNET Research Unit belonging to DeustoTech -- Deusto Institute of Technology. He holds a BSc in Computing from the Faculty of Engineering of the University of Deusto, an MSc in Distributed Information Management Systems from University of Essex and a PhD in Engineering from University of Cambridge. He obtained his PhD in 2002 with a dissertation entitled "Visual Sensing and Middleware Support for Sentient Computing". His main research areas are: Ambient Intelligence, Ambient Assisted Living, Mobile-mediated Human-Environment Interaction, Semantic Web, Internet of Things, Linked Data and Social Data Mining.

SketchyDynamics: A Library for the Development of Physics Simulation Applications with Sketch-Based Interfaces

Abílio Costa[1], João P. Pereira[1,2]
[1] Computer Science Department, School of Engineering (ISEP), Polytechnic of Porto, R. Dr. António Bernardino de Almeida 431, Porto, Portugal
[2] Knowledge Engineering and Decision Support Group (GECAD), School of Engineering, Polytechnic of Porto, R. Dr. António Bernardino de Almeida 431, Porto, Portugal
amfcalt@gmail.com, jjp@isep.ipp.pt

***Abstract* — Sketch-based interfaces provide a powerful, natural and intuitive way for users to interact with an application. By combining a sketch-based interface with a physically simulated environment, an application offers the means for users to rapidly sketch a set of objects, like if they are doing it on piece of paper, and see how these objects behave in a simulation. In this paper we present SketchyDynamics, a library that intends to facilitate the creation of applications by rapidly providing them a sketch-based interface and physics simulation capabilities. SketchyDynamics was designed to be versatile and customizable but also simple. In fact, a simple application where the user draws objects and they are immediately simulated, colliding with each other and reacting to the specified physical forces, can be created with only 3 lines of code. In order to validate SketchyDynamics design choices, we also present some details of the usability evaluation that was conducted with a proof-of-concept prototype.**

***Keywords* — Gesture Recognition, Physics Simulation, Rigid Body Dynamics, Sketch-Based Interfaces.**

I. INTRODUCTION

USING pen and paper to draw or sketch something in order to express an idea is very common and also very natural for us. By using this concept in user interfaces one can make the interaction process more natural and spontaneous.

In this paper we propose SketchyDynamics, a programing library to aid in the creation of applications for 2D physics simulations in which the user interacts directly with the scene using a "pen and paper" style interaction. Thus, instead of selecting from a menu which objects compose the scene to be simulated, the user can simply draw them directly into the scene. We hope that developing this library will provide a boost for developers to create new applications around this concept, be they for educational purposes, like an application used to teach physics with an interactive whiteboard, or for entertainment purposes, such as a physics-based game where the user draws parts of the scene in order to reach a goal.

The library supports three gestures to draw rigid bodies and other three to define connections between them. The first three gestures are used to produce rectangles, triangles and circles, which can be created by drawing these symbols directly. Also, the user can draw a zigzag to connect two bodies with a spring, an alpha to pin a body over another and a small circle to define a rotation axis between two bodies. Since both the circle body and the rotation axis relation use the same gesture, we only have in fact five gestures to recognize, presented in Fig. 1.

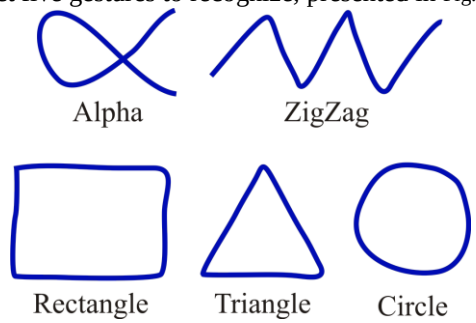

Fig. 1. Set of gestures used in our library

Although there are already several applications that combine physics simulation with a sketch-based interface, most of them have a specific scope and audience. As a library, SketchyDynamics is intended to be used in different types of applications and does not have a definite scope. We hope that our work helps developers create new and exciting applications with little effort in combining the physics simulation with the sketch-based interface.

In the next section we present an overview of the results achieved in the sketch recognition field and also works that combine sketch-based interfaces with rigid body physics simulation. Section 3 gives a little insight into a previous evaluation whose purpose was to select the sketch recognizer that best integrates with our library. In section 4 we present our library, its technical characteristics, along with its functionality. Section 5 discusses a preliminary informal evaluation and section 6 concludes this paper and presents potential future work.

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II. Related Work

This section presents some of the related work in the sketch-based interfaces domain and is divided into two subsections. The first subsection will address the work done in the sketch recognition field, while the second presents some examples of applications that result from the combination of sketch-based interfaces with rigid body physics simulation.

A. Sketch Recognizers

Given the potential of automatic sketch recognition, a lot of work has been done in order to develop recognizers capable of dealing with the intrinsic ambiguity of hand-drawn sketches. Since there is a wide variety of sketch recognition algorithms, it is only natural that there's also diversity in their characteristics. Examples of these characteristics are the ability to be trained to recognize new gestures, the capacity to recognize multi-stroke gestures or the sensitivity to the gesture's orientation, scale or drawing direction.

Rubine's recognizer [1], a trainable gesture recognizer, classifies each gesture using a linear classifier algorithm with a set of distinct features. The recognizer is very flexible since features can be easily added or removed to make the recognizer fit the application needs, as proven by Plimmer and Freeman [2]. The major limitations of Rubine's recognizer are its sensitivity to the drawing direction, scale, and orientation and inability to identify multi-stroke sketches. Pereira et al. [3] made some modifications to Rubine's recognizer in order to make the algorithm accept multi-stroke sketches, but only when drawn with a constant set of strokes, as pointed out by Stahovich [4]. Pereira et al. also present a way to make the algorithm insensitive to drawing direction.

CALI [5] is an easy to use multi-stroke recognizer that uses Fuzzy Logic and geometric features to classify gestures independently of their size or orientation. CALI divides gestures into two types: shapes and commands. Shapes can be drawn (and recognized) using solid, dashed and bold lines, while commands are only recognized with solid lines. Since CALI is not trainable, adding new gestures is not an easy task, involving analysis of which features characterize and distinguish the new gesture and hand-coding these features. To solve this limitation the authors also present a trainable recognizer but it has a lower recognition rate and requires numerous training templates for each gesture class[1].

Wobbrock et al. [6] present the $1 Recognizer which aims to be easy to understand and quick to implement. It is insensitive to scale and orientation of sketches, but sensitive to their drawing direction. One major advantage of $1 Recognizer is the simplicity to add support for new gestures, requiring only one training template per gesture class to be effective. Furthermore, the authors also explain how to make the recognizer sensitive to scale or orientation, for some or all gesture templates.

In order to solve some of the limitations of the $1 Recognizer, such as not being able to recognizing multi-stroke gestures, sensitivity to the drawing direction, and problems recognizing uni-dimensional gestures such as lines, Anthony & Wobbrock extended it and created the $N Recognizer [7]. Despite the improvements over the $1 Recognizer, $N has problems recognizing gestures made with more strokes than those used in the training templates. Also, it is not well suited to recognize "messy" gestures like a scratch-out, commonly used for erasing-like actions.

Lee et al. [8] present a trainable graph-based recognizer that is insensitive to orientation, scale and drawing direction and is able to recognize multi-stroke gestures. Since the recognizer uses statistical models to define symbols, it handles the small variations associated with hand-drawn gestures very well. Despite being a trainable recognizer, it requires all training templates of a gesture class to be drawn with a consistent drawing order or consistent orientation.

Vatavu et al. [9] present a trainable recognizer that uses elastic deformation energies to classify single-stroke gestures. The recognizer is naturally insensitive to gesture scale and orientation, since the same gesture has similar curvature functions independently of the drawing orientation or size, but is sensitive to drawing direction and starting point within the gesture.

Sezgin and Davis [10] present a multi-stroke sketch recognizer, based on Hidden Markov Models (HMM), that is capable of recognizing individual sketches in complex scenes even if the scene is not yet completed, i.e. while it is being drawn, and without the need to pre-segment it. On the other hand it can only recognize sketches in their trained orientations, thus being sensitive to orientation. Since the recognition relies on the stroke order of the trained templates, it is not well suited for domains where the stroke ordering cannot be predicted. Also, because HMMs are suited for sequences, it cannot recognize single-stroke sketches, unless they are pre-segmented.

B. Physics Simulation with Sketch-Based Interfaces

The idea of using a sketch-based interface to create and manipulate a simulated scene is not something new. For example, ASSIST [11] is able to recognize sketches and convert them to mechanical objects which can then be simulated. The system recognizes circles and straight-line polygons (simple or complex) made of single or multiple strokes. The recognition is done incrementally, while the user is drawing, which makes the system feel quicker and also gives an instantaneous feedback to the user, since hand-drawn lines are converted to straight lines and colored according to the type of object recognized. When an improper interpretation of a gesture is made, the user is able to correct it using a list of alternative interpretations. In ASSIST, users can also pin one object over another with a rotational axis by drawing a small circle, or anchor objects to the background by drawing a small cross. After finishing the sketch, the user can press a "Run" button to transfer his design to a 2D mechanical simulator that runs and displays a simulation of the designed scene.

[1] A gesture class represents a unique gesture, but can be made from multiple representations of that gesture, i.e. multiple templates.

Another application, "Free-Hand Sketch Recognition for Visualizing Interactive Physics" [12] enables users to draw simple 2D objects and simulate how these objects behave in 3D. The application is able to recognize four types of objects: lines, circles, rectangles, and triangles. When the gesture cannot be recognized a small dialog is presented, requesting the user to specify the desired gesture. After creating an object, the user is able to anchor it so that it remains static during the simulation. The design process consists of three modes: the "Ink" mode where the user can draw new objects; the "Select" mode, where a circle selects the enclosed objects; and the "Erase" mode, used to remove objects. Despite the designing being done in 2D, the physics simulation is 3D and the user is able to move the camera and also move objects in 3D space.

There are also games that take advantage of a sketch-based interface and a physics simulated environment to entertain the player. One popular example is Crayon Physics Deluxe [13], a puzzle game where the main objective is to guide a ball so that it touches all the stars in each level. Instead of controlling the ball directly, the user needs to draw objects that influence the ball, leading it to the stars. The user can draw rigid bodies with any shape and connect them with pivot points and ropes. Since the simulation is always running, sketched objects are simulated and interact with other objects right after being drawn. The game has a "children's drawing" theme, with a background that resembles a yellow paper sheet and crayon-like sketches, both characteristics that make it successfully adopt the pen-paper paradigm. Crayon Physics Deluxe also includes a level editor and an online playground, so users can create their own levels and submit them online.

III. Sketch-Based Recognition Evaluation

Due to the high importance of having good gesture recognition, since the user must feel the interaction to be as natural and unrestrictive as drawing with a pen on a paper, the gesture recognizer used in SketchyDynamics was selected based on previous evaluation [14] [15]. The evaluation was conducted using real gesture samples drawn by 32 subjects, with a gesture set specifically arranged for our library (Fig. 1).

For the evaluation process we developed an application to collect gesture samples from the subjects, process them, and compute the recognition results. With this tool we evaluated Rubine's recognizer, CALI and the 1$ Recognizer, concluding that for our gesture set CALI achieved the highest recognition rates.

With this evaluation we were also able to improve recognition rates by tweaking the templates and the recognizer's implementation to our specific gesture set.

IV. The SketchyDynamics Library

SketchyDynamics is a programing library that aims to simplify the implementation of 2D physics simulation applications with sketch-based interfaces. Using 2D graphics and physics simulation means that the user sketch (in 2D) produces a 2D object, which resembles the pen-paper paradigm and simplifies user interaction.

Out of the box, SketchyDynamics provides an interface for the user to interact with an application along with recognition and processing of user actions such as drawing, moving, scaling and removing rigid bodies and their joints. SketchyDynamics also deals with the physics simulation of these elements and visually represent them on the computer screen along with other user interface elements. Thus, a developer can integrate these features in an application with almost no effort.

A. Architecture

A major concern when designing SketchyDynamics was to make it versatile, so that developers can create all kind of applications, but at the same time simple enough to enable rapid prototyping. For example, with only 3 lines of source code a developer can create a simple test application where the user can draw objects and see their simulation, while they collide with each other and react to the specified "gravitational force". With a dozen more lines the developer is able to add a background body where the user is able to attach objects, or a ground body so that drawn bodies have something to fall onto.

As stated previously, we use CALI as the gesture recognizer since it yielded the best results in our evaluations.

For the physics simulation SketchyDynamics uses the Box2D physics engine. Despite using Box2D, SketchyDynamics does not encapsulate it or hide it from the programmer. Instead programmers have access to all Box2D objects and functionality so they are able to parameterize them according to the application's needs.

Although bodies and joints are created automatically by the library when the user draws them, the application is also able to programmatically create and remove them (along with their visual representations). Furthermore, SketchyDynamics also gives the application full control over the simulation state.

To render the bodies simulated by Box2D and any other visual elements we used the OpenGL API. Despite that, SketchyDynamics was designed so that a developer can easily use another API. This is achieved by ensuring that all OpenGL-specific code is encapsulated in a few classes, thus creating a conceptual abstraction layer.

While implementing the OpenGL abstraction we took the opportunity to add some "graphics library" functionality. For example, a programmer can easily create polygons by defining their vertices and then apply geometric transformations to them, toggle their visibility on screen, among other operations, all done in an object-oriented manner. Additionally, the library provides scene query functionality and easy texture management for the developer. To render each object SketchyDynamics offers three rendering queue layers so that each individual object can be drawn on the background, on the front (as a user interface element) or in the middle of these two layers. Furthermore, the depth or order of each object inside each layer can also be specified.

Another design decision that resulted from the OpenGL abstraction was the incorporation of the window creation

process inside SketchyDynamics, thus reducing the effort on the developer's side. Moreover, SketchyDynamics delivers events received by the window, like mouse and keyboard inputs, to the application using the observer pattern, thus letting the developer take actions based on the user input.

B. User Interaction

In order to best represent the pen-paper paradigm, the user interaction was designed to take advantage of systems with a touchscreen and stylus. Thus, the user only needs to press and move the stylus to interact with the system, without needing extra buttons[2]. Furthermore, no menus are used and most of the interaction is done by sliding the stylus across the screen. Although it was designed with that type of devices in mind, SketchyDynamics also works well with a traditional computer mouse.

There are two types of objects the user is able to create: bodies and joints. Bodies are rigid objects that are simulated according to physics laws while joints are used to connect bodies. Fig. 2 shows various bodies and three types of joints.

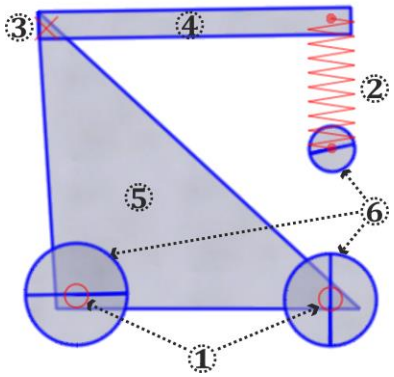

Fig. 2. Various types of joints and bodies: 1) revolute joints; 2) spring joint; 3) weld joint; 4) rectangular body; 5) triangular body; 6) circular bodies.

It is also important for the user to be able to manipulate the objects to a certain degree so SketchyDynamics lets the user change an object's position, scale, and orientation, or even delete it.

1) Creating

The creation of an object, be it a body or a joint, is done by drawing it. So, for example, if users want to create a rectangle body, they simply draw the rectangle on the screen. SketchyDynamics then recognizes the rectangle and its properties, like size and orientation, and creates the physical and visual representations of it.

SketchyDynamics supports four types of bodies: rectangles, triangles, circles and freeform bodies. When the user input is recognized as a rectangle, triangle or circle, it is represented in a beautified manner, as illustrated in Fig. 3. Otherwise, when the input is not recognized, it is interpreted as a freeform and represented in a simplified manner (with fewer vertices) for performance reasons.

[2] In a traditional mouse system this means that only the left mouse button is needed.

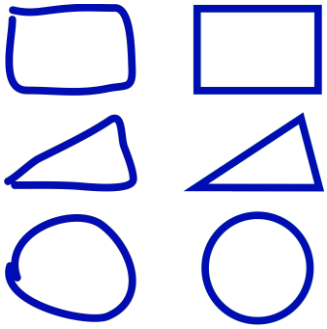

Fig. 3. Example of drawn shapes (left) and respective beautified representations (right).

The user can also connect two bodies with three different joint types: weld, revolute and spring. Weld joints connect two bodies at a specific anchor point, preventing any relative movement between them. Like weld joints, a revolute joint connects two overlapping bodies at a specific point but allows the bodies to rotate freely around that point. Spring joints try to keep a constant distance between two connected bodies, based on the distance at the time the joint was created, stretching and shrinking like a real spring.

Just like creating bodies, the creation of joints is done by drawing them. Drawing an alpha gesture over two bodies connects them with a weld joint with an anchor at the gesture's intersection, while drawing a small circle creates a revolute joint anchored at the circle's center. To create a spring joint, the user draws a zigzag gesture starting in one body and ending in another one, defining the two spring's anchor points as the start and end points of the gesture.

Regarding the visual representation of joints, the weld and revolute joints are represented by a small cross and by a small circle, respectively, on the joint anchor point while the spring joint is displayed as a zigzag line starting in one anchor point and ending on the other, stretching and shrinking subject to the distance between the bodies. The object presented in Fig. 2 was constructed using joints of the three types.

In order to better deal with the ambiguity in hand-drawn gestures, a guesses list is presented whenever the user executes a gesture. The guesses list shows all the available objects so that the user can choose an object other than the recognized one. The objects corresponding to gestures identified as matching by CALI recognizer appear bigger and first in the list, since they are the most probable choices, followed by the remaining objects. The guesses list feature can be disabled by the developer, in which case the most probable object is always selected.

Depending on the application-specific setup passed to SketchyDynamics, objects can be created while the physics simulation is in a paused state or while it is running and thus making other objects react instantly to the new object. This instantaneous simulation mode is useful for applications where the user interacts with a live environment as usually happen in games.

2) Selecting

For an object to be manually manipulated by the user, it first needs to be selected. When any object is selected the physics simulation is paused so that the user can easily edit it without being interrupted by other moving bodies. If the simulation was running before the selection of an object, it will resume after all objects are unselected.

Objects are selected by tapping on them with the stylus (or left-clicking them with a mouse), and can be deselected with the same action. This makes selecting multiple objects an intuitive process since users only need to keep tapping on the objects they want to select. It is also possible to unselect individual objects when there are multiple objects selected. When an object is selected, its lines assume a distinctive color, returning to the original color after being unselected. As shown in Fig. 4, this gives a clear feedback regarding the object's state. Also, tapping on an area of the screen with no objects or on an object configured as non-selectable, deselects all selected objects. Non-selectable objects are useful to create the application's scenery, which the user cannot manipulate but may be able to interact with, for example by connecting a user-made body to a scenery object.

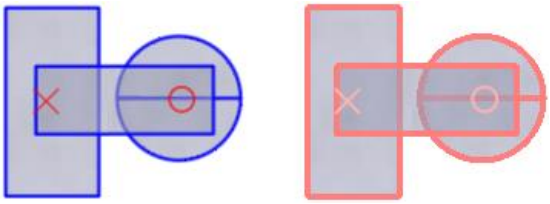

Fig. 4. Set of objects in unselected (left) and selected (right) states

When there are multiple bodies connected by joints and one of them is selected, all the other connected bodies are automatically selected, as long as they are selectable objects. This feature was introduced in order to improve the usability of the system, since we found that when multiple bodies are connected the user typically wants to manipulate them as a whole.

3) Moving

A selected body or joint can be moved by pressing over it and dragging the stylus. The object will move in sync with the stylus as long as the user keeps it pressed on the screen.

When there are multiple objects selected they all move in a synchronized manner, regardless of which object was pressed by the stylus.

4) Scaling and Rotating

Scaling and rotation of bodies is done simultaneously in a single action. As the action to move an object, scaling and rotation is done by pressing and dragging the stylus, but instead of pressing inside the selected body, the user needs to press outside it. As the user drags the stylus, the selected bodies scale and rotate based on the stylus initial and current positions. Only bodies can be rotated or scaled, so this operation is not applicable to joints.

The scale factor is calculated based on the current distance from the stylus position to the body center and the initial distance (before dragging the stylus). Regarding rotation, it is done based on the angle between two imaginary lines: the line from the current stylus position to the body's center, and the initial line (before dragging the stylus). Thus, moving the stylus closer or farther from the body scales it while moving the stylus around the body rotates it.

When multiple bodies are selected, they are all subject to the same rotation and scaling factor, but instead of using the body's center point as the reference point, the geometric average of all individual center points is used.

In order to aid the user during a scaling and rotation operation, SketchyDynamics displays a rectangle enclosing the selected objects, which rotates and scales along with them. Also, a small circle is displayed on the center reference point, along with a line connecting that point to the mouse cursor, so that the user can clearly perceive the operation being done. These visual cues are displayed in Fig. 5.

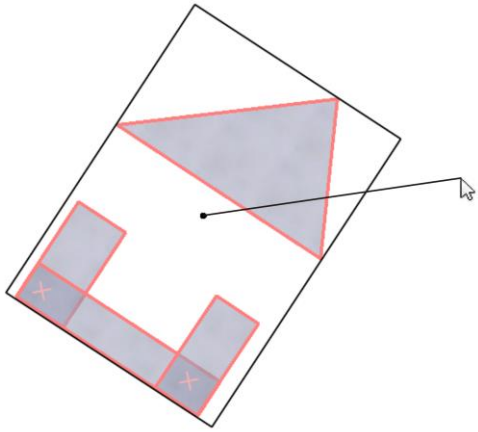

Fig. 5. Set of objects being subject to simultaneous rotation and scaling operations

5) Removing

Since removing objects is an important operation that contributes to user's creative freedom, it was designed to be simple, intuitive, and to have a low impact on the user's cognitive load. In fact, removing an object is a just special case of moving it.

When an object starts being moved by the user, a large rectangle with a trash bin icon slides down from the top of the screen, sliding back up and off-screen when the object cease to be moved. If the stylus enters the trash bin area while moving any object, the trash bin icon turns red. If the user lifts the stylus while on this rectangle, all the selected objects are removed. Fig. 6 shows the trash bin area in context of a simple, almost empty, application, and also the trash bin icon representations before and after the stylus drags an object onto it. We choose to keep this area hidden unless the user starts moving objects to improve the use of screen real estate, since objects can only be deleted when they are being moved by the user.

Joints can also be removed by simply being moved outside any of the two bodies they connect, without the need to move them to the trash bin rectangular area, although the trash bin works for joints too.

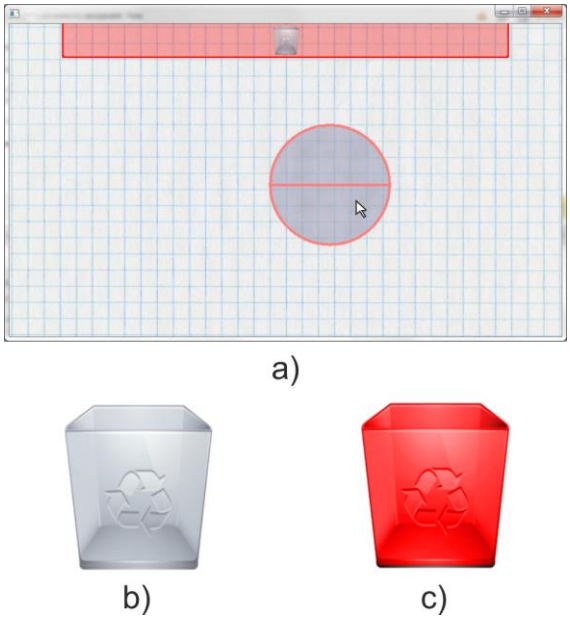

Fig. 6. a) simple application showing the trash bin area in context; b) trash bin icon in its normal state; c) trash bin icon when an object is dragged inside the trash area.

V. USABILITY EVALUATION

In order to validate SketchyDynamics' features and also to better understand what needs improvement, we conducted a usability evaluation session that was attended by 8 subjects (2 females and 6 males), comprising students, teachers and researchers from the Computer Science field. During the session, participants experienced SketchyDynamics' functionalities using a traditional mouse but also using an interactive display with a stylus (Wacom Cintiq 15X).

Using a prototype application developed with SketchyDynamics, each subject performed an efficiency test by creating a complex scene[3], consisting of 17 bodies and 11 joints (Fig. 7). Before beginning the execution of the efficiency test, 5 subjects had a few minutes to experiment with the prototype. Also, during the test, the session coordinator clarified doubts raised by each of the 5 subjects. Regarding the remaining 3 subjects, they executed the test in a slightly different manner: they all done the test simultaneously, using only one computer; the experience was timed from the moment they had contact with the prototype; and had no help from the session coordinator. With this group we hope to evaluate the usability of SketchyDynamics when users are in a more adverse situation: for example, when they have no access to touchscreen and stylus, and/or have no time to get familiar with the application.

Considering the complexity of the scene to reproduce along with the inexperience of the subjects with the SketchyDynamics library prototype, the results of the efficiency tests are very encouraging. The first 5 subjects completed the test on an average of 9 minutes and 12 seconds, with a standard deviation of 3 minutes and 34 seconds.

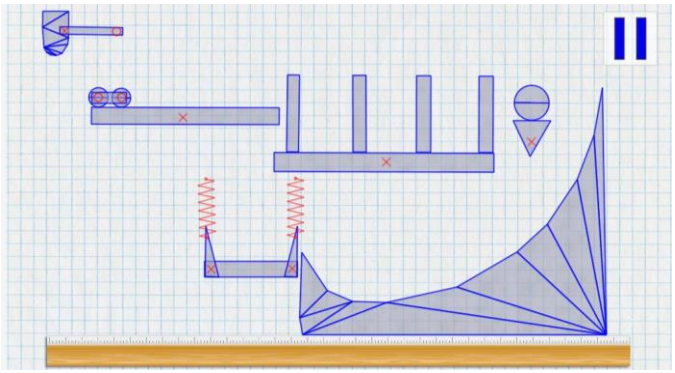

Fig. 7. Scene reproduced by subjects during the efficiency test (the ruler, at the bottom, along with the pause indicator, at the top-right corner, are part of the prototype and not user-made objects)

Regarding the remaining 3 subjects, who performed the test together, it took them about 24 minutes to complete the test, which we consider to be a positive result since these 24 minutes include the time they spent learning how to use the system and discovering its functionalities. Fig. 8 presents the time taken by each subject to complete the efficiency test. Note that since subjects 6, 7 and 8 executed the test together, their results are unified.

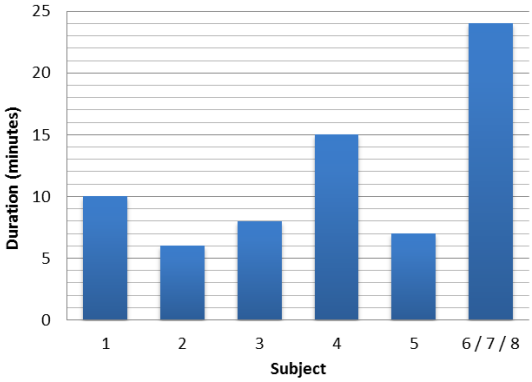

Fig. 8. Time spent per subject in the efficiency test

After the efficiency test, each subject filled out a survey form regarding their experience with the prototype. All the questions in the survey achieved average results above 1 point, in a scale from -3 (awful) to +3 (excellent), where 0 represents a neutral response, showing that SketchyDynamics pleased the users and is on the right track.

In order to know if the selected gestures were successful, one section in the survey asked about the suitability of each gesture in the creation process. As shown in Fig. 9, the average results for the majority of the gestures were equal or above 2 points, except for the gesture used to create weld joints. This lower result can be explained by the difficulty to draw an alpha gesture using a traditional computer mouse.

[3] A video demonstrating the creation of such scene can be found at http://youtu.be/1niigTt_m_I

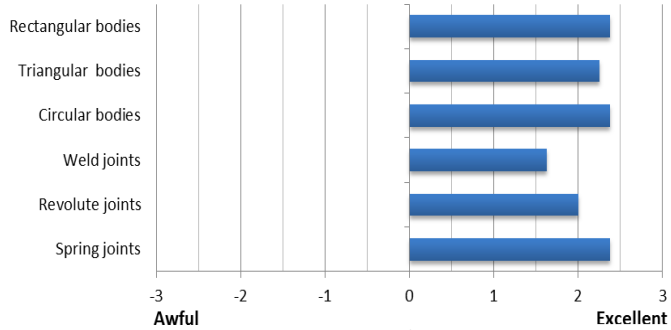

Fig. 9. Average results on the suitability of each gesture in the creation process

Regarding the object transformation process, we found the results to be very positive (Fig. 10), since the only action that achieved an average score lower than 2 points was the continuous selection of multiple objects. By observing the subjects during the interaction with the prototype, it was evident that the action to select multiple objects caused some trouble, since it conflicts with the usual experience users have with computer applications. While in most applications a click over an object selects it and deselects any other object that was previously selected, in SketchyDynamics clicking over an object selects it but does not deselects the remaining objects. As a result of this conflict, participants would misguidedly apply transformations on objects that they thought to be deselected. Despite that, the overall opinion of the participants in relation to the object transformation process was very good, with an average score greater than 2 points.

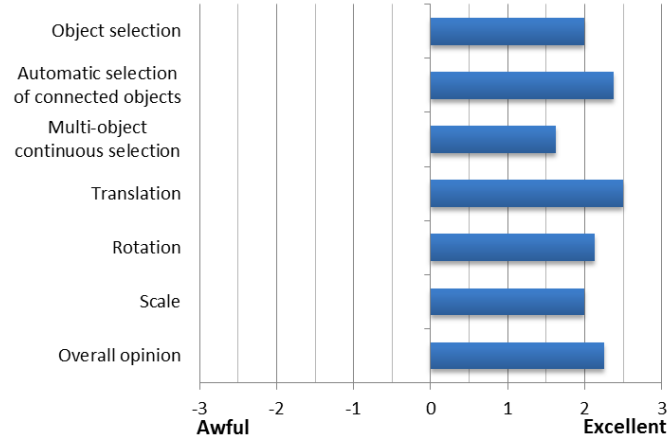

Fig. 10. Average results on the object transformation process

Although subjects found that it was useful to remove a joint by simply displacing it out of the bodies it connects, the results presented in Fig. 11, despite being very encouraging, show that there is still some room for improvement in regards to the object removal process. One of the criticisms mentioned by several subjects was the impossibility to remove and object by pressing the "Delete" key. In fact, this is a feature that is present in most computer applications for the operation of removing or deleting an object.

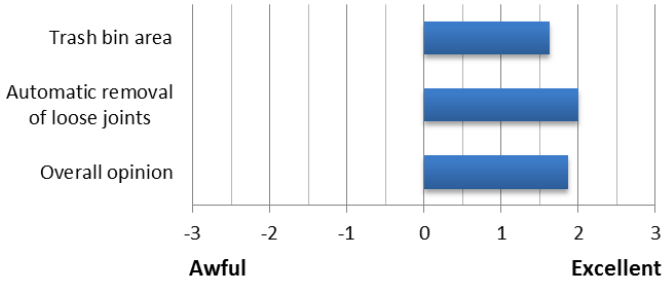

Fig. 11. Average results on the object removal process

Regarding the overall perception of SketchyDynamics, the results showed that subjects feel that it is easy to use and is also adequate for creating physically simulated scenes (Fig. 12). Concerning the stimulus, which achieved a lower result, certain participants demonstrated frustration when using the stylus, due to hardware problems. Also, some participants complained about the impossibility to undo operations. In relation to flexibility, participants have suggested that SketchyDynamics should support a larger number of object types.

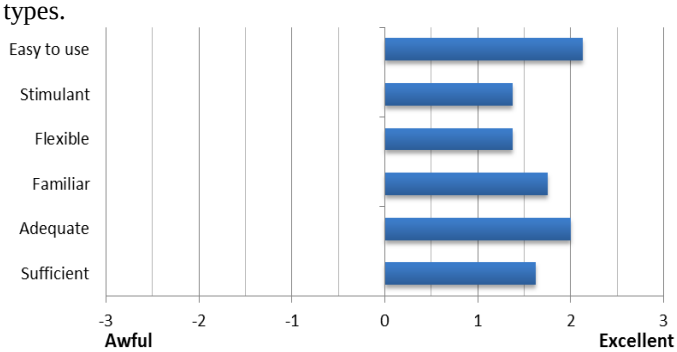

Fig. 12. Average overall results on SketchyDynamics' functionalities

In addition to these questions, the survey also inquired subjects about the interaction devices, the arrangement of the user interface, and also about the manipulation of the simulation. Further discussion on the usability evaluation and also on the SketchyDynamics library can be found on [15].

VI. Conclusions

We have presented a library capable of speeding up the development of applications by providing developers a sketch-based interface combined with physics simulation. The library also provides facilities in managing the graphical side of the application and dealing with user input.

In an effort to make the library suitable for the widest range of applications we are working on adding more functionality into it, such as a new rope-like joint.

One useful feature would be the ability to select an individual body from a set of connected bodies and transform it using the joint anchor point as a reference. This poses some design problems since an object can have multiple joints (which one should be used?). The problem further increases if there is more than one selected object. Before implementation, further study on how to overcome these problems is needed.

Another interesting feature would be the existence of object hierarchies, in which transformations applied to one object are propagated onto its child objects, but not the opposite. The construction of this hierarchy could be based on the depth of the objects.

As noticed during the usability evaluation, implementing common functionalities such as clipboard to duplicate objects and undo/redo capabilities is extremely important to improve the system's usability and reduce user's frustration

Another requested feature is the ability to perform a scale or rotation operation individually. A possible and familiar solution would be the use of a modifier key to restrict the action to a single operation. Every time this key is pressed, the system could check if the mouse movement was mainly radial or tangential, doing only a scale or rotation operation, respectively. This concept could also be applied to restrict the movement of objects to horizontal, vertical and 45 degree translations.

Nevertheless, we think that current state of SketchyDynamics already enables it to be integrated and used to develop exciting applications.

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Abílio Costa received his MSc in Computer Science Engineering at the School of Engineering, Polytechnic of Porto (ISEP-IPP), in 2012, where he also accomplished his graduation. Currently working on the graphics and rendering engine of a new product at NDrive, he has experience in user interfaces and computer graphics.

João P. Pereira earned his BSc, MSc and PhD in Electrical and Computer Engineering from the Faculty of Engineering of the University of Porto (FEUP).
He is currently teaching at the Computer Science Department of the School of Engineering, Polytechnic of Porto (ISEP-IPP), and researching at the Knowledge Engineering and Decision Support Research Center (GECAD). His main areas of interest are Computer Graphics and Human-Computer Interaction.

From Management Information Systems to Business Intelligence: The Development of Management Information Needs

Rimvydas Skyrius, Gėlytė Kazakevičienė, and Vytautas Bujauskas
Economic Informatics Department, Vilnius University, Lithuania

***Abstract* — Despite the advances in IT, information systems intended for management informing did not uniformly fulfil the increased expectations of users; this can be said mostly about complex information needs. Although some of the technologies for supporting complicated insights, like management decision support systems and technologies, experienced reduction in interest both from researchers and practitioners, this did not reduce the importance of well-supported business informing and decision making. Being attributed to the group of intelligent systems and technologies, decision support (DS) technologies have been largely supplemented by business intelligence (BI) technologies. Both types of technologies are supported by respective information technologies, which often appear to be quite closely related. The objective of this paper is to define relations between simple and complex informing intended to satisfy different sets of needs and provided by different sets of support tools. The paper attempts to put together decision support and business intelligence technologies, based on common goals of sense-making and use of advanced analytical tools. A model of two interconnected cycles has been developed to relate the activities of decision support and business intelligence. Empirical data from earlier research is used to direct possible further insights into this area.**

***Keywords* — management decision support, business intelligence, information needs**

I. Introduction

THE job of informing business managers and other people in charge of running organizations stays on the agenda of many researchers and practitioners around the information systems and information management community. While the advances in technological foundations of management information systems have been impressive, the advances in efficient satisfaction of management information needs have been less impressive. The development of systems for managerial information needs, while having a rich history of several decades, has been based on a heterogeneous set of needs: some of these needs stay stable (developing, implementing and adjusting strategy; keeping track of own activities), and some evolve or have a turbulent life cycle: monitoring close environment; looking out for threats and opportunities. Information environment (support infrastructure) is driven by the nature of business activities. On one hand, this nature is recurrent and cyclical, supported mostly by the function of a MIS. On the other hand, this nature is turbulent and unpredictable, requiring intelligent and insightful support; this is a function of a BI system and related applications – decision support, competitive intelligence, operational intelligence, early warning systems and other types of systems to support monitoring, sense-making and problem solving.

The recent research on complex information needs including decision support and business intelligence has been diversified into quite a few related areas; far from being an exhaustive set, several examples follow. Lemieux and Dang [7] have researched the issues of accountability for decision making, and suggested tools for tracking the decision-making reasoning of human agents, thus adding to the research on a problem of experience management. Thorleuchter and Van den Poel [17] have investigated the use of website content analysis in partner search for improved research and technology collaboration planning, adding to the body of research on information integration. Saad et al [11] have researched a conceptual framework for early warning information systems for crisis situations, expanding the research on intelligence technologies for monitoring and detection. Castano [1] has researched the possibility of putting together business process management (BPM) and data mining techniques to provide intelligent BPM management functions. Redondo-Garcia et al [10] have researched information integration tasks when using disparate (heterogeneous) information sources.

The sample of research directions presented above for a long time has been attributed to the area of decision support systems and technologies, serving the complex or high-end side of user information needs. In the field of technologies for satisfying complex information needs, the once-prominent area of management decision support systems (DSS) apparently has settled to stable levels of both academic and practitioner activities [9]. However, a somewhat faded interest in decision support systems does not imply any reduction in importance of well-supported decision making, as well as general awareness of the state of internal and external business environment. On

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the contrary, the current economic situation in most settings demands an efficient and reliable, „military grade" management environment to support decisions, insights, recovery or mere survival.

Decision support alone, being reactive and activated only when a problem is encountered, eventually proved to be insufficient. The problem solving context received IT-based support mostly from the resources of a regular information system, therefore of a limited nature and in most cases complicated by time pressures. An alternative use of decision support, if coupled to a proactive monitoring of the environment, ensured better understanding of the problem context, leading to higher decision quality. A term "business intelligence" came into use, serving as an umbrella term for tools and technologies that let business information users stay aware of changes in internal and external environments.

The research problem of this paper is centered around how the current array of technologies and approaches provides support for functions of insight building. Currently there is a confusion in defining whether management information systems overlap with intelligence systems, and whether business intelligence is a part of decision support function, or vice versa; eventually this confusion spreads to business management community which at all times has expressed the need for insight building and reliable decision support which would justify substantial investments into support technologies. In this paper, the authors have decided to use the results of their earlier research to make an attempt in developing a model positioning business intelligence and decision support functions.

The paper is structured as follows. Section 1 defines the dimensions of the problem and the goal of the paper. Section 2 clarifies the definition of business intelligence and its information needs. Section 3 defines a relation between the areas of decision support and business intelligence. Section 4 presents empiric data on user responses towards decision support anad business inteligence functions. Finally, Section 5 presents conclusions and directions for further research.

II. Business Intelligence and Information Needs

Although business intelligence is regarded as a relatively new term, with authorship assigned to Howard Dressner of Gartner Group in 1989, we can have a retrospective look at the mission of management information systems (MIS), whose role of keeping management aware of the state of business has never been downplayed, and mission definitions for MIS sound very much like the mission definitions for business intelligence today. A few explanations of MIS role from earlier sources are presented below:

- "Two types of information for strategy implementation are in use. The first one is the external information, used for strategy development. The second type is internal information, used to monitor strategy execution" [14].

- "A management information system refers to many ways in which computers help managers to make better decisions and increase efficiency of an organization's operation" [7].

- "For information to be useful for managerial decision making, the right information (not too much and not too little) must be available at the right time, and it must be presented in the right format to facilitate the decision at hand" [4].

- "A management information system is a business system that provides past, present, and projected information about a company and its environment. MIS may also use other sources of data, particularly data about the environment outside of the company itself." [6].

- "The systems and procedures found in today's organizations are usually based upon a complex collection of facts, opinions and ideas concerning the organization's objectives. … For an organization to survive, it must learn to deal with a changing environment effectively and efficiently. To accomplish the making of decisions in an uncertain environment, the firm's framework of systems and procedures must be remodeled, refined, or tailored on an ongoing basis." [3].

There are definitions of business intelligence that do not differ much from the above definitions; e.g., Vuori [20] states that "… business intelligence is considered to be a process by which an organization systematically gathers, manages, and analyzes information essential for its functions". In order to have a more precise definition of business intelligence, we have to decide whether all informing functions are „intelligence" because they increase awareness, or does BI have a clear separation from other (lower level) informing functions. If so, the separation criteria between BI systems and any other management information systems have to be defined. For the purposes of this paper, we will use the division of management information needs along two dimensions – their simplicity or complexity, and common or specific focus, as presented in the Table 1 and based on earlier work by one of the authors [14]:

TABLE 1.
RELATION OF SIMPLE-COMPLEX AND COMMON-SPECIAL INFORMATION NEEDS

	Simple needs	Complex needs
Special needs (problem-specific)	Simple special needs	Complex special needs
Common needs (available permanently)	Simple common needs	Complex common needs

The mission of BI becomes clearer if weighted against the types of served information needs. Regarding the positioning of these needs against the axis of simple-complex information needs, they usually fall into the more sophisticated part of the information needs complexity spectrum. Same can be said

about the process of decision making, which often requires sophisticated tools to support awareness, communication, sense-making and evaluation of risks. The dimension of common and special information needs separates decision making from the rest of business intelligence in a sense that while decision support activities are directed towards a certain problem which has been recognized and has created a task of its solving, business intelligence can be considered an activity which, apart from encompassing decision support, has a permanent nature and allows the discovery of problems and general awareness about the state of activities.

III. Decision Support and Business Intellgence Processes

A. Structure of Decision SupportProcess

A decision support process includes a number of stages, and if accumulation and subsequent use of experience is included, the process takes a cyclical nature (Fig. 1, from [13]):

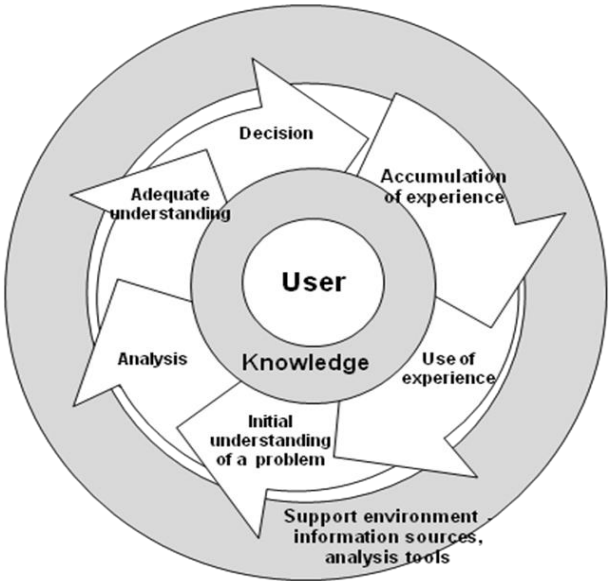

Fig. 1. The decision support process

The structure of the decision support process can be related to relevant information needs:

1. Monitoring (using previous experience): the environment, both internal and external, is being watched to notice things worth attention; *simple* and *common* information needs prevail.
2. In the case of recognizing a situation of interest (initial understanding of a problem or opportunity) the situation is evaluated and given extra attention to achieve desired understanding. At this stage *special* information needs arise.
3. Additional analysis and decision development is required if the situation is complex enough (semi-structured or unstructured); *simple* needs are complemented by *complex* needs; more information is brought into decision making environment; specific problem-solving tools such as formal approaches and models are likely to be used to achieve an adequate understanding of a problem.
4. The decision-making stage involves formerly available as well as newly gained understanding of the situation, and the decision maker or makers will use all possessed knowledge to arrive at the best possible decision, time or other circumstances permitting. In this paper, the term "knowledge" is deliberately avoided most of the time, but here it serves to show that data or information alone are insufficient for decision making; all that is known will be used in its entirety, and new knowledge most likely will be gained.
5. The experience accumulation stage records the newly gained experience from both decision making and its implementation, and keeps it for possible reuse. *Special needs* become *common*, adding new material to the already available body of experience, and the need to capture the essential features of the recorded case keeps this sort of information need in the complex segment. This phase should also include the practical experience in decision implementation, which can sometimes reveal additional circumstances of the problem.
6. The use of new experience, along with that formerly accumulated, brings the process back to stage 1 – monitoring.

Stage 1 of the above process is directly related to (or can be considered a part of) business intelligence, because that's where the actual monitoring of the business environment is being done. Stage 2 is a principal point of joining business intelligence and decision support.

As we can see, during the decision making process the focus of information needs moves around the quadrants of Table 1: stage 1 concentrates in the simple/common sector; stage 2 moves on to simple/special sector, stages 3 and 4 concentrate in the special/complex sector, stage 5 moves into complex common sector, and finally stage 6 brings the focus back to simple/common sector.

B. Structure of Business Intelligence Process

The business intelligence process, too, takes a cyclical nature (Fig. 2., from [20]), and includes the stages of information needs definition, information collection, information processing, analysis, information dissemination, information utilization and feedback. The cycle structure is justified if the received feedback helps to reevaluate or redefine information needs.

In business intelligence process, there's usually no clear concentration on a specific topic or problem, and the resources of a BI system are used for constant monitoring of internal and external business environment. In other words, such systems serve *common* information needs to keep users informed about the state of business environment, often combining a monitoring function with alerts, exception reports and other tools to draw attention to changes or inconsistencies. Therefore, an important feature of BI systems is their ability to

produce a complete composite view that would help avoiding surprises.

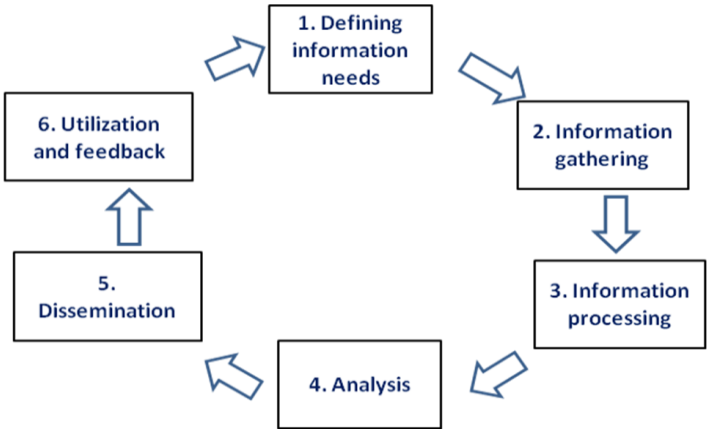

Fig. 2. A generic business intelligence process model [20]

The business intelligence cycle, as presented in Fig. 4., raises several questions. First of all, it does not disclose the difference between regular management information systems or their current incarnation, ERP systems, and business intelligence systems. It is unclear, for example, whether external information is used in the cycle, and if so, in what ways. Secondly, the cyclical feedback should invoke the re-evaluation of information needs, as business conditions change, or some needs have been incorrectly assessed from previous cycles (inclusion of irrelevant information or omission of important information).

From the above descriptions of technologies and processes for both decision support and business intelligence we can define two different but interrelated cycles: cycle 1 for business intelligence process, and cycle 2 for decision support process (Fig. 3).

As cycles 1 and 2 unfold, the focus moves around different types of information needs. In cycle 1, the steps of information gathering and processing can be attributed to the *common* and *simple* part of information needs. The analysis step uses processed information and produces derivative results that produce additional insight and move from *simple* to more *complex* needs. If a problem situation is recognized, *special* needs arise, and cycle 2 is activated. For a problem analysis, *special* needs may be both of *simple* and *complex* nature, depending upon the severity of a problem. A problem-specific model is developed for better understanding of the problem and evaluating the alternatives. Decision implementation brings in valuable experience that is saved for later reuse and, together with other experience, satisfies *common* information needs important both for future business intelligence and decision making.

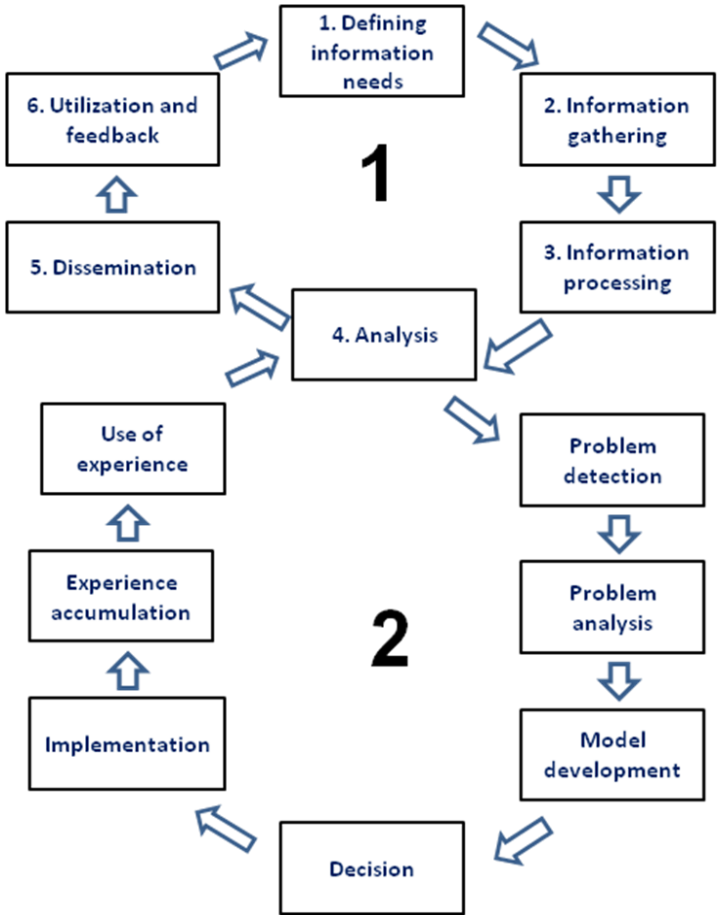

Fig. 3. Relation of business intelligence (1) and decision support (2) cycles

IV. User Responses on IT Use for Decision Support and Business Intelligence

The opinions on IT role in supporting the sophisticated side of information needs can be roughly split into deterministic approaches and behavioural, human-centered approaches. The former assign prime importance to IT performance and ability to automate complex analytical procedures [2], while the latter assign prime importance to human skills and creative powers ([16], [5], [19]), at the same time stating that the majority of existing decision support and analytical tools are technology-centric rather than user-centric. The conflicting attitudes have initiated a survey, performed earlier by one of the authors [14], where issues like monitoring of internal and external environment, IT role in the monitoring process, and experience management have been researched to gain insight on IT use to support the compl;ex side of management information needs, including DS and BI. The survey had yielded 250 responses from a convenience sample of managers of small and medium businesses in a Central-Eastern Europe country.

Regarding the *monitoring of internal organization environment*, the users appeared to be quite comfortable using IT for monitoring key data about their organization's activities. Such information is contained within their in-house information system that has been created to monitor these activities. The absolute majority of responders (161 or 64.4%) have indicated that IT is used to monitor all issues relating to an organization's internal information needs; such needs are

attributed mostly to the simple common needs. The information system-based information tasks are largely routine, and satisfaction of this type of information needs does not pose any significant problems**.**

For *external monitoring* the use of IT is significantly lower; the number of responders having indicated that they use IT to monitor all external issues has been 125, or 50%; 122 responders, or 48.8%, had stated that they use IT for some of the external monitoring issues. The lower numbers of use do not point to second-rate importance of external monitoring; rather, they indicate that the sources of external information are not under the control of a single own information system, as it is in the case of internal information sources. The external environment, being an important source of changes, opportunities and risks, is much more turbulent, and there is a greater variety of issues to be monitored, information sources, formats, and access modes; this variety significantly complicates the use of IT for external monitoring.

Supporting the detection of important changes, IT had been considered a helpful aid in monitoring and detecting changes, but rather limited in supporting information needs for sense-making. The absolute majority of responses (105 out of 207 responders having indicated that IT has some role in detecting important changes, or about 51%) stressed the role of IT as a principal technical support tool. No responses stated that IT had significantly supported the function of sense-making (revealing important changes in the environment).

The reuse of experience and competence information is one of the most important functions in the process chains of BI and DS; this statement can be supported by a seemingly growing number of published work on experience management systems. The results of the survey have indicated that the reuse of important problem-solving and decision making experience is of mixed success; recorded practice is reused – in most cases conditionally, as situations change and information needs have to be constantly re-evaluated. The survey had also shown that experience records are recorded in all convenient ways: free text format in digital media, structured format (with some standardized features and values) in digital media, and same on paper. IT role can be seen mostly in arranging, managing structures, imposing standards, and allowing easy filtering and retrieval. Level of reuse is limited due to changing context, although the reuse of templates, structures, models and other procedural issues is commonplace.

Decision-making information needs are hard to plan because of their variety and unstructuredness. Regarding this issue, the respondees have been asked about:

- decision making infomation needs that are known beforehand, and the principal types of such information;
- decision making information needs that are not known beforehand and emerge in the process of developing a decision, and the principal types of such information.

The *known* information needs relate to information whose content and location are known and accessible because of earlier experience, or this information is already available. This information or tools for its access can be placed in close proximity to the decision makers. The distribution of responses between the different types of this information is given in Table 2.

TABLE 2
KNOWN INFORMATION NEEDS FOR DECISION MAKING

Type of information	**No. of cases**	**Percent**
Market information (customers, sales, needs, opportunities)	49	19,6%
Competition information (competitors' status, strength, intentions, actions)	29	11,6%
Internal information (financials, capacity, inventory)	27	10,8%
Legal information (laws, regulations, standards)	26	10,4%
No such cases	26	10,4%
Technical information	2	0,8%
Did not specify	91	36,4%
Total:	**250**	100,0%

A separate important group of information needs is the *unexpected* information needs, which emerge mostly because of turbulent business nature, are hard to plan, and the use of programmed solutions is rather limited. The distribution of responses between the different types of this information is given in Table 3.

TABLE 3
UNEXPECTED INFORMATION NEEDS FOR DECISION MAKING

Type of information	**No. of cases**	**Percent**
No such cases	86	34,4%
Yes, there have (without specifying the information)	46	18,4%
Market information	23	9,2%
Internal information	15	6,0%
Competition information	14	5,6%
Legal information	14	5,6%
Technical information	14	5,6%
Informal, "soft" information (e.g., opinions, foresights)	12	4,8%
Confidential information (e.g., customer reliability checks)	5	2,0%
Did not specify	21	8,4%
Total:	**250**	100,0%

The distribution of both responses is not much different, and suggests that often decision makers have to look deeper into existing issues ("more of the same"). However, the significant presence of unexpected information needs might require a set of support tools that would allow tailored approaches using assorted decision support techniques – e.g., modeling, data mining, text mining, information integration and others.

The above separation of information needs into known and unexpected roughly corresponds to the related cycles pictured in Fig.5, where the business intelligence cycle is performed mostly against known information needs. If a specific problem

is detected, the known needs together with readily available information move to the decision support cycle, where additional information needs of unexpected nature are likely to emerge. This approach can be useful in designing business intelligence environments incorporating a sub-level for decision support, with generic functionality contained mostly in the 1st cycle, and the problem-specific tools and techniques in the 2nd cycle.

V. Discussion and Conclusions

There's no doubt that the need for well-informed business decisions, as well as for general awareness of developments in the business environment, will remain acute. The current state of management decision support gets more complicated as rapidly changing conditions often require swift reaction, information overload is commonplace, and additional issues arise regarding information quality [9]. Under these conditions, a need for right information at the right time and in the right place remains essential, and the well-aimed and reasonable use of support technology can increase decision making quality and efficiency, regardless of whatever name this technology is bearing at the moment.

We suggest here to use here the arguments presented in this paper, regarding the development of an efficient information environment for decision makers. It has been proposed that such environment should be split into two tiers:

- the first tier containing a simple set of support tools that are close and easy to use;
- the second tier containing more distant and more complicated information sources and processing techniques that are required much less often;
- manageable support environment that allows easy switching of items between tiers, similar to the form of managerial dashboards with interchangeable items on display.

The items contained in the first ("lite") tier would be required most of the time, simple to use and able to be configured to the users' needs:

- basic data on internal and external environment: sales, market share, cash-at-hand, order or project portfolio, comparative figures by time/place/product etc.;
- information access tools: simple search in own sources – databases and data warehouses, simple search in public sources, tools for arranging search results (e.g., by relevance or size), easy classification and annotation;
- tools for simple calculations: templates, financial models, other simple models.

The second ("heavy") tier might include:

- access to more distant and complex information sources with advanced search tools;
- modelling tools for forecasting, simulation, scenario development;
- data analysis and presentation technologies – drill-down tools, OLAP queries, data and text mining facilities, graphing and visualization tools.

Such split of functionality would roughly reflect required functions for generic business intelligence and decision support cycles respectively. It would also allow for required cross-functionality in the cases when simple decision support needs would be well-served by first tier functions alone, or when business intelligence needs would required more advanced tools. The more defined set of features for both tiers of the support environment could lead to a possible set of requirements for the interface design of an information environment for decision makers.

The further research is planned in several related and more specific directions. Firstly, it is important to research what part of business decisions are adequately supported by the first tier of the support environment, thus possibly defining an efficient and economical set of support tools. Secondly, the issues of handling experience information and providing experience support should be investigated in more specific terms of what key information on decisions already made should be recorded to create brief yet essential context, and what is the reusability and relevance rate for different types of experience records.

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Rimvydas Skyrius is a professor at the Economic Informatics department, Faculty of Economics, Vilnius University, Lithuania. He has a PhD in Management (Management Information Systems) from ASU-Moskva research institute, Moscow, former Soviet Union, 1986. From 2008 he is a head of the Economic informatics department. His research interests include Management Information Needs, Management Decision Support, Business Intelligence, Information Systems Usability.

Vytautas Bujauskas is an Associate Professor (retired) at the Economic Informatics department, Faculty of Economics, Vilnius University, Lithuania. He has a PhD in Management (Management Information Systems) from Moscow Plekhanov institute of National Economy, 1978. His research interests include Management Information Needs, Management Decision Support, Business Intelligence.

Gelyte Kazakeviciene is an Associate professor at the Economic Informatics department, Faculty of Economics, Vilnius University, Lithuania. She has a PhD in Mathematics from Vilnius University, 1993. Her research interests include Management Information Needs, Management Decision Support, Financial applications.

An Example in Remote Computing Over the Internet applied to Geometry

Ferreira, M[1] and Casquilho, M.[2]
[1] Department of Computer Science and Engineering,
Instituto Superior Técnico, Technical University of Lisbon, Lisboa, Portugal
[2] Centre for Chemical Processes, Department of Chemical Engineering,
Instituto Superior Técnico, Technical University of Lisbon, Lisboa, Portugal

***Abstract* — Scientific computing over the Internet can suit many activities that have not, in the authors' opinion, been explored enough in general. Resources such as executables, languages, packages, can be used from a remote computing system. In this study, largely based on academic practice, a simple illustrative example in Geometry is implemented on a distributed system that outsources the computing-intensive tasks to remote servers that may be located in other universities or companies, linked to grids and clusters and so on. The software stack and software developed to support the communication is explained in detail. The architecture developed stresses the interoperability of the software, and a suitable high degree of decoupling between components hosted in various locations. The results of this study motivate further work and serve a practical purpose that may be useful to everyone doing scientific computing.**

***Keywords* — Internet, remote executables, Scientific computing, university-industry links.**

I. Introduction

MANY areas of scientific computing can be addressed over the Internet, but this approach has not, in general — in these authors' opinion — been appropriately explored, all the more if compared with most uses of that ubiquitous communication network. One of the authors has, since more than a decade, intensively used this mode of computing in research and teaching at his university work, in domains related to Mathematics, namely Operational Research, Statistics or Chemical Engineering. The computing has been mainly done in a server of the university's information technology centre, intended typically to host faculty and students' webpages. The present study, largely based on that previous academic practice, focuses on the establishment of a link between two universities, one supposedly wishing to execute software made available by the other. This would also apply to any two entities, such as a set of two companies or a university-company linkage (a particular application of [5]). In the Internet context, resources adequate to the particular technical purpose, such as executables, languages, or packages, can be used, if accessible at this level with due permissions, from a remote computing system.

The Internet affords nowadays an unprecedented ease of communication at a very low cost, so that a step can be taken to reap benefits from using remote resources. There are, of course, many resources for computing on the Web, dealing with small tasks, ranging from conversions of units to more complex mathematical problems. Regarding scientific computing over the Web, an extensive example of this activity in the academic environment is the original work by Ponce ([7]), containing a large number of (Fortran) programs to solve problems dealing with Hydraulics and related areas in Civil Engineering. These applications are presumably (as all of our previous work) deployed wholly on single nodes, which also host the web interface and logic. Building on such projects as the excellent one referred above and our own previous projects, the present work intends to take this topology into a next stage, allowing further decoupling of components, by introducing an intermediate communication layer between distributed nodes, which together form the web computing system.

Internet-based computing as an everyday activity has been deemed by one of the authors indispensable to his activities as a tool in the academic practice, and a gateway to the university-industry linkage — widely praised but often scanty — in an era of cheap information technology gear.

The present study is based on a simple, yet surprising, illustrative example in Geometry — an example that might be used in a lecture — chosen both to be clear to a wide readership and to avoid beclouding the underlying software structure. Thus: the problem is started in a webpage of one entity; and the computation is done, without the user's perception, at another machine (suggesting the extension to more), allowing a certain software to be accessed.

In the following sections: the illustrative example is briefly described in its mathematical aspects; the developed resolution based on network computing is presented, with the implemented software architecture to support it; and finally some conclusions are drawn about the proposed solution and system developed.

II. Illustrative Example

A problem in Geometry, otherwise conceived as a simple template for more applied cases, was chosen as an illustrative

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example for the technique. Let the minimum distance be sought between points *A*, source, and *B*, destination, as seen in Fig. 1, both on the *X*-axis, passing by point *P*, to be determined, on the half line *s* making an angle γ with the horizontal axis. The problem is treated in [1] and solved by simple differential calculus. The analytical solution for $P = (X, Y)$ is given in (1).

$$\frac{1}{X} = \frac{1}{2}\left(\frac{1}{x_1} + \frac{1}{x_2}\right)\sec^2\gamma \qquad (1)$$

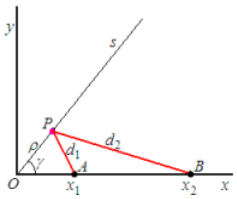

Fig. 1. Route from A to B, passing by P on s, for minimum distance.

With $Y = X\tan\gamma$, (1) leads to (2):

$$X = 2\frac{x_1 x_2}{x_1 + x_2}\cos^2\gamma \qquad Y = 2\frac{x_1 x_2}{x_1 + x_2}\sin(2\gamma) \qquad (2)$$

More concisely, in polar coordinates, (ρ, θ), with $\theta \equiv \gamma$, the radial coordinate is

$$\rho = X/\cos\gamma = \left(2\frac{x_1 x_2}{x_1 + x_2}\cos^2\gamma\right)\Big/\cos\gamma = 2\frac{x_1 x_2}{x_1 + x_2}\cos\gamma \qquad (3)$$

The interest of this problem — the reason it was chosen — lies in the unexpected result as γ decreases towards 0. In Fig. 2, the optimum routes are shown, to which correspond the optimum positions of *P*, for various descending values of γ, always with $x_1 = 1$ and $x_2 = 3$. The results come from the authors' website ([2]). Now, intuition would possibly lead ρ to the *arithmetic mean* of x_1 and x_2.

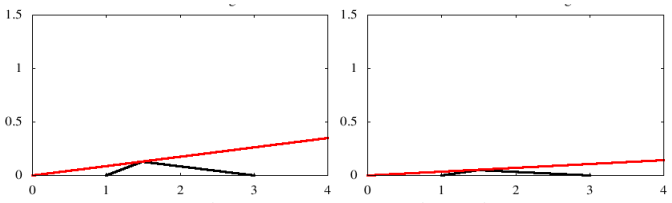

Fig. 2. Optimum routes for □ = 60, 40, 20, 10° (from left to right).

Observation of the sequence in Fig. 2, however, disputes intuition, and confirms (3): ρ tends to the *harmonic* mean of x_1 and x_2. Images for small angles, 5 and 2°, in Fig. 3, show the limiting ρ to be not 2, the arithmetic mean of $x_1 = 1$ and $x_2 = 3$, but 1.5, their harmonic mean.

The adequacy of the arithmetic mean in its own right should be noted (for $\gamma = 0$), notwithstanding, by verifying that, just by letting x_1 and x_2 grow indefinitely, with $x_2 - x_1 = \delta$ (δ constant), the harmonic mean tends to the arithmetic mean, as seen in (4).

$$\lim_{x_1\to\infty}\frac{1}{\rho} = \frac{1}{2}\left(\frac{1}{x_1} + \frac{1}{x_1 + \delta}\right) = \frac{1}{2}\frac{x_1 + \delta + x_1}{x_1(x_1 + \delta)} = \frac{1 + \frac{\delta/x_1}{2}}{x_1 + \delta} = \frac{1}{\frac{x_1 + \delta}{1 + \frac{\delta/x_1}{2}}} \qquad (4)$$

Considering the infinitesimal δ/x_1, (4) becomes (5), where the arithmetic mean is now visible ($\rho = x_1 + \delta/2$).

$$\lim_{x_1\to\infty}\frac{1}{\rho} = \frac{1}{(x_1 + \delta)\left(1 - \frac{\delta}{2x_1}\right)} = \frac{1}{x_1 + \delta - \frac{x_1\delta}{2x_1} - \frac{\delta^2}{2x_1}} = \frac{1}{x_1 + \frac{\delta}{2}} \qquad (5)$$

Another interesting property of the optimum routes is that, for varying γ (with fixed x_1, x_2), the locus of the optimum points *P* is a circle with radius $R = x_1 x_2/(x_1 + x_2)$ (same physical units of the *x*'s, of course) centred at (0, *R*), here $R = 3/4$. These facts, out of the scope of this study, corroborate the adequacy of the Internet also to openly reveal noteworthy features.

III. Software Architecture

This study is based on previous applications for many types of scientific problems and expands their capacity using the Internet, following past and current academic practice. In this work, we developed a decentralized computing architecture, distributed on a network, using the HTTP protocol to communicate between the servers, in what is usually known as a web4 service. The architecture is composed by servers playing two separate roles:

a) a front end role, providing the computing services to the clients, with a simple, practical web interface that can be easily accessed through any browser; and

[4] In *web* (as attributive) or *Web*, the Chicago Manual of Style Online ([4]) was roughly followed.

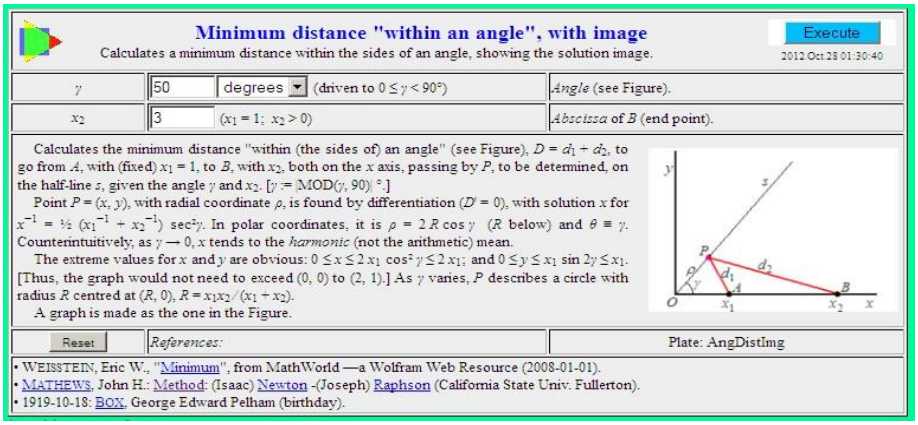

Fig. 3. Optimum routes for = 5, 2° (from left to right).

b) a back end role, receiving the computing tasks from the front end and having the required software to execute them.

The remote call may incur a substantial delay, depending only on the network latency, and mainly the complexity of the problem and computing power of the remote server machine.

The back end addresses must be known to the front end servers, so that they can be located on the public network. Likewise, the front end must be publicly accessible to the users/clients, and have a well-known address.

In the architectural layout described, both the front and back end servers are highly decoupled between them and from the other servers, having no structural dependencies on any single network point [no SPOF5 (e.g., [4])]. Therefore, they can be easily brought up and down, and change location, without disturbing the overall functioning of the system, which grants a very valuable comparative advantage. The only requirement for the system to work is just one front end and one back end servers online at any given time.

The decoupling is highly beneficial for two reasons: i) load balancing of requests between the front ends, and of computing tasks between the back ends; and ii) fault tolerance against possible node crashes.

The front end and the back end support parallel task/requests that require a separation and isolation of execution contexts. This is guaranteed by the HTTP server and the script engine used, which is PHP, with additional safeguards required in the code to carefully avoid any conflict in the resources used (filenames, etc.).

The system is illustrated in this study with the geometric example above, implemented on an Internet link between two semi-closed local networks, the Sigma cluster of IST, and the web servers of FCUL, following the steps described in the next two subsections.

The IST server is deployed on a cluster of AMD64 Opteron processors (2.4 GHz) running Debian Linux, Apache 2.2.16, and PHP 5.3.3-7. The FCUL server runs on a cluster of i386 Intel Xeon processors with Red Hat Linux, Apache 2.2.3 and PHP 5.1.6.

[5] "single point of failure"

Local execution

The starting point of the study, based on previous work done, was a system deployed in a single local server. This system combines the front end and back end functionalities locally. This is a simple case scenario that served to develop and test the basic computing service.

The system uses the following five files in turn:

a) Webpage, such as [2], in a well-known address of a front end server — It is a PHP file containing an HTML 'form' to receive the user's data, which is then sent via an HTTP POST method to a processing PHP script (following item);

b) PHP script 'interface.php', which

1. Extracts the user's arguments from the HTTP request;
2. Launches the required program in a new process (via PHP's 'proc_open') with redirected streams to new process pipes, open to the calling PHP process;
3. Feeds it with the given arguments through the child process read pipe;
4. Waits to read the output of the called program from the other, write pipe; and
5. Closes the pipes and terminates the child process.

c) Binary program ('angDist.exe', compiled from a Fortran 90 source), which also writes to the output stream the data required for a graphic to be created afterwards.

Now, the 'interface.php' script [in b)] constructs a dynamic webpage from:

a) 'interfacetop.php' (constant), the top of the webpage;

b) body (main) section, in HTML 'pre' format, with the results of the program call, and (typically) a graphic with plotted results, closing HTML bottom.

The screenshots are shown in Fig. 4 for the user data and in Fig. 5 for the results of the computation.

Results

```
2012-10-28 UTC+0000  1:36:55.952
*** Distance within an angle ***                              (Oct-2012, MC)

gamma (deg., rad),  50.0      0.8727    |
x_1, x_2,             1.       3.000    |
-------------------------------------------------------------------------------
COS, TAN(gamma), 0.64279      1.1918    | COS^2,                    0.41318
                                        |
If x_2 = x_1:                           | (absolute minimum, d0)
  x_P, y_P,      0.41318      0.49240   | d0 = x_1 cos^2 = x_P =    0.41318
If x2 = infinity:                       |
  x_P, y_P,      0.82635      0.98481   | x_P = 2 d0
                                        |
MINIMUM DISTANCE for given x_2          |
x_P, y_P,        0.61976     0.73861    | Cartesian coordinates
rho_P,                       0.96418    | (Polar) radial coordinate
d_1, d_2,         0.8307       2.492    | A--P, P--B
Min. distance,                3.3229    | A--P--B

2012-10-28 UTC+0000  1:36:55.952
2012-10-28 UTC+0000  1:36:56.386        CPU:       0.4 sec.          End
```

Fig 4.. Webpage for the user data..

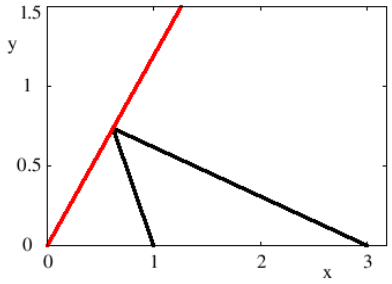

Fig. 5. Webpage for the results.

A. Remote execution

The remote execution mode is the focus of the present work. In this mode, the computing component was distributed to a remote network allowing for a scalable expansion of the system by adding more computing nodes. The decoupling adopted thus requires the development of a middle-ware communication layer between the web-interface (front-end) and the computing nodes (back-end). The decoupled architecture also provides scalability for the front-end, allowing the deployment of multiple interface nodes, scaling up according to the number of incoming requests. The accessible web front-end is available in [3]. The system can be easily deployed throughout many nodes, which can be switched on and off depending on the desired system throughput and efficiency.

Starting from the local execution system described in the previous section, the interface between the computing program and the web front end was greatly modified to support the distribution of both parts, mainly the computing intensive tasks. A muddle-ware was developed to implement the network communication, with the required transfers and conversions of data. The process of service lookup by the remote servers is done by a semi-static approach, i.e., a list of hostnames of the known service providers, contacted in sequence until a live one replies.

To the desired end, the following changes were made:

a) Refactoring the PHP complete service module, into two separate modules: a local front end component, and a back end web service interface for the remote program;

b) The front end interface loads the list of known back end servers' addresses, and polls them to find one available;

c) The front end makes an HTTP request to the available server, by invoking the PHP script on the back end. The front end forwards the input data using the HTTP POST method, specifying in the request which service is required (i.e., 'angDist' in the example);

d) The back end interface calls the binary program in a manner similar to the local execution mode, executing the requested task in isolation in that node;

e) The back end sends the results back to the front end, i.e., both the main results and the parameters of the to-be-created graphic, formatted following a well-defined template, and packaged in the same HTTP response body;

f) The front end process receives the output of the task, and unpacks the two blocks of data (results and graphic's parameters), which have been pre-formatted accordingly; and

g) The front end retains the responsibility of generating the graphic with the parameters received from the remote request, using the GNU tool gnuplot.

The choice was made not to send the graphic itself over the Web, for it could lead to problems of text data encoding (one of the tenets of web services being the use of textual ASCII data), and it would considerably increase the messages' payload size.

The results for the user are, of course, the same as previously. A different HTML background image was chosen to differentiate between a service running in local execution mode (the front end at IST) and another in remote mode (the one at FCUL [3]). The remote execution network is schematically shown in Fig. 6.

The system performed as expected, namely, the communication latency introduced by the network was negligible when compared to the typical computing time for scientific problems, and it is a constant delay depending only on the size of input and output data, and the underlying network infrastructure.

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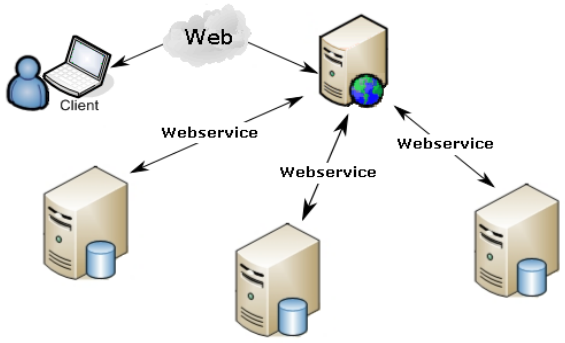

Fig. 6. Remote execution network.

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IV. Conclusions

The present study inherits former extensive work in scientific computing over the Internet by one of the authors, akin to the work by [7]. Our work has been done in one server of IST, where the webpages and their respective executables are located. The study extrapolates that approach to a two-server solution permitting a webpage on a new server, at FCUL, to access an executable placed on the other server, at IST, without the user's perception. The access is governed by two PHP scripts, each placed in one of the servers.

This shows the ease of use of an executable in a remote locus possessing required resources (executables, languages, packages), thus avoiding the breach of the source webpages' style. With the current ease of communication, this points to the use of remote software among collaborating entities, such as companies or universities or in the university-industry linkages. Thus, some software components topologically isolated from a web gateway or from unsecure locations outside its LAN may be accessed by a trusted web server and provided to the worldwide web users.

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Miguel Ferreira was born in Lisbon, Portugal, in 1979. He got his M. Sc. in Computer Engineering from Instituto Superior Técnico, Technical University of Lisbon, Lisbon, Portugal, in 2013.

Miguel Casquilho was born in Lisbon, Portugal, in 1948. He got his M. Sc. from Instituto Superior Técnico, Technical University of Lisbon, Lisbon, Portugal, in 1971 and his PhD in the same subject and University. He has been an Assistant Professor till 2012, now retired, and has worked in scientific computing on the Internet in modelling, simulation and optimization in Operations Research, Quality Control, and Computing. Prof. Dr.Casquilho is a member of the Union of Portuguese Engineers, and of the American Society for Quality.

An Agent-Based Approach for Data Fusion in Homeland Security

Dr. José Miguel Castillo Chamorro[1], D. Rafael de Solís Montes[2]
[1]Pontifical University of Salamanca, Madrid –Spain-
[2]Superior School of Telecommunications, Polytechnic University in Madrid, Madrid –Spain-

***Abstract* — This article presents an agent-based solution for data fusion in Homeland Security. Communication technology has been developed very fast in the last decades. We can get lots of data in milliseconds. Our current problem is to process such amounts of data in order to provide useful information. We have to focus our effort on developing intelligent information systems able to handle big amounts of data extracting or revealing relations among data and able to produce information easily understandable for the human user. That is the case of data fusion in tactical operations, especially in the field of defense and Homeland security. Our research is focused on obtaining a Multi-agent system able to inference future enemy's actions or behaviors from data received from heterogeneous sensors.**

***Keywords* — MAS, Data fusion, tracks, merge, inference, Homeland Security.**

I. INTRODUCTION

IN the last decades the concept of HOMELAND security plays an important role in our lives. Everybody is concerned about the necessity of protection against undesired attacks from outside our borders or from internal terrorists' threats.

Nowadays, the concept of military defense is merged with the national security concept. Both are complementary and have a common aim: to preserve the social stability against external or internal threats. Furthermore, this need is spread in most occidental countries which implies the necessity of taking common measures by developing common regulations and promoting technological initiatives that make our community less vulnerable.

This article introduces an agent-based architecture [1] [2] as a solution to solve data fusion problems in a tactical environment. One of the advantages that this solution has is that it can be used also for training; so the operational team can be trained in a virtual environment by using the same architecture.

In tactical operations either in the military or for civil purposes like borders control or coasts surveillance, data fusion is a process that facilitates intelligence tasks and will be an important input for planning operations.

When using different sensors to locate objects or targets we will get the same number of synthetic representations as sensors. Our first problem consists of comparing features of these tracks in order to determine if all of them are representing the same target or there are multiple objects in the scene. After that, we have to know if we are dealing with a single object or a group of organized targets. Through sensors we can know about the current and past location of targets, but it is necessary to extrapolate future positions in order to prevent undesired enemy actions to happen.

We have faced the problem with the idea of giving a general solution for such kind of different problems under a single architecture.

This article is divided into different sections. In Section II we introduce the need of data fusion in tactical operations. An analysis of the State of the Art in that field is made in Section III. The system architecture that gathers the four phases in a data fusion system is depicted in Section IV. Our first approach to a communication solution among agents is explained in Section V. In Section VI, the multi-agent operational approach is introduced. And finally we end the article with our plans to complete the research and the conclusions.

II. DATA FUSION IN TACTICAL OPERATIONS

Data fusion is one of the main activities within the intelligence process. It is essential to figure out the enemy tactics as well as its plans and purposes.

Any Command and Control system within the field of HOMELAND security requires an easy-to-use data fusion system that would not demand specific management tasks as IT personnel will not be available in the lower levels.

The unbalanced capabilities of command and control currently available require an evolution of the platform-centric to a network-centric capability that allows the use of unique data fusion capabilities.

Defense operations cover a wide spectrum of threats and deployment scenarios that range from conventional war through limited operations, crises response operations, asymmetric conflict, and terrorism.

The successful execution of fast moving operations needs an accelerated decision-action cycle, increased tempo of operations, and the ability to conduct operations.

Unilateral capability is important but most planning is made on the assumption of alliance and coalition operations in scenarios that are difficult to predict and which often arise at short notice. Thus the nature and composition of the force structure to meet defense requirements will be specific to

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requirement and based upon a general and flexible HOMELAND security capability [8]. Data fusion capabilities must allow the deployment of military forces. Additionally, as tactical forces could need to interact with non-governmental organizations, including international aid organizations, Data fusion should be able to pass information to them through web pages in an off-line and secure control way.

It is not only the new capabilities and concepts that accompany the Information Age that are different, but also the nature of the technology itself and the ever increasing rate of change that make our times very different. The discomfort associated with the nature of the changes combined with the incredibly rapid pace of change and the very high cost of error associated with decisions that involve our national security create a formidable set of challenges.

Data fusion should actively seek to provide users with both, the most accurate and timely information, and also, that the users can trust the information they have available is exactly the same information to the members involved in an operation.

Data fusion not only helps us detect redundant data regarding targets location but also contributes to enriching our knowledge about the possible enemy actions by guessing an enemy's future manoeuvres.

Specific requirements

The design of the present data fusion project is based on the following requirements:

a) Centralization of data. A standard database model will be the core of the system. There will be a unique database regarding data fusion.

b) Decentralization of inputs. Inputs to the database will be introduced by any acquisition device. Other command levels can also introduce inputs to the database.

c) Data fusion process can be run in high level headquarters on demand or in headquarters of subordinate units.

d) Aggregation and identification of target groups will be done by grouping isolated targets.

The design of the data fusion module has some technical requirements that it are worth highlighting:

- In order to cluster targets and identify undesired groups of targets, it is necessary to have a precise definition of them in the data model. The definition of potential enemy units should be provided beforehand.
- Any time that a headquarters wants to run the data fusion module, the updated data model has to be accessible. This circumstance implies an efficient use of the communications network.

Data fusion is necessary for intelligence phase and supports planning tasks.

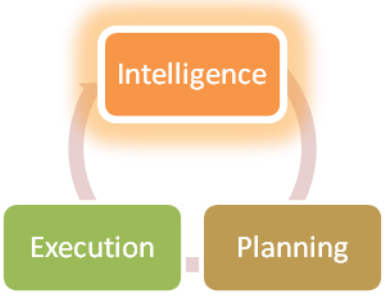

Fig. 1. Intelligence cycle

The phases of the intelligence cycle are illustrated in Figure 1. All these phases are continuous through time. We get information from the scenario that facilitates the planning process of operations. The plan is executed and as a result the scenario changes and we get new information that feeds the intelligence phase that will start a new planning process.

III. State of the Art in Tactical Data Fusion

Data fusion is a process that combines data from multiple sensors, and related information from associated databases, in order to improve accuracy and to make better inferences than could be achieved by the use of a single sensor or data set alone [20].

While the coverage of methodological areas of data fusion systems includes artificial intelligence procedures, pattern recognition, and statistical inference; application areas of data fusion include automated target recognition, guidance for autonomous vehicles, remote sensing, battlefield surveillance, and automated threat recognition systems, such as identification-friend-foe-neutral (IFFN) systems [13].

As explained in [15], the JDL's definition (Joint Director of Labs) of information fusion has four levels, ranging from identifying and tracking targets of interest, to determining whether these targets are real threats.

Other authors divide the fusion process in five, or even six, levels starting in level 0 with the source pre-processing and ending in level 5 with the user refinement.

The JDL model was proposed by the US Joint Directors of Laboratories Data Fusion Sub-Group in 1985 [12].

The model from 1992 is explained by Steinberg, Bowman & White [21] and it proposes five levels for the data fusion process explained as follows:

- Level 0 − Sub-Object Data Assessment: estimation and prediction of signal/object observable states on the basis of pixel/signal level data association and characterization;
- Level 1 − Object Assessment: estimation and prediction of entity states on the basis of observation-to-track association, continuous state estimation (e.g. kinematics) and discrete state estimation (e.g. target type and ID);
- Level 2 − Situation Assessment: estimation and prediction of relations among entities, to include force structure and cross force relations, communications and perceptual influences, physical context, etc.;
- Level 3 − Impact Assessment: estimation and prediction of effects on situations of planned or estimated/predicted actions by the participants; to include interactions between action plans (e.g. assessing susceptibilities and vulnerabilities to estimated/predicted threat actions given one's own planned actions);
- Level 4 − Process Refinement (an element of Resource Management): adaptive data acquisition and processing to support mission objectives.

On the other hand, the Data Fusion Information Group (DFIG) model is divided into six levels, as explained bellow:

- Level 0: Source Preprocessing/subject Assessment
- Level 1: Object Assessment
- Level 2: Situation Assessment
- Level 3: Impact Assessment (or Threat Refinement)
- Level 4: Process Refinement
- Level 5: User Refinement (or Cognitive Refinement)

Level 1 is in charge of fusing filtered sensors data to determine the identity, position and speed of the entities.
Four functions can be distinguished:

- Data alignment: this task transforms the data received from the heterogeneous sensors into a common spatial and temporal frame.
- Data association: this task performs the correlation observations from the sensors into different groups. Related data is represented as a single distinct entity.
- Tracking: this task aims to determine an estimation of the position and speed of the targets through the multiple observations of positional data coherently for successive instants.
- Identification: this task classifies the objects originated by the measurements of their characteristics.

Feature-level fusion, referred to state-level fusion, involves the extraction of representative features from sensor data. In feature-level fusion, features are extracted from multiple sensor observations, and are combined into a single concatenated feature vector which is used as an input to pattern recognition approaches based on neural networks, fuzzy logic, clustering algorithms or template methods [20][25].

Modeling procedures involved in data fusion consist of association, estimation and identity declaration [20]. First of all, association determines which pairs of observations belong together, by representing observations of the same entity. Commonly used association measures include correlation coefficients, distance measures, association coefficients, and probabilistic similarity measures. Next, parameters of the fusion model are estimated using maximum likelihood estimator, least square estimator, or Kalman filter estimator. Finally, for identity declaration, typically one of the following three level of fusion is used: data-level fusion, feature-level fusion and decision-level fusion level [13].

IV. Four Levels, One Architecture

Taking into account the State of the Art in Data Fusion, in this section we are going to illustrate the conceptual architecture on which we are going to develop the multi-agent system. This architecture is based upon the Steinberg approach [21] and it is described in details as follows:

Five are the main characteristics that a data fusion system should include:

- Capacity to detect and merge duplicate tracks
- Capacity to identify a single target by its features
- Capacity to identify groups of targets regarding their behaviours
- Capacity to assess the scenario and extrapolate future targets positions or actions.
- Possibility of indicating mitigation actions that can prevent enemy attacks from happening.

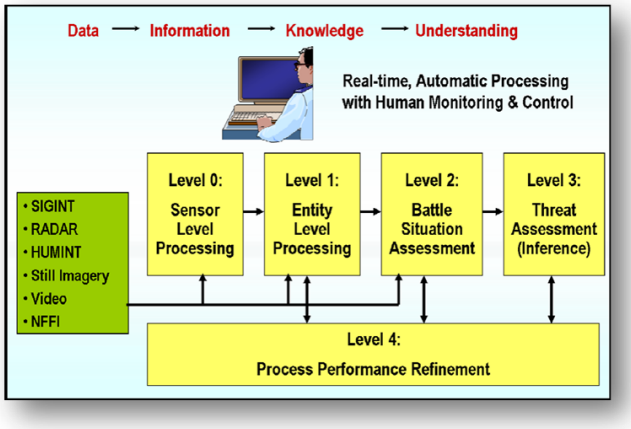

Fig. 2. Four levels, one architecture

The above figure shows the integration of the four different levels in data fusion in a single architecture.

A. Level 1 Data Fusion Submodule

At level 1 the following associations are made (in the case that several sources are available), recognition, identification and tracking of received tracks from different sources or associated tracks.

At this level the association of various data sources available is made. This level receives information about level 0 tracks and user settings and user corrections, this process of data fusion is made up of a collection of functions, these functions are recognition of tracks received from different sources, to obtain information from the merging of several tracks in the data fusion processes, the spatial and temporal alignment of tracks and the application of predictive algorithms to simulate the future position about an identified track

To summarize, Level 1 has functions to discriminate non valid information and corrupted signals, and provides the capability to generate recognized tracks and generate output information for other levels. The information generated from this level will be tracks with entity types information associated.

B. Level 2 Data Fusion Submodule

Level 2 data fusion performs clustering of single entities in order to create higher hierarchy entities. It also performs the recognition, identification and tracking of the higher level entities.

The level 2 sub module accepts the output provided by level 1 sub module and from other sources.

Level 2 data fusion carries out the clustering process of single entities in order to create aggregations. An aggregation is made up of various entities related, that generate a unique element with its own behavior. It performs the recognition, identification and tracking of the aggregations.

The system is able to automatically create clusters. The user can manually create new clusters or uncluster erroneous aggregations.

Level 2 is able to accept changes and new rules generated by the level 4 in order to optimize processes.

C. Level 3 Data Fusion Submodule

At level 3 possible future situations are identified, utility/cost assessment shall be made for each of the proposed actions.

Level 3 looks for a prioritized list of enemy potential targets. These targets are retrieved from tactical database. Once the objectives are listed, the system carries out the targets route prediction by using path finding algorithms.

D. Level 4 Data Fusion Submodule

Level 4 monitors operations from levels 1, 2 and 3 in order to generate statistical data, assess results and optimize processes.

Level 4 permits performing management, control, monitoring, optimization capabilities, statistical functions, management recording, report tools and parameter modifications tools of fusion process, in real time.

Level 4 submodule allows interaction with a user so as to perform queries on historical data, decision making, visualize/edit logs, configure optimization/monitoring, etc.

V. The Multi-Agent Communication Model

Current specifications and approaches to connectivity in Multi Agent Systems are discussed [18] and related to the needs of a tactical data fusion system. Results from an implementation of a Multi-agent system [10] are used to illustrate how using these theories can enhance the development and improved development of a C2IS (Command and Control Information System) [8].

We are researching AI techniques [17] suitable for providing connectivity among intelligent agents within C2IS and data fusion modules.

We have analyzed the multi-agent systems literature to identify how theories of agent's interaction can help provide a theoretical framework on which to base improvements to our system.

These theories have been successfully applied by Dominique Benech [5] to improve the MAS interaction by using CORBA specifications [22].

KQML [23] is, in fact, a formal specification for an Inter-agent language, to be placed at the application layer in the OSI schema. It makes the communication protocol independent of the contented message semantics.

Application
Presentation
Session
Transport
Network
Link
Physical

Fig. 3. OSI Layers

It is clear that this 'application layer' needs to be divided into other n sub-levels, where the KQML would occupy the lowest one, wrapping the upper levels knowledge in order to transfer it to the lower ones.

Agent
VKB[1]
Kwowledge language (KIF)
KQML

Fig. 4. Application layer sub levels

KQML [9] doesn't describe a complete MAS architecture, in that sense, is, so to say, a wrapper for the exchanged knowledge, similar to a PDU at the application layer.

KQML head (interaction info)	Body (shared Knowledge)

Fig. 5. KQML Message

KQML establish an inter-agent speech mechanism, regardless of the knowledge that is to be exchanged.

This interaction protocol is not clearly defined, so we will use it for the syntax and semantics but for the interactions we need to use another specification (FIPA) [11], which is an evolution of KQML.

Besides, this specification rests in the upper levels for the ontology definition, which needs to be the same between the agents, so they have to be in the same domain's problem.

On the other hand, they also have to share the syntax to be able to understand that content.

It's interesting to take into account the study that has been accomplished, related to the different distributed management protocols, where CORBA is not simply a protocol but a complete architecture for distributed systems. CORBA [3] works as a middleware to offer an abstract view of the network to application objects. Thus, it also adds an intermediate layer and communications are slower than when using lower-level protocols'.

These extra complexities drive us not to use CORBA as a MAS support platform for multi-agent communications in C2IS.

TCP could be used as a transport protocol for the purpose of distributed management, but a higher-level protocol is necessary in our context to answer to the requirements we defined'.

So the Multi-agent system for Data fusion will require to organize the higher layers to provide the needed services, but keeping the simplicity and low-cost of TCP at the transport layer.

[1] Virtual knowledge base

So we have to conclude that for the aim of COBALT, the CORBA specification is suitable as a management and transport protocol, but the mentioned drawbacks make us to decide for using sockets TCP/IP in C2IS, passing to the higher levels the responsibility to manage the rest of the requirements.

This section has focused on the inter-agent communication protocol, in the following section the multi-agent model regarding operational functionalities is faced.

VI. The Multi-Agent Operational Model

In this section, we illustrate a new approach to data fusion based on a Multi-Agent System. The objective consists of the construction of a model that faces the problem of extracting information from data produced from different sources.

From an operational point of view, agents within a Multi-Agent model have to perform cognitive tasks [4] that facilitate to automate the complexity of the data fusion process [6].

The following figure illustrates the agents that a multi-agent model includes to elaborate data producing information and to make decisions with the supervision of the human operator.

The data fusion system is an open system, which means that it can receive tracks and locations from different sensors, such as radars, human observers, unmanned air vehicles, etc. The data received from heterogeneous resources need to be processed and stored following a specific format. The DB Storing Agent is in charge of collecting data from different sensors and applying the correct format to those data to store them in a database.

Each track and location is produced taking into account spatial and time coordinates regarding the specific location and identification source. All this tracks need to be aligned in terms of location and time. The Alignment Agent is in charge of doing such task.

Once tracks have been pre-processed, the Fusion Agent is responsible for merging different tracks in order to examine if tracks produced from different acquisition sources are representing the same target.

The behavior of individual tracks have to be analyzed to check if they belong to group, so the Classifier agent is in charge of clustering tracks and analyzing their behaviors through time.

The Predictive Agent has the mission of figuring out the location, manoeuvre and intentions of a cluster of tracks in a near future.

Since the Data Fusion System works following the Intelligence Cycle, in every cycle the system will obtain an output that can be compared to the real scenario, consequently the system output can be validated. Possible errors in alignment, fusion, classification or prediction can be treated by the Optimizer agent with the idea of improving the performance of the Agents responsible for such tasks.

Finally, the Intelligent Planning Agent will give mitigation strategies or recommendations to thwart enemy's manoeuvre.

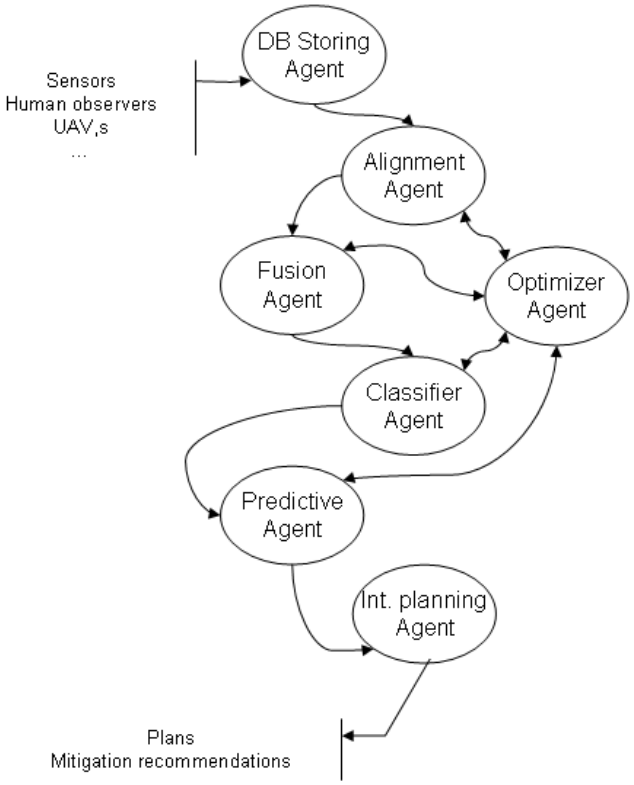

Fig. 6. The Multi-Agent operational model

A. Tools to build the Agents

Each cognitive task to be developed by every agent needs a specific Artificial Intelligence procedure [7] [19]. Some of them are described in the following paragraphs.

DB Storing Agent: The agent receives data from different sources and formats, and yields records in a formatted database. The core of this agent is based on mapping inputs with a structured format.

Alignment Agent: This agent has been developed by using proved algorithms like Kalman filter.

Fusion Agent: This agent uses logical rules to analyze if the location and time coordinates from different sources are related to the same track.

Classifier agent: Neural networks are used to develop the Classifier agent. A Multilayer Perceptron works efficiently in this cognitive task.

Predictive Agent [24]: In order to extrapolate future locations and manoeuvres, historical data of the same track or cluster and a pathfinder analysis on a GIS are required.

Intelligent planning Agent: To develop the Intelligent planning Agent we are using intelligent searches based on Artificial intelligence techniques as well as Neural networks to classify the importance of targets.

Optimizer agent: The Optimizer Agent is being developed by validating historical data and the user's decisions compared to the real scenario. The system will carry out automatically all Data Fusion Process taking into account former user's decisions.

VII. FUTURE WORKS

In this article we have presented a solution based on agents to develop an architecture that supports the solution for data fusion problems in tactical operations.

The agents-based architecture is designed not only for being implemented and used in Command and Control centres, but also it can be used in the training field in order to improve operators' skills when dealing with operational data fusion problems. In the near future, we have to work in depth in the training area, by implementing new agents that facilitate such tasks.

Presently we are tackling the study of the application of data fusion on other domains.

In order to validate the architecture and new approach showed in this article, in near future we are going to develop some software prototypes that individually demonstrate the feasibility of this solution in each data fusion phase.

VIII. CONCLUSION

One of the most important advantages that this work offers is an agent-based approach to solve data fusion problems in tactical operations.

Computers have a larger capacity to process data than humans have. When receiving data in headquarters or HOMELAND security operational centers, the processing time for a person will be larger than for the computer. For that reason, computers play a vital role in this issue. Humans cannot easily detect redundancies in a large amount of data they are dealing with; a computer is able to do it.

A Data Fusion module is going to receive large amounts of tracks, which have to be aligned, merged and recognized almost in real time in order to proceed with the Intelligence cycle.

The lack of time to process large amount of data and the use of complicated reasoning rules raise the probability of human errors. The use of a multi-agent solution for the data fusion module avoids this kind of problem.

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José Miguel Castillo Chamorro is the CEO of SoftCast Consulting. From 2011 to 2013 he was the Director of the Area of Information Systems, training and decision making support in 'Tecnalia Research and Innovation'. From 2007 to 2011 he was Director of Division in European Virtual Engineering (Tech. Center). In 2001 he earned his PhD in Telecommunications from the Universidad Politécnica in Madrid. The same year he was awarded with the 'General Fernández Chicarro' prize by the Spanish Ministry of Defence for his work on Operations Research.
He has a large experience leading projects in which simulation, artificial intelligence and project management are involved. He is Associate Professor at the Universidad Pontificia de Salamanca in Madrid. In 2007 he obtained his PhD in the Statistics and Operational Research department from the Universidad Rey Juan Carlos in Madrid. In June 2007 he was awarded with the prize on Research by the Spanish Ministry of Defence. In the same year he was awarded with the prize on Research on the field of Security by the Directorate of Civil Protection and Emergencies (Spanish Ministry of Interior).

Rafael de Solís Montes is the CEO of Proytecsa (www.proytecsa.net). He is Lt.Col SP Army (Ret) with a large experience n C4ISR system in Spain and NATO. His degrees include Master of Science and "Research Aptitude" degree both in Artificial Intelligence and Computational Mathematics, he also possesses a Master of Science in Computer Science. He received post-graduate diplomas in CIS, High Logistics and Cryptology, and has 3 yrs of studies in Economics Science. Between his military courses, parachutist, night combat, PIO can be highlighted. He is completing his PhD thesis on Artificial Intelligence and Computational Mathematics about "Multiagent Systems and Data Fusion techniques in support of the interoperability between information systems" at the UPM University of Madrid. His research interests include Multi-agents Systems, Data Warehousing and co-operation techniques.

Improvements in the native development environment for Sony AIBO

Csaba Kertész

Tampere University of Applied Sciences (TAMK), Research Department, Tampere, Finland
Vincit Oy, Tampere, Finland

***Abstract* — The entertainment robotics have been on a peak with AIBO, but this robot brand has been discontinued by the Sony in 2006 to help its financial position. Among other reasons, the robot failed to enter into both the mainstream and the robotics research labs besides the RoboCup competitions, however, there were some attempts to use the robot for rehabilitation and emotional medical treatments. A native software development environment (Open-R SDK) was provided to program AIBO, nevertheless, the operating system (Aperios) induced difficulties for the students and the researchers in the software development. The author of this paper made efforts to update the Open-R and overcome the problems. More enhancements have been implemented in the core components, some software methodologies were applied to solve a number of restrictions and the achievements are summarized here.**

***Keywords* — AIBO, Aperios, toolchain, Open-R, SDK, URBI.**

I. INTRODUCTION

AIBO [5] was ahead of its time and the robot hardware can be still competitive for robotics research, however, the main emphasize of the industry is on humanoids, drones, manufacturing and healthcare services these years. Simpler four-legged robots (e.g Pleo [10], i-Cybie [6]) compared to AIBO have been on the market with similar target audience though less than a million entertainment robots with total value of US$ 166 million was sold in 2011 [12]. Interpreting these numbers, this is a small business segment worldwide with low demand and people are not familiar with robots.

Pleo [10], developed by Ugobe and later Jetta, imitates a baby dinosaur and the owner needs to teach from a toddler stage until a mature. This robot has two processors, 18 motors, plenty of sensors (camera, touch sensors, microphones, infrared distance sensor etc.) and it is capable for locomotion. Actions can be programmed in Python language, but the image and sound processing is slow and unreliable while AIBO ERS-7 can capture medium resolution images with 30 Hz and 2 msecs compression time.

i-Cybie [6] resembles a dog like AIBO and it can autonomously recharge itself, however, the repairs are not easy because of the lack of the modular design. It was sold during 2005-2006 without development environment, but the community did modifications to the hardware (Super i-Cybie) with soldering a communication port near the CPU and installing a new bootloader. With these changes, i-Cybie can be programmed in C under Windows and the sensors are accessible, but the SDK was abandoned in pre-alpha state with frequent freezes and almost no documentation.

A South Korean company (Dongbu Robot) sells a robot dog [3], which has a similar hardware configuration to AIBO, but Genibo does not have an open, low level software development environment, making impractical for researches.

Currently, there is no such an advanced and highly sophisticated quadruped system on the market like AIBO. If the shortcomings of the software environment can be fixed, the robot can be used for upcoming research topics. Several efforts have been done by the author of this study to renew the potential of the programming tools for AIBO. The next chapter gives a general overview of the operating system (Aperios) and the software development environment for AIBO then the updates of the cross compilation toolchain and a higher level middleware engine are described in details. The last chapters present the general development practices before a conclusion and an acknowledgment chapter.

II. APERIOS, OPEN-R SDK

The Aperios, a real time operating system, was developed by the Sony's Computer Science Laboratory for TV set top boxes and AIBO. While the scheduling produces low latency, it is a closed, proprietary operating system without a Unix-like environment and lacking on-demand binary loader (shared libraries) or a reliable console emulator via serial connection.

There is no modern multithreading; the applications run as Open-R objects [11], loaded during the boot process from a memory stick, and they can communicate to each other with an inter-object messaging system. One object corresponds to one individual thread and the system scheduler gives control for a program in every 33 milliseconds (30 Hz). When a runtime error (e.g segmentation fault, division by zero or memory corruption) happens, the robot crashes and a dump is written to the memory stick (emon.log) before the immediate shut down. In practice, the crash cause can be obtained from this file, but instead of a meaningful backtrace, only crash address in the memory is provided. The compiler optimizations along with the function inlining make almost impossible to determinate the exact place of the error in the source codes.

The native software development kit, called Open-R SDK, is primarly targeted the Linux based systems although there was a Cygwin based version for Windows systems. The

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gcc/newlib/binutils toolchain does not contain standard C programming APIs (e.g socket communication, data and time management) though some replacements are available.

These restrictions are troublesome for the native C/C++ development on AIBO because the written codes must be "perfect" to avoid any crash or memory leaks in the limited, not upgradable resources (e.g ERS-7: 576 Mhz MIPS processor, 64 MB RAM).

The update process of the software development kit is discussed in the following chapter.

III. TOOLCHAIN UPDATE

The Linux flavor of the Open-R SDK was selected for upgrade with newer components because the Windows version would be extremely hard to update. The official toolchain relies on four components to build programs for AIBO:

1. Gcc 3.3.x: a compiler to build C/C++ sources into mipsel object code.
2. Binutils 2.15: linker tools to assembly static libraries.
3. Newlib 1.15: minimal C library for non-Linux systems.
4. Pre-built Open-R system libraries and header files (robot hardware, network communication, date, time and other replacement APIs).

These tools are outdated and the C++ template support in gcc 3.x was quite incomplete, therefore, typical source codes do not build with this compiler nowadays. Extra efforts are required for backward compatibility and maintaining the changes over time. The intention was to bring the modern softwares to AIBO when the author of this paper upgraded the core components of the toolchain.

The building process for AIBO has four steps:

Step 1. The sources are cross compiled into object codes for the mipsel target.

Step 2. A static library is assembled from the compiled object codes and the prebuilt Open-R libraries.

Step 3. A new C++ source file is created with some Open-R tools because the Aperios needs a special descriptor about the exported symbols.

Step 4. The generated file is cross compiled and linked together with the static library. The result file is executable on the robot.

Since the Open-R object loading is hard coded and encrypted into the operating system, to update the cross compiler and the linker tools, the newer versions have to produce a compatible binary for Aperios. These programs are evolved mostly together, thus the choices are determinated which gcc/binutils release pairs can be tried as well as the delta between the gcc 3.3 and the later compilers grown over time. Because the verification method of the different compilers is to boot up the robot dog with a cross compiled binary and check if the robot runs or shuts down unexpectedly, the selection was done with trial and error in this first phase.

The original toolchain was distributed by Sony with a build script and some patches against the vanilla sources of the binutils, gcc and newlib. The patches were updated for later versions and a working set of the components were found: gcc 4.1.2, binutils 2.17 while the newlib remained the same. The last remaining challenge was the crashing exception handling. After low level debugging of the cross compiler with printf() and sleep() commands, the memory address translations were fixed when the exceptions are rethrown.

The unmodified, prebuilt Open-R libraries were compiled with the standard C++ library (libstdc++) in the gcc 3.3. Two software built against different versions of libstdc++ can not be mixed during linking (undefined symbols, redefinitions), as a result, all gcc 3.3 specific symbols were renamed in the Open-R libraries along with a copy of the old standard C++ library. In practice, some static memory allocation overhead (~120kB) happen for the new toolchain and the prebuilt Open-R libraries will call the old standard C++ implementation, but it does not result any abnormal operation in the applications on the robot. After these all kinds of modifications, it is interesting that the toolchain can be bootstrapped and compiled with the latest gcc versions (4.4-4.6.1) under Ubuntu Linux without updates to the build patches.

Finally, some words about the auxiliary tools. A helper source file is created during Step 3 with an application called gensnap. This script was written by Sony in Perl to dump the symbols with their addresses into text form with readelf/objdump for analysis and it outputs the needed new source file for Step 4 in the building process without any validation. This stage was slow while the Perl is an interpreted language. The gensnap and a validator (gensnapval) tools were written by the author in C++ along with a program (crashparser) to read the crash dump from emon.log and show the demangled symbol of the crashed function as well as where the return address points.

After the reborn of the original AIBO toolchain was described in these sections, the next chapter presents the update attempt of a new version of an interpreter engine.

IV. URBI 2 PORT

The Universal Robot Body Interface (URBI) was developed by Jean-Christophe Baillie [1] and later by the Gostai company. An URBI engine usually runs on a robot with an interpreter to parse scripts written in urbiscript language to manipulate the robot actuators and query the sensors. Remote objects for the robot can be created on the computer side to execute the heavy computations on the PC, but the bandwidth, the quality and the latency of the network connectivity limit this configuration.

The original URBI engine was written for Aibo and it was updated until version 1.5. Since the AIBO brand has been discontinued by Sony and the platform is difficult for development, it was dropped from the supported platforms in URBI 2.x. The author of this paper attempted to backport the new engine to AIBO and these efforts led to the toolchain upgrade described in the previous chapter.

After about half year programming, an alpha version of the URBI 2 engine built with the new toolchain was finished for

AIBO, the unnecessary features were cut, a setjmp()-based coroutine implementation was done and the software was adopted to the AIBO specific APIs, resulting a ~200kB patch against the URBI 2.3. The urbiscript tests passed, the engine was run on the robot, but the main bottleneck was the performance to finish the port.

In the URBI 2.x branch, more and more language primitives of the urbiscript were written in the script itself and relied extensively on the bison based parser. The further porting was stopped because writing some language constructs back to the native code and maintaining it with the upcoming URBI releases needed many efforts and the acceptable performance was not guaranteed. The URBI 2.x was claimed to run on the Spykee [9] (CPU: Armel, 200 Mhz) and the ERS-7 has a more powerful processor (MIPS, 576 Mhz), but the parser overloaded the CPU in idle state after constructing a couple of pure objects in urbiscript when it should not have any overhead (e.g without objects the parser consumed about 800 µs/cycle opposed to 16 msecs/cycle with 20 objects). The performance penalty could come from the fragmented memory usage and many cache misses, but the URBI 2.x did not prove to suit for AIBO as an embedded system. Albeit it was not a clear success, the efforts were rewarded by a 3rd place on the URBI Open Source Content in 2010.

The next chapters describe details about the development practices used in a real project for AIBO.

V. Development practices

The open source AiBO+ project[1] [7]-[8] is an attempt to write an alternative artificial intelligence for the Sony ERS-7 from the grounds. The first step of the project was the selection of a development environment and since the URBI 2 engine was not a viable option (Chapter 4), the Open-R SDK was updated (Chapter 3) and chosen.

By the reason of the Open-R SDK is a cross compilation toolkit, the usual architecture of the computers (x86/x64) and AIBO (MIPS) are different. Thus the Open-R binaries are not executable on the computer where they were built whilst a rich set of the debug tools (e.g valgrind, gdb, code coverage) are available there. A solution was needed to test the implemented algorithms without a real robot. The architectural, module, singleton and observer design patterns [2] have been applied to define functionally separated modules, but maintaining the interconnections between the objects with events. The behaviors, the actuator controllers have been developed in distinct components and integrated with a glue layer to the robot. Except this latter part, all other codes can be compiled on the host machine and tests are defined to verify the correct results with mocked hardware functions.

Usually, the bugs can be revealed and fixed with the previously mentioned patterns easily, but the performance and a solid medium for troubleshooting are also important.

The next subchapters describe several compiler optimizations, and in addition, improved WiFi stability for debugging.

TABLE I
Hardware features of the Sony AIBO robots

Robot name	Processor	Memory	Wireless
ERS-110	R4300i aka VR4300 (100 Mhz, RISC, MIPS)	16 MB	No
ERS-2x0	RM5321 (192 Mhz, RISC, MIPS)	32 MB	802.11b (optional)
ERS-2x0A	RM5321 (384 Mhz, RISC, MIPS)	32 MB	802.11b (optional)
ERS-3xx	RM5321 (192 Mhz, RISC, MIPS)	32 MB	No
ERS-7	RM7000 (576 Mhz, RISC, MIPS)	64 MB	802.11b (built-in)

A. Compiler optimizations

The faster execution is the primary reason to use compiler optimizations, however, the restricted resources in embedded systems introduce some trade-offs. The Sony robots have 16-64 MB RAM and their processors are limited to 100-576 Mhz (Table 1). The memory consumption is a major challenge because the dynamic memory allocations done by an Aperios program (Open-R object) decrease the overall available memory in the system and they are not usable by other objects anymore. The freed heap memory can be reallocated by the same Open-R object again, but it does not increase the free system memory anymore.

The data and code segments of a binary are loaded to the system memory, therefore, both the lower memory utilization and the faster execution through the less processor cache misses can benefit from a smaller program size. On the other hand, the function inlining can boost the performance, but it raises the chance of the 1st and 2nd level cache misses and the compiled code will reserve more system memory after loading. This trade-off needs a clever compromise to balance the memory usage and the fast execution.

Many optimizations of the compiler (gcc) and the linker (binutils) were examined to achieve improvements on the size individual flags almost accumulated after combining them together (Table 2) and the size of the compiled Open-R objects were reduced by ~25-35 %. The flags had no negative side-effects on the stability, but less static memory allocations and they have been used in the development of the AiBO+ project for years now. Table 2 contains gcc options for the ERS-7 robot model which have not been tested for the ERS-2x0 series, but all flags should behave the same, except the processor tuning flags (-mtune=vr5000 -march=vr5000 for ERS-2x0/ERS-2x0A).

Albeit the minimal size is an important measure, the shorter execution time what really matters. The most aggressive compiler optimization for speed (-O3) inlines the functions heavily and increases the binary size, nevertheless, it is faster 1.5-2 times than the compiler optimization for size (-Os).

[1] The project web address: http://aiboplus.sf.net

TABLE II
COMPILER FLAGS FOR SMALLER EXECUTABLE SIZE (RM7000, ERS-7). EACH ROW SHOWS THE IMPACT ON THE BINARY SIZE OF SOME COMPILER FLAGS WHILE THE LAST ROW HAS THE FINAL RESULT WHEN ALL FLAGS ARE APPLIED WITH THE SUM OF THE INDIVIDUAL IMPACTS IN BRACKETS.

Option	Description	Impact on binary size (URBI2 server)	Impact on binary size (AiBO+ server)
-mtune=rm7000 -march=rm7000	Optimization for the CPU in ERS-7	-11.8 %	-8.5 %
-fdata-sections -ffunction-sections	Removes the unused binary data from the code and data sections	-23.4 %	-17.9 %
-fno-enforce-eh-specs	Skip the runtime check of the C++ exception specifications	-1.03 %	-0.99 %
-fno-threadsafe-statics	Skip the thread-safe initialization of local static variables		
All flags applied		-34.7 % (-38.23 %)	-24.60 % (-27.39 %)

B. Wireless connectivity

The wireless connection is the only useful and direct debugging tool for application development on AIBO. The 2x0 series can be equipped with an optional 802.11b WLAN card which is built-in into the ERS-7M1/2/3. After the boot process, the robot dog can connect to a WiFi network, a telnet session may be opened on the port 59000. The system messages from Aperios and the debug messages of the Open-R objects are printed to this console. A solid connection is essential in this situation and it was analyzed by Hemel et al [4] to compare the ad-hoc and interactive mode performances with TCP transmission. They found the ad-hoc mode less reliable and fast than the connection via an access point. The best transfer rates were achieved when the computer was connected to a wireless router or access point with wired connection while AIBO used its wireless LAN card.

A basic requirement is the quick and frequent transfers of small packets. The robot can not satisfy this expectation with TCP sockets which are slow to deliver packets over the network (>= ~40 ms) and the socket state may be stuck for several hundred milliseconds caused by retransmissions. Therefore, the UDP transport layer was chosen and a minimalistic protocol was built upon. The log messages, the robot state and the camera images are bundled into a packet and sent to the computer. By compressing the content, a smaller packet (~5 kB/datagram) can be transmitted in every 100 msecs whereto an acknowledgment response is received.

The UDP is a connectionless protocol, packets can be lost or their order changed and the WiFi in ERS-7 has stability issues to be improved. To ensure the utmost arrived packets, an algorithm was developed whose pseudo code is shown in Figure 1. The steps are executed every time when a new packet is received from the robot and lists of the missing and received packets are maintained to handle the cases of lost or reordered datagrams. In the AiBO+ project, an ERS-7 opens a UDP socket to the computer automatically, it constructs and sends the datagrams continuously. Each packet has a unique, incremented ID and if the identifier of the arrived packet on PC side is higher than expected, the non-received IDs between the previous packet and the current are marked as missing. When missing packets are detected, higher latencies are taken into account and the oldest lost packets are requested again in a rotating order. This heuristic algorithm can recover the connection in most situations, but a bigger congestion can happen with high number of missing packets (element_count (MissingPacketIDs) >= 50) and the missing IDs are considered lost. Despite this technique, sometimes the socket to AIBO can be disconnected by unrecoverable problems on the link or internet layers which are out of control inside the operating systems.

```
MissingPacketIDs = ∅ // Sorted vector (ascending)
RequestedPacketIndex = -1
ArrivedPacketIDs = ∅ // Sorted vector (ascending)

Function PacketArrived(Packet, NewPacketID)
  if (NewPacketID ∈ ArrivedPacketIDs)
     Return
  if (NewPacketID ∈ MissingPacketIDs)
     MissingPacketIDs = MissingPacketIDs \ {NewPacketID}
  else
  if (NewPacketID – 1 >= ArrivedPacketIDs[last] + 1)
     Iterate (ID = ArrivedPacketIDs[last] + 1 to NewPacketID - 1)
        if (ID ∉ MissingPacketIDs)
           MissingPacketIDs = MissingPacketIDs ∪ {ID}
  end
  if (element_count(MissingPacketIDs) > 50)
     MissingPacketIDs = ∅
     RequestedPacketIndex = -1
  end
  if (MissingPacketIDs ≠ ∅ )
     MaxRotationIndex = min(element_count(MissingPacketIDs), 5)
     RequestedPacketIndex = (RequestedPacketIndex+1) mod
                            MaxRotationIndex
     Request packet with ID = MissingPacketIDs[RequestedPacketIndex]
  end
  ArrivedPacketIDs = ArrivedPacketIDs ∪ {NewPacketID}
  if (sizeof(ArrivedPacketIDs) > 100)
     ArrivedPacketIDs = ArrivedPacketIDs \ {ArrivedPacketIDs[0]
```

Fig. 1. Heuristic algorithm to improve the network connection stability between a computer and Sony AIBO ERS-7

The last chapter summarizes the conclusions of the paper and gives an insight in the future work.

VI. CONCLUSION

When the AIBO brand was discontinued by Sony, it created a gap in the market and none of the upcoming developments could fill the need for a sophisticated quadruped robot with software access to the low level hardware.

The work detailed in this paper improved the toolchain support for AIBO and a more robust network connectivity was achieved. The compiled binaries have less size by ~30 % with gcc 4.1.2, modern softwares can be built for ERS-7 and the memory utilization is made better. The results have been used in the AiBO+ project successfully in the past years and the old

gcc 3.x based as well as the new updated gcc 4.x based toolchains can be downloaded by anybody from a Personal Package Archive (PPA) for Ubuntu Linux[1]. The URBI 2 was not been finished, but it provided important experiences.

The future work can include the examination of more compiler flags for further optimizations in speed and size, but the current results needs also an applicability check for the ERS-2x0/ERS-2x0A models whose CPU and optional wireless cards are different from the ERS-7 model.

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Csaba Kertész received his BSc degree in Computer Sciences focused on Artificial Intelligence from Budapest Tech and MSc in Computer Sciences from University of Szeged, Hungary. He is a Lead Engineer at Vincit Oy and works for Tampere University of Applied Sciences (TAMK) in Technical Lead/AI Specialist role in Tampere, Finland. His research interests include image processing in robotics, behavior-based systems and specialization in Sony AIBO robot dog.

Emerging Technologies Landscape on Education. A review

Luis de-la-Fuente-Valentín, Aurora Carrasco, Kinga Konya, and Daniel Burgos
UNIR Research, International University of La Rioja, Paseo de la Castellana 163, Madrid, Spain

***Abstract* — This paper presents a desk research that analysed available recent studies in the field of Technology Enhanced Learning. The desk research is focused on work produced in the frame of FP6 and FP7 European programs, in the area of Information and Communication Technologies. It concentrates in technologies that support existing forms of learning, and also in technologies that enhance new learning paradigms. This approach includes already adopted and successfully piloted technologies. The elaboration of the desk research had three main parts: firstly, the collection of documents from CORDIS and other institutions related to TEL research; secondly, the identification of relevant terms appearing in those documents and the elaboration of a thesaurus; and thirdly, a quantitative analysis of each term occurrences. Many of the identified technologies belong to the fields of interactive multimedia, Human-computer Interaction and-or related to recommendation and learning analytics. This study becomes a thorough review of the current state of these fields through the actual development of R&D European projects. This research, will be used as a basis to better understand the evolution of the sector, and to focus future research efforts on these sectors and their application to education.**

***Keywords*— Interactivity, Multimedia, R&D European projects, ICT and learning, emerging technologies**

I. Introduction

Trends and hot research topics in a specific field are reflected on the research areas promoted by public and private funding programs. This is the case of the Framework Programs launched by the European Commission that "*bundles all research-related EU initiatives together under a common roof playing a crucial role in reaching the goals of growth, competitiveness and employment*" [35]. Therefore, the identification of the most repeated research topics in projects funded by FP6 and FP7 leads to the identification of the most relevant research topics in Europe since 2002. The work presented in this document focuses on the educational field, and aims to identify the most relevant technologies that have impacted and will impact education in the near future. It is part of HoTEL, a European project that will provide a methodological framework to increase the impact of technological innovations in the educational field.

The desk research is focused on work produced in the frame of FP6 and FP7 programs (projects and Networks of Excellence), in the area of Information and Communication Technologies (ICT). The identified trends have been complemented by those mentioned in related works such as the reports published by the Institute for Prospective Technological Studies (IPTS), and the Horizon Reports produced by the New Media Consortium (NMC). The result is a landscape of the currently most relevant research topics in Technology Enhanced Learning (TEL), and the areas of learning in which these technologies are being applied.

Being one of the goals of this paper the identification of already adopted technologies for learning, we have reviewed the existing literature in order to identify those aspects of TEL that are considered effectively adopted or planned to be adopted in the near future. In particular, we have focused on review studies from the IPTS, who gathered their information from experts workshops, field consultations and desk research. Thus, they provide a complete view of current state of TEL in the European countries.

Another aim of this paper is to identify those technologies that will impact future education. For this purpose, we have focused the analysis of the different editions of the Horizon Report (i.e. Higher education, K-12 and museums) produced by the NMC.

This document is structured as follows, Section II describes the methodology used to perform the desk research and Section III presents the thesaurus used as reference. Sections IV, 0 and VI analyse the information from different perspectives: research trends, research areas and application learning areas, respectively. Section VI.H elaborates on the analysed Networks of Excellence (NoE). Next, Section depicts the future applications of the presented study and,finally, Section VIII presents the conclusions of the study.

II. Methodology

A. Data Sources

This desk research is aimed at identifying technologies enhancing new forms of learning, specially focusing on the research produced in the frame of EU funded programmes. However, for the elaboration of this document we have also considered other information sources.

In particular, we have analysed the EU research projects and NoEs funded by the FP6 and FP7 programs, and studies and reports from the IPTs and the NMC.

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1) FP6 and FP7 projects

As stated in [35], the CORDIS repository stores information about research projects funded by the European Union which are carried out by European, research institutions such as commercial organizations, research institutes and universities.

The CORDIS repository stores the project information once the agreement has been signed, and, if there is a change in the contract, updates the stored information upon specific request. The records remain in the repository after the project has ended. Not all projects contain the same set of information fields, however, there is an overall homogeneity that allows bulk retrieval and classification of projects information.

2) FP6 and FP7 Networks of Excellence (NoE)

Information about NoEs is stored and structured in CORDIS in the same way as in the case of the projects. However, a NoE project should not be strictly considered as a research project. Therefore, NoEs have been analysed separately from projects, and they are described in order to complement the conclusions extracted from FP6 and FP7 projects.

3) Institute for Prospective Technological Studies (IPTS)

The IPTS is one of the seven scientific institutes of the European Commission's Joint Research Centre (JRC). The studies carried out by the IPTS lead to the publication of reports, which are focused on specific scientific and technical issues. These reports (around 700) are publicly available for consultation, being some of them quite aligned with the goal of this desk research. Therefore, they have been considered as one of the sources for our analysis.

4) The New Media Consortium (NMC)

For the sake of this desk research, the most popular report offered by NMC: the Horizon Report. Annually published, it is "*a decade-long research project designed to identify and describe emerging technologies likely to have an impact on learning, teaching, and creative inquiry in higher education*".

Since the objective of the Horizon Reports is quite aligned with the goal of this desk research, they have been considered as one of the sources of our analysis.

B. Selection criteria

1) FP6 and FP7 projects and NoEs

From all the FP6 and FP7 projects available for consultation at CORDIS[1], we have selected those particularly interesting in the field of Technology Enhanced Learning. At the CORDIS page, we used the simple search interface as follows:

- Search terms: education, TEL, learn, learning, teach, teaching, train, training and school
- Framework programme: FP6 and FP7 checked.

We reviewed the description of the found projects and discarded those that did not fit with the desk research goals. For example, the *3D VIVANT* project was in the results set, but it was discarded because it is not directly related to education. As a result of this manual review, 102 projects were selected.

[1] http://cordis.europa.eu/fp7/ict/projects/home_en.html

The collection of 102 projects used for this desk research contained 7 Networks of Excellence. In a second review round, we examined the project descriptions in more detail and assigned several keywords to each project. More details about the keywords assignment are given in subsection C. As we read the project descriptions more carefully in this second round, more projects were discarded, containing the resulting set a total of 86 projects.

2) Institute for Prospective Technological Studies

From all the reports available at IPTS, we have focused on those regarding ICT and TEL. Therefore, we have filtered the number of documents by applying the criteria described as follows:

- Using the search engine provided at the web page [25], we have restricted the reports to those matching the keyword "ICT".
- Then, we have manually reviewed the project descriptions, and we have selected those that explicitly mention education.
- Finally, we have reviewed the reports given the summary of e-Learning related projects [26] and added them to our selection.

3) The New Media Consortium

In this desk research, we have used the NMC Horizon Reports to analyse trends and predictions on ICT and education. We considered the reports produced since 2009, because older reports are no longer relevant in the identification of trends.

C. Analysis

1) FP6 and FP7 projects

It was the authors' opinion that the *Subjects* field (a classification of projects on thematic areas provided by CORDIS) does not offer sufficient information of the project's research topics. For example, the ELEKTRA project aims at the development of an educational game, which is hardly outlined by its subjects (education, training - information processing, information systems-telecommunications).

Thus, the first task was to obtain a more descriptive set of keywords to summarize each project topics. This was manually done by the authors: firstly, reviewing the project description; secondly, writing keywords that matched with the description. A combination of the identified terms with the terms extracted from the IPTS and NMC reports resulted in the elaboration of a thesaurus that guided the classification of the research topics and the areas of learning they support, to be presented in Section III.

The identified NoEs have been separately discussed, and they are described in Section VII in order to complement the analysis of the projects.

2) NMC and IPTS reports

All NMC Horizon Reports follow the same structure: they choose six different technologies and classify them by the expected time for adoption. Three classifications are available:

"one year or less", "two to three years" and "four to five years". For each identified technology, the report includes an executive description, a discussion of its relationship with education, and a collection of examples that use technology in the educational field. For the purpose of this desk research, we have compiled all the identified technologies in the reviewed reports, also considering its field of application (given by the report in which they appear) and the time period on which the prediction was made.

The IPTS reports do not follow such a fixed structure and the way the information is presented depends on the specific objective of the report and the project that frames the document. Thus, it is not possible to extract the information from these documents with the methodological approach adopted in the case of NMC. Due to this, and considering the nature of IPTS reports, they have been used to take note of the technologies they explicitly mention. In other words, to determine which technologies were considered relevant for their studies.

Information collected from both NMC and IPTS reports were used in Section IV to analyse research trends in the TEL field, and to perform a time based analysis of the TEL predictions.

III. ICT Thesaurus Used As Reference

During the analysis of the documentation, a number of technologies have been identified. In some cases, the same technology was mentioned using different terms, in other cases, different technologies are related among themselves so that they can be clustered in research areas. With all the identified terms and technologies, we have elaborated a thesaurus that classifies them by research topics and the areas of learning they support, finds synonyms and allows for a more systematic analysis. The thesaurus has been created as follows:

Firstly, the descriptions of all the selected FP6 and FP7 projects were manually reviewed, assigning them keywords. The keywords identified the main and secondary technologies used in the project, as well as the area of learning where the project applies. The reviewers were asked not to use a pre-defined set of keywords, but to be spontaneous. The technologies that appeared at IPTS and NMC reports were also considered, and this time the names were collected as they appeared in the documents. Note that the manual nature of the keywords selection could have introduced an involuntary bias on the study.

Then, synonyms were identified from all the keywords collected at the previous steps, reducing the number of available terms, and translating the spontaneous keywords assigned in the first step, into a collection of more formal terms. Finally, the related technologies and areas of learning were grouped into clusters. The creation of the clusters was guided by the research areas identified in all the reviewed documents and the expertise of the authors of the help desk.

The thesaurus, shown at appendix A, has been used for the classification of FP6 and FP7 research projects. It is divided in two main categories (technologies and areas of learning), which are divided into subcategories (also referred as clusters). The technologies related to Artificial Intelligence and Interactive Multimedia play a transversal role in the thesaurus. That is, these technologies are represented in most of the clusters, but there is no cluster specifically dedicated to them.

IV. Trends In Technology Enhanced Learning

This section presents the review of the NMC and IPTS reports and the conclusions extracted from them. The reviewed documents can be classified in three types:

a) IPTS review reports: this type of documents usually review the existing examples and are focused on past research.
b) IPTS reports identifying trends: documents such as [29], [31] or [33] have the goal of identifying trends that will build the future of TEL.
c) NMC reports: the Horizon Report charts the landscape of emerging technologies and provides a complete collection of the technologies that are expected to impact education in future years.

The analysis resulted in Table I, which summarizes the occurrences of relevant keywords in the reports. In the table, each column represents one of the above mentioned document types, and each row refers to one of the clusters identified in the created thesaurus. Each cell's content determines whether or not a given cluster is mentioned in the corresponding type of documents. For example, the reference to [24] in the first row, second column, means that this document mentions one of the keywords belonging to the UC cluster. Mentions per document, are ordered in decreasing occurrence order per cluster. Giving an idea of the number of reports in which they appear, and their relevance in them.

Note that cells in the table may contain two or more references to the same document. This is because we placed one reference to the document for each different mentioned keyword. For example, document [4] mentions 'digital preservation' and 'electronic publishing', both classified into the CRT cluster, therefore, two occurrences of the reference to this document are in the corresponding cell.

If we consider a technology to be more relevant the more occurrences it has in the reports and the more number of documents where it is mentioned, three different behaviours appear on the table: (i) technologies relevant in past research, but not so relevant in the predictions; (ii) technologies that are as relevant in the past research as they are in the predictions; and (iii) technologies more relevant in the predictions than in past research.

The only cluster that might fall in (i) category is PA, which is mentioned in IPTS predictions but not in the Horizon Reports. In group (ii) we find WEB and SAS clusters. The relevance of web based systems in past TEL research cannot be denied, and the semantic web has counted with the support of the W3C. Finally, most of the clusters fall in (iii) category.

TABLE I
MENTIONS TO THE IDENTIFIED CLUSTERS IN IPTS AND NMC REPORTS

Clusters	IPTS Review Reports (past)	IPTS Trend Reports (future)	NMC Horizon Reports (future)
Ubiquitous computing (**UC**)	[30] [30] [24]	[31] [31] [31] [33] [33] [29]	[4] [4] [4] [5] [5] [5] [9] [9] [9] [6] [6] [7] [7] [8] [8] [3] [3] [10] [11] [12] [1] [2]
Web 2.0 based tools and systems (**WEB**)	[24] [24] [24] [13] [30]	[29] [29] [29] [29] [33] [33] [33]	[7] [7] [7] [2] [2] [5] [5] [3] [6] [8] [12]
Games and Virtual Worlds (**GVW**)	[30] [24]	[31] [31] [31] [33] [33] [29] [29]	[2] [6] [9] [10] [11] [12]
Augmented reality (**AR**)		[29] [31] [33]	[1] [3] [4] [6] [8] [10] [12]
Other technologies (**OT**)	[21] [19]	[33] [33] [23]	[11] [11] [1] [10] [12]
Human computer interaction (**HCI**)		[31] [33]	[1] [3] [6] [8] [9] [10]
Access-to-content related technologies (**CRT**)		[29] [31] [33]	[4] [4] [1] [2] [3]
Learning Analytics (**LA**)		[33] [33]	[1] [2] [9] [10] [11]
Environments and technologies for collaboration (**CSCL**)	[30]	[29] [33]	[7] [7] [12] [2]
Personalized, adaptive technologies (**PA**)	[30]	[31] [31] [31] [33] [29]	
Semantic-aware systems (**SAS**)	[30] [30]	[33]	[5] [8]

It is worth to mention the case of LA, AR and HCI. Such technologies have recently appeared in the TEL world, so they receive no mention in past TEL research. These clusters are highly related to artificial intelligence and interactive multimedia, which emphasizes the relevance of those technologies in the learning world. Surprisingly, CRT cluster has no presence at all in past research reviews. MOOCs and OpenCourseWare will definitively impact TEL research in the future years.

Artificial intelligence technologies play an important role in clusters such as UC, LA and SAS. This emphasizes their relevance in current research and in future trends. Also, interactive multimedia

A. Time analysis of NMC predictions

In this subsection we have visually represented the predictions made by NMC reports in a time line, in order to determine how they evolved over the years. We provide three different figures: one for higher education, another one f or K-12 education (the US equivalent to the 'schools' area of learning), and the last one for museums.

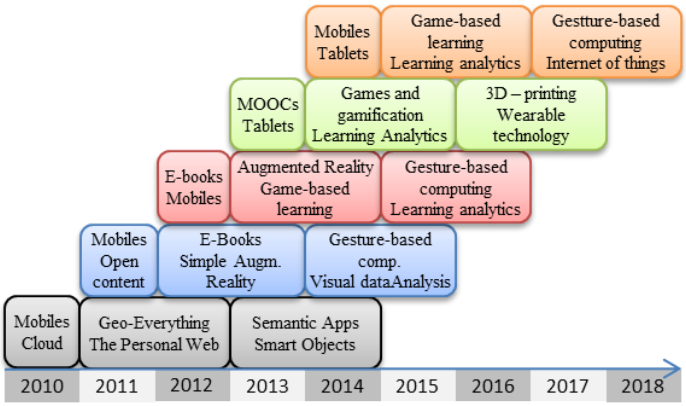

Fig. 1: NMC predictions for higher education

Fig. 1 shows the predictions for higher education. The following observations can be made:

- Since 2009, mobiles adoption is expected to occur in "one year or less". The prediction is repeated year by year but the goal does not seem to be achieved. In the last two editions of the report, 'mobiles' are being replaced by 'tablets'.
- Learning analytics appeared in the 2011 report and, since then, they are expected to have an impact on higher education sooner or later. The same can be said about games.
- Massive Open Online Courses suddenly appeared in the 2013 report, and are expected to have a clear and immediate impact in higher education.
- The 2013 report introduces new and interesting concepts, such as 3D-printing and wearable technology.

From Fig. 2, which shows the predictions for K-12, the following observations can be made:

- Mobiles are expected to be adopted, but the prediction is less "aggressive" than in higher education. However, it seems to be an always live promise.
- Game based learning is expected to play a relevant role in K-12 education. This is coherent with Section VI.A.1).

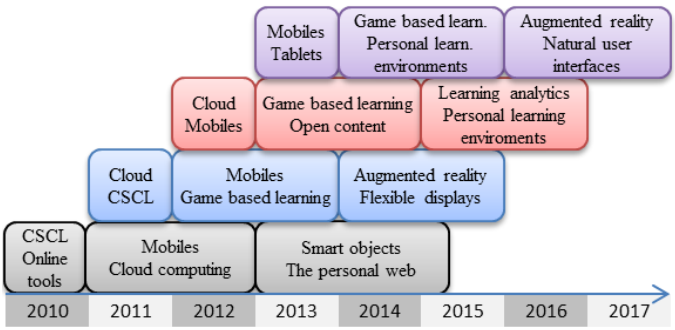

Fig. 2: NMC predictions for K-12

From Fig. 3, which shows the predictions for museums, the following observations can be made:

- Innovative methods to interact with the information are subject of research. Thus, augmented reality, gesture-based computing and natural user interfaces are expected to be adopted. This is consistent with Section VI.I.
- As it happened in higher education and K-12, mobiles are expected to be adopted in the next year (since 2010), but the goal does not seem to get accomplished.

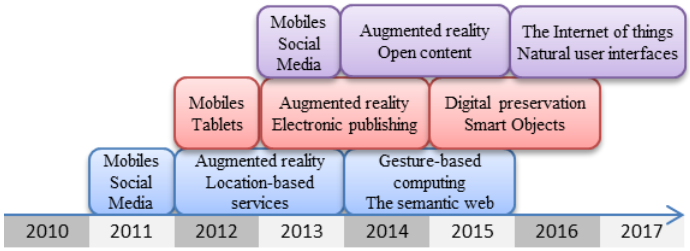

Fig. 3: NMC predictions for museums

The above analysis emphasizes how interactive multimedia is expected to impact the learning world, mainly by means of educational games and augmented reality. Also, artificial intelligence is essential part of learning analytics and is therefore expected to be widely used in higher education and other areas of learning.

V. ICT Research At FP6 And FP7

In this section, we first provide a quick overview of the topics researched in the projects funded by the European Commission within the FP6 and FP7 programs and, after that, we present a cluster-by-cluster analysis based on the thesaurus of Section III.

A first approach to determine the most frequent research topics in the analysed projects was to study the most repeated terms in the project summaries provided by CORDIS. However, the analysis revealed that the most relevant words were 'learning, project', 'knowledge, research', 'support' and 'technology', being therefore difficult to get an overview of the research topics with this method.

The second approach was to analyse the most repeated terms in the manually assigned keywords, which were selected from the thesaurus. The resulting set contains much more technology related terms, and it is therefore more feasible to obtain a quick overview of the most relevant technologies. The terms that appear the most are shown in

TABLE II. It can be seen that technologies related to learning games, content management, interfaces, collaborative environments or semantic analysis (just to mention a few) are frequent topics in FP6 and FP7 research projects, and therefore play a relevant role in recent research on Technology Enhanced Learning.

TABLE II
MOST REPEATED KEYWORDS IN REVIEWED PROJECTS

Term	#	Term	#	Term	#
semantic-aware technologies	11	human computer interaction	5	learning standards	4
Games	10	context-aware systems	5	grid computing	4
learning management systems	9	personalized content presentation	5	content repositories	4
collaborative environments	7	web 2.0	4	augmented reality	4
social networks	5	personal learning environments	4	mobile devices	4

Table III shows the most repeated keywords within the different identified clusters. A project may be related to different clusters, and thus can contain keywords associated to several of them. As a consequence, the table allows the identification of how clusters are related among themselves. Next subsections give an overview of each cluster and depict their mutual relationships. For presentation purposes, some of the keyword lists in Table III have been truncated.

A. Web 2.0 based tools and systems (WEB)

The traditional web, based on static HTML pages and with no chances for interaction, experienced a big change with the widespread use of technologies that allowed dynamic generation of web content. With such approach, the users became able to interact with the web, easily writing and publishing their own content. Then, the traditional web shifted to the web 2.0. Such change also impacted educational systems, so that learners were able to interact with the content and with peers. The "web 2.0 based tools and systems" cluster refers to those learning technologies whose typical interface is web based, designed or not for educational purposes.

According to Table III, the keywords in this cluster show that projects related to WEB are also related to SAS (7 occurrences of 'semantic-aware technologies'), UC (4 occurrences of 'mobile devices', 3 of 'context-aware systems'). LA and PA are also related to the WEB cluster.

B. Ubiquitous computing (UC)

Ubiquitous (or pervasive) computing refers to a type of human-computer interaction where the information processing is integrated into everyday objects and activities. The term ubiquitous computing was coined by Mark Weiser in 1988, and the topic has received much attention since then.

Ubiquitous computing is related to distributed computing, mobile computing, sensor networks, human-computer interaction, and artificial intelligence. There are many ways in which information can interact with people. For example, from a non-intrusive perspective, ambient displays may react to events by changing their decoration; another example could be the TV volume automatically turned down when a visit enters the living room.

Ubiquitous learning refers to the support of anytime-anywhere learning, that is, when the specific goal of the ubiquitous technology is to support the learning process. Intuitively, this technology fits with informal learning approaches, but also applies to formal learning strategies such as shifting the classroom, or activities involving different spatial locations.

Table III shows how the UC cluster is quite related to PA (2 occurrences of 'personalized content presentation') and WEB (2 occurrences of 'social networks').

C. Augmented reality (AR)

Our lives are increasingly surrounded by technology, and it is difficult to think of a daily task that is not supported by any device or gadget. We use computers for work and leisure, and we communicate with others by using smartphones which integrate a lot of functionalities. In this scenario we can use the displays of our devices to view the real world, but another interesting usage is to augment our view of the real word by mixing such view with elements drawn by the computer. Such mixture of the real world with virtual elements, only visible through the corresponding display, is what we call augmented reality.

Such technology has been exploited in games, e-commerce and also learning. The information that we capture with our senses can be enhanced with augmented reality techniques, with the corresponding impact in the learning process.

Projects in the AR cluster are quite related to HCI, with occurrences of 'human-computer-interaction', 'haptic devices' and 'gesture-computing'. Keywords such as 'immersive virtual worlds' or 'simulations' also reveal a kind of overlapping with the GVW cluster.

D. Access-to-content related technologies (CRT)

Before the digital revolution that came with the Internet, the production of educational content was hardly affordable by teachers, who used textbooks created and sold by third parties. However, digital content is easier to create and, more important, easier to reuse. Reusability of learning content increases the efficiency of the authoring process, so the definition of methods for an efficient creation, distribution and use of learning content has been on hot topic in educational research.

Content repositories store large amounts of learning objects, which can be used to compose new and richer learning objects. Interoperability among repositories enables a more agile distribution of such learning objects. Such agile distribution of content required new copyright strategies, compatible with the surrounding technology. Thus, in 2002 the OpenCouseWare initiative (course lessons created at universities and freely published via the Internet) was launched at the MIT and was soon reinforced by the launch of similar projects at different universities. Also, the Creative Commons license defined the copyleft (as opposed to copyright), that provided legal mechanisms to authors to allow free access to their content. The last step towards such open culture is the MOOC movement (Massive Open Online Courses), consisting on online courses (not only content) freely offered via the web. MOOC is one of the current buzzwords in educational research.

Personalization and adaptation, possibly enabled by semantic analysis, are promoted by the large availability of learning content. Thus, the CRT cluster is mainly related to SAS, PA and WEB.

E. Human computer interaction (HCI)

Human–computer Interaction (HCI) involves the study, planning, and design of the interaction between people (users) and computers. It is often regarded as the intersection of computer science, behavioural sciences, design and several other fields of study. Strictly speaking, HCI research brings on innovative computer interfaces, including new way of presenting the information and new ways to introduce human's input.

The HCI cluster is quite related to AR, with 2 occurrences of 'augmented reality'.

F. Learning Analytics (LA)

While we interact with computers, we produce large amounts of information that can be stored and processed. The analysis of such information has been used in fields such as e-commerce to determine the customers' personal habits, and vendors use this technique to offer them personal recommendations, usually aimed at increasing the benefits.

As computers enter in the educational world, learners' activities can be traced and stored and this fact enables the use of the abovementioned analysis techniques. Thus, learning analytics is defined as the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs.

According to Table III, the LA cluster is mainly related to WEB and GVW. However, LA is so recent in the TEL field that not so many projects have been funded in the topic. As a result, there is no meaningful overlap with other clusters.

G. Games and Virtual Worlds (GVW)

The term virtual world is largely used as a synonym of 3-D virtual environment. In such environments, the user plays the role of an avatar and "lives" inside this world. Virtual worlds have evolved from simple text-based interfaces to rich 3-D environments that allow for an immersive user experience, where a real person interacts with objects in computer simulated environments.

Virtual worlds provide means to augment or enhance the way we receive information and have received the interest of educational researchers. In them, interaction with peers is an important part of the environment, so they enable the collaborative and cooperative learning strategies. User engagement in the virtual world can be achieved by gamification techniques, thus enabling serious games to be developed for educational purposes.

Projects aimed at the research of educational game are also usually complemented by very different technologies. As a result, GVW cluster is related to almost all other clusters in the proposed thesaurus.

TABLE III
KEYWORD OCCURRENCES GROUPED BY CLUSTER

LA		GVW		CSCL		WEB		CRT		PA	
information visualization	3	Games	9	collaborative environments	7	learning management systems	8	content repositories	4	learning management systems (WEB)	5
learning analytics	3	immersive virtual worlds	3	computer supported collaborative learning	2	semantic-aware technologies (SAS)	7	open source content	3	personalized content presentation	5
social networks (WEB)	1	simulations	2	online communication tools	2	social networks	5	digital preservation	3	semantic-aware technologies (SAS)	4
social media (WEB)	1	Mobiles (UC)	1	tactile interfaces (HCI)	1	mobile devices (UC)	4	semantic-aware technologies (SAS)	2	personal learning environments	4
online applications for teaching (WEB)	1	information visualization (LA)	1	semantic-aware technologies (SAS)	1	learning standards	4	personalized content presentation (PA)	2	collaborative environments (CSCL)	3
learning management systems (WEB)	1	content repositories (CRT)	1	information visualization (LA)	1	web 2.0	4	grid computing (WEB)	2	electronic tutors	3
Games (GVW)	1	adaptive learning system (PA)	1	electronic tutors (PA)	1	grid computing	4	web interfaces (WEB)	1	web 2.0 (WEB)	2
data mining	1	virtual environments	1	attention management (PA)	1	context-aware systems (UC)	3	super rich online repositories	1	Games (GVW)	2
virtual environments (GVW)	1	tactile interfaces (HCI)	1	artificial intelligence (PA)	1	learning analytics (LA)	3	serious games (GVW)	1	adaptive content	2
student monitoring	1	student monitoring (LA)	1	ubiquitous computing (UC)	1	personal learning environments (PA)	3	semantic interoperability (SAS)	1	emotion-aware systems	2
semantic-aware technologies (SAS)	1	social networks (WEB)	1	Telepresence	1	Interoperability	3	learning standards (WEB)	1	context-aware systems (UC)	2
multimedia content (WEB)	1	Interfaces (HCI)	1	social networks (WEB)	1	collaborative environments (CSCL)	3	content creation	1		
mobile devices (UC)	1	gesture based computing (HCI)	1	personal learning environments (PA)	1						
Interfaces (HCI)	1	emotion-aware systems (PA)	1	immersive virtual worlds (GVW)	1						
e-portfolio (WEB)	1	collaborative environments (CSCL)	1								
computer supported collaborative learning (CSCL)	1	augmented reality (AR)	1								

UC		AR		OT		HCI		SAS	
context-aware systems	5	augmented reality	4	smart-tv	1	human computer interaction	5	semantic-aware technologies	11
mobile devices	4	human computer interaction (HCI)	2	semantic web (SAS)	1	gesture based computing	3	learning management systems (WEB)	4
ubiquitous computing	3	immersive virtual worlds (GVW)	1	context-aware systems (UC)	1	haptic interfaces	2	translation technologies	2
personalized content presentation (PA)	2	haptic interfaces (HCI)	1	wearable technology	1	augmented reality (AR)	2	personal learning environments (PA)	2
smart spaces	2	gesture based computing (HCI)	1	Interfaces (HCI)	1	Interfaces	2	content repositories (CRT)	2
social networks (WEB)	2	Simulations (GVW)	1	interactive whiteboards	1				
Mobiles	2	merge virtual and physical worlds	1	future classroom (UC)	1				
pervasive computing	2	enriched interfaces (HCI)	1	ambient intelligence (UC)	1				
pervasive technologies	2								

H. Environments and technologies for collaboration (CSCL)

The ability to carry out an effective collaboration is a transversal skill that, thanks to constructivist learning approaches, receives lots of attention in the educational research world. Collaboration involves interaction between humans which is, by nature, quite unstructured. Such interaction can be supported by computers. When collaborative techniques are used to foster learning with the support of computers, we call it CSCL (Computer Supported Collaborative Learning).

The case of the CSCL cluster is similar to GVW. That is, projects in this cluster are also usually complemented by very different technologies, resulting in relationships with many other clusters. Among them, PA seems to present a stronger overlapping.

I. Semantic-aware systems (SAS)

In computer science, a semantic reasoner is a piece of software able to infer logical consequences from a set of asserted facts. These facts (called semantic metadata) are usually represented by a formal language such as RDF and refer to textual or multimedia objects stored in a repository, and to users' information.

In the educational field, semantic analysis research is oriented towards the understanding of natural human language (as opposite to computer languages) in order to provide better search mechanisms on learning content, and also to provide better interaction with computers.

The SAS cluster is related to WEB (4 occurrences of 'learning management systems'), PA and CRT.

J. Personalized, adaptive technologies (PA)

According to the learning styles theories, different students achieve learning with different methods, and prefer different content types. However, computer systems usually make no difference among users and present the same content to every student, structured in the same sequence, and offering the same interface.

The personalization and/or adaptation of the learning process may cover the different needs of the different students, so they can achieve learning in a more efficient manner.

The PA cluster is quite related to WEB (5 occurrences of 'learning management systems'), SAS (4 occurrences of 'semantic-aware technologies') and CSCL.

K. Other technologies (OT)

This cluster includes all those technologies that are somehow related to the analysed projects and documents, but have not been included in the defined clusters.

Not so many projects in this cluster have been funded by the FP6 and FP7 programs, however, it is interesting because it presents not so frequent emerging technologies, that can be promising for TEL research. For example, no project related to 3D printing have been found, while the last NMC report mentions such technology in its predictions.

Other interesting technologies are wearable interfaces (also related with UC cluster), or e-books as an innovative way to deliver learning material.

In this section, we depict the use of ICT in Education, in which technologies related to interactivity, multimedia, and artificial intelligence, become a mainstream in the application context. In Table III, we highlight the topics of highest relevance, in which semantics, collaboration, social networks, HCI, context-aware, web 2.0, and personalisation, combined, score 46 out of 85, meaning a 54% of the total keywords. This combination of key concepts related to interactive multimedia and artificial intelligence become a major guideline for current and future research and development projects.

VI. Areas Of Learning

This section analyses the areas of learning to which the technology is being applied. In some projects the proposed system is aimed to a very specific field. For instance, the ELEKTRA project was focused on the development of a game to help teaching grade 8-level optics. On the contrary, the technology researched by other projects, such as E-LEGI, claims to be pedagogically neutral. That is, it could be used in any learning situation.

According to the thesaurus presented in Section III, six different areas of learning were identified:

- Formal education
- Non-formal learning
- Workplace learning
- Museums
- Unspecified field
- Others

The analysis presented in this section is based on

Table **IV**, which represents the cluster occurrences grouped by areas of learning, an asterisk at column C, row R, means that there is a project that research technological cluster C, and applies to area of learning R.

A. Formal education

Formal education corresponds to a systematic, organized education model, structured and administered according to a given set of laws and norms, presenting a rather rigid curriculum as regards objectives, content and methodology [36].

For the convenience of this study, we have divided the formal education learning area in three main parts: schools (primary education), secondary education, and higher education.

1) Schools

Table **IV** shows the list of projects that research technologies for schools. The most repeated cluster is GVW, related to games and virtual worlds, which seems logical, since games are used to increase learners' motivation and children are especially prone to like games. Therefore, games appear to be a promising technique to improve learning at schools. Another relevant technology for schools is human computer interaction

(HCI). That is, new interfaces offer more intuitive interactions with computers, and allow children (not yet used to other interfaces) to learn more intuitively.

2) Secondary education

The most relevant technologies for secondary education are the Web and learning analytics. On the other hand, promising techniques such as augmented reality and human computer interfaces are not even mentioned, and there are only two occurrences of ubiquitous computing techniques. It could be argued that innovation in secondary education is limited by the classroom scenario, where mobile phones are in most cases not even allowed.

3) Higher education

In the case of higher education, the Web is the most researched technology, with personalization techniques playing a relevant role. Access-to-content technologies are also relevant in the field. This is logical since initiatives such as OpenCourseWare and MOOCs initially started at universities.

B. Non-formal learning

Educative processes endowed with flexible curricula and methodology, capable of adapting to the needs and interests of students, for which time is not a pre-established factor but is contingent upon the student's work pace, certainly do not correspond to those comprised by formal education, but fit into the so-called non-formal education [36].

Non-formal and informal education terms are frequently used indistinctly. Without entering in a debate of the appropriateness of each term, in this study we have identified that projects that focuses on informal learning are in fact related to what we have defined as non-formal learning. Thus, these two terms have been used indistinctly.

In the field of non-formal learning, the Web is the most researched technological cluster, and research on access to content technologies also plays a relevant role. It sounds logical since non-formal learners are usually intrinsically motivated to learn, so what they need is a good collection of learning materials (provided by the CRT cluster) and a method to interact with such material at their own pace (provided by the WEB).

C. Workplace learning

By 'workplace learning' we refer to those strategies applied by companies in order to allow their employees

TABLE IV
CLUSTER OCCURRENCES IN AREAS OF LEARNING

	WEB	UC	AR	CRT	HCI	LA	GVW	CSCL	SAS	PA	OT	TOTAL
Schools	**	*	*	**	***	*	*****	**	**	***	*	23
Sec. Ed.	****	**		*		****	***	*	**		*	18
High. Ed.	******	*		***		*		**	***	****		20
Non-formal	******	**	*	***			*	*	*	*		16
Workplace	***	*					**	****	**	*****		17
Museums		*	*		**	*	**					7
Not specified	******	***	*	*	***	*	**	**	**	*****	*	27
Not exp. for learning	*******	********	*	*****	***	*		*	****		*	31
Other	*****	*	*		***		***		**	***		18

D. Workplace learning

By 'workplace learning' we refer to those strategies applied by companies in order to allow their employees acquire new competences related to their position.

Environments for collaborative learning are the most researched technologies in this area of learning. Furthermore, this is the area of learning that gives more priority to collaboration technologies (CSCL). In other words, collaborative and cooperative skills are highly demanded at the workplace. On the other hand, personalization techniques are also relevant in this area.

E. Museums

Museums could be considered as a vehicle for non-formal or informal learning. However, the development of new methods to engage visitors by mixing leisure and information delivery has unique characteristics in museums, and several projects are aimed to this specific field. Thus, we have considered museums as an area of learning different to non-formal learning.

Few projects are explicitly devoted to research technology for museums. Among them, human computer interaction techniques and Virtual Worlds are the most relevant technological clusters. In museums, it is important to engage visitors, which requires innovative methods to interact with the exhibits, therefore, research is oriented toward this goal.

F. Unspecific field

The area of learning to which a project applies was determined by extracting such information from the project description, as published at CORDIS. However, there are

some project descriptions in which such information is not explicitly stated, so we were not able to classify to which area of learning they belong. This group of 'unspecific field' projects, is divided in two subgroups: firstly, projects whose goal is explicitly oriented towards educational purposes, but do not state to which area of learning they belong. We have classified these projects as 'not explicit area of learning'. And secondly, projects that matched with the selection criteria, but are not explicitly aimed at educational purposes. We have classified these projects as 'not explicitly for learning.'

1) Not explicit area of learning.

This category is composed by projects regarding educational research, but that do not explicitly specifying to which area of learning they apply.

The Web is the most relevant researched technology in this type of projects. As it also happens in the higher education cluster, personalization techniques are researched as a way to improve the educational face of the web. It can be argued that those projects that do not explicitly state their area of application are generically designed, and can be adapted to different educational settings. It is therefore important to achieve a high degree of personalization and adaptation.

2) Not explicitly for learning

Some projects are related to technologies to might be applied to educational settings, but it is not explicitly stated on the project description. In those cases, we classified these projects as *not explicitly for learning.*

Ubiquitous computing (UC) is the hot research topic in this type of projects. Surprisingly, this topic has no major relevance in the rest of the areas of learning. It could be argued that ubiquitous computing is a promising research field, but it is not still clear how to apply it in educational settings.

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K. Other

Finally, there are some cases where the project description states an educational purpose, but the application area does not fit to any of the previous criteria. Topics covered in this 'others' area of learning are digital libraries, social inclusion, conflict resolution, learners with specific needs, music institutions and educational curriculum.

It can be seen that music education puts emphasis on HCI technologies to improve learning. Another observation is that

games are used as the vehicle that drives motivation in projects toward social inclusion.

VII. Networks Of Excellence

- AIM@SHAPE: by recognizing the relevance of multimedia objects (called shapes) in different application fields such as scientific simulations or edutainment, this NoE promoted semantic-based shape representations and semantic-oriented tools to acquire, build, transmit, and process shapes with their associated knowledge
- PROLEARN: this NoE worked in personalized adaptive learning and interactive media, with learning resources connected to real-world settings and reusable in different contexts. It investigated issues especially relevant for professional training in SME's and larger companies.
- MUSCLE: aims at harnessing the potential of machine learning for the automatic semantic annotation of multimedia content, creation of interfaces for the exploration of complex content, improvement of interoperability and exchangeability. This NoE also aims at the distribution of such technology to the stakeholders, such as educational institutions.
- KNOWLEDGE WEB: Supporting the transition process of Ontology technology from Academia to Industry is the main and major goal of this NoE. This is achieved by providing support to incorporate this technology, developing high-class education in the area of semantic web, and researching new uses of semantic web and web services.
- GaLA: This NoE that acknowledges the potential of serious games in the support of the learning process. It aims at the integration and harmonization of research activities across European institutions, as well as at the organization of joint research activities and the dissemination of serious games to support learning.
- IRIS: Interactive Storytelling is a major endeavour to develop new media which could offer a radically new user experience, with a potential to revolutionise digital entertainment. European research in Interactive Storytelling has played a leading role in the development of the field, and this creates a unique opportunity to strengthen its position even further by structuring some of its best actors within a Network of Excellence. IRIS (Integrating Research in Interactive Storytelling) aims at creating a virtual centre of excellence that will be able to achieve breakthroughs in the understanding of Interactive Storytelling and the development of corresponding technologies.
- STELLAR: represents the effort of the leading institutions and projects in European TEL to unify our diverse TEL community. This Network of Excellence is motivated by the need for European research on Technology-Enhanced Learning (TEL) to build upon, synergize and extend the valuable work we have started by significantly building capacity in TEL research within Europe, which is required to allow the European Union to achieve its goals via the Bologna Agreement and the execution of the Lisbon Agenda. The European TEL agenda has been set for the last 4 years by the Kaleidoscope network - with a huge strength in pedagogy and scientific excellence, and the Prolearn network with a complimentary strength in technical and professional excellence. We see integrating this excellence and moving on to the higher strategic formation of policy based in leading research is the challenge for the next three years. STELLAR will move beyond the earlier networks by setting a new and critical foresight agenda for TEL via an annually reviewed Grand Challenge programme.

VIII. Future works and Applications

The research presented in this paper is part of the HoTEL European project, a Support Action that will propose a methodological framework to support technological innovations in the educational field, speeding up the innovation cycle. The presented work is an exploratory research, the output of which will serve as the basis for an online consultation, and a number of interviews with acknowledged experts in the field. The overall goal is to better understand how innovation takes place in the learning world, and to elaborate a map of the most relevant technologies that will affect education in the near future. This research is focused on technologies. Next steps include the identification of innovative pedagogical approaches, and the creation of a grassroots innovators network that will benefit from the HoTEL innovation cycle.

IX. Conclusion

This desk research has presented an analysis of the information from a total of 86 research projects and 7 Networks of Excellence funded by the European Union as part of the FP6 and FP7 programs. Also, we have considered the information from reports offered by the IPTS on the educational field, and the predictive Horizon Reports, produced by the NMC.

A detailed analysis of the compiled information has allowed to identify the most relevant technologies, and to produce clusters that group them by similarity. The following 11 different clusters were identified, many of them of the highest relevance to interactive multimedia and artificial intelligence:

1. Web 2.0 based tools and systems
2. Ubiquitous computing
3. Augmented reality
4. Access-to-content related technologies
5. Human computer interaction
6. Learning Analytics
7. Games and Virtual Worlds
8. Environments and technologies for collaboration
9. Semantic-aware systems
10. Personalized, adaptive technologies
11. Technologies that could not be grouped in any other

cluster.

The analysis showed that web based technologies are the most funded topic within EU programs. Furthermore, they are usually researched in combination with other technologies such as semantic technologies or personalized learning content. In fact, in some cases it is not obvious at all to make a clear distinction among the different clusters. The analysis also shows the upcoming interest of ubiquitous computing on learning, especially via mobile and tablet computing. Another interesting conclusion is the irruption of learning analytics, an approach that has recently appeared and is gaining momentum rapidly. The analysis also revealed which technology combinations are more frequent. For example, the new interfaces suggested in the field of Human Computer Information are usually researched in combination with augmented reality techniques.

Another focus of the analysis was the identification of learning areas in which the researched technologies can be applied. The following 4 areas were identified:

- Formal education (including primary, secondary and higher education)
- Non-formal learning
- Workplace learning
- Museums

We also considered projects that do not apply to any explicit area of learning, and also projects that do not even explicitly apply to learning, but whose researched technologies are aligned with TEL research.

The analysis shows the relationship among areas of learning and technology clusters, for example, games are mainly researched for their application in schools, while computer supported collaboration is the preferred topic for workplace learning. Furthermore, a number of projects not explicitly for learning research ubiquitous computing technologies, so it is expected that such technologies will impact in the near future of TEL research.

The IPTS and NMC reports (a total of 34 reviewed documents) reveal predictions on what technologies will be used in the near future of education. It is worth to note how mobile computing is always expected to be immediately adopted, but never seems to be mature enough for an authentic usage. The most recent predictions introduce new and interesting concepts, such as 3D-printing, the Internet of Things, learning analytics, massive online open courses, augmented reality and wearable technology.

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Dr. Luis de-la-Fuente-Valentín works as post-doctoral Senior Researcher UNIR. He is focused on the field of Technology-enhanced Learning, and a strong background in learning standards and specifications, learning analytics, information visualization, student centered learning systems, recomendations, mobile learning and gamification techniques. He works in European projects Intuitel and Hotel. He holds a PhD in Telematics Engineering

Aurora Carrasco works as Senior Project Manager at UNIR. She is Responsible for the R&D Projects Office. She has deep experience in European and International Programme and Projects Management (e.g. EC EuropeAid, World Bank, FP7, LLP), and extensive knowledge of the EC's Project Cycle Management (PCM), and in the preparation of international project proposals, and offers. She holds degrees in Biology (BSc and MSc with major in Environment and Education)

Kinga Kónya works as Media Officer of Research & Technology Projects at UNIR. She is responsible for the dissemination and communication of project objectives, research and development activities and results. In parallel, she works at the Postgraduate Department of UNIR. She holds a Bachelor's degree in French Studies (minor in Spanish Iberian-American Studies) and a Master's degree in International Economic Relations. She speaks Spanish, English, French and Hungarian.

Prof. Dr. Daniel Burgos works as Vice-chancellor for Research & Technology, and Director of Engineering at the International University of La Rioja. He is or has been involved in a number of R&D projects like, i.e. Intelleo, Hotel, Edumotion, Inspiring Science Education, EU-USR, Stellar, Gala, IntelLEO, Go-MyLife, Grapple, Unfold, ProLearn, TenCompetence, EU4ALL, NiHao, Kaleidoscope, Sister, ComeIn, Veritas, et cetera. He holds degrees in Communication (PhD), Computer Science (Dr. Ing), Education (PhD), and Business Administration.

APPENDIX A: THESAURUS USED AS REFERENCE

Categories	Subcategories	Keywords			
Technologies	Web 2.0 based tolos and systems (WEB)	web 2.0 online communication tools blogs podcasting eportfolio accessible web content e-portfolio	multimedia content web interfaces widgets integration distributed open infrastructure linked data service-oriented	online applications for teaching learning management systems learning standards interoperability cloud computing grid computing	social networks social media foaf online communities social network analysis social software
	Ubiquitous computing (UC)	ambient intelligence internet of things smart objects location based services ubiquitous computing	intelligent contexts pervasive technologies context-aware systems pervasive computing smart spaces	mobiles tablet computing mobile apps mobile devices	mobile learning geo-everything creative classrooms future classroom
	Augmented reality (AR)	augmented reality	simple augmented reality	merge virtual and physical worlds	
	Access-to-content related technologies (CRT)	open source content massively open online courses alternative licensing	super rich online repositories electronic publishing digital preservation	creative commons opencourseware	content repositories content creation
	Human computer interaction (HCI)	human computer interaction gesture based computing natural user interfaces	brain-machine interfaces 3-d holographic displays adaptable interfaces	haptic interfaces enriched interfaces interfaces	tactile interfaces voice interfaces
	Learning Analytics (LA)	data mining big data and learning analytics	learning analytics information visualization	student monitoring	visual data analysis
	Games and Virtual Worlds (GVW)	immersive virtual worlds computer generated simulations simulation of physical, chemical models	simulations for training virtual environments simulations	games game-based learning	serious games 3d virtual worlds
	Environments and technologies for collaboration (CSCL)	collaborative environments computer supported collaborative learning	telepresence	online communication tools	sincronous learning
	Semantic-aware systems (SAS)	semantic web metadata generation	natural language processing semantic-aware technologies	semantic interoperability	translation technologies
	Personalized, adaptive technologies (PA)	virtual mentors electronic tutors realtime assessment monitors artificial intelligence	attention management adaptive content smart learning content adaptive learning system	personalized content presentation recommender systems the personal web	personal learning environments roleswitching emotion-aware systems
	Other technologies (OT)	flexible displays smart-tv	e-books 3d printing	interactive whiteboards	wearable technology
Areas of learning	Formal education	higher education	secondary education	Schools	
	Non-formal learning	domestic learners	broad public	informal learning	lifelong learning
	Workplace learning	SME	industry	workplace	training
	Museums	museum			
	Unspecific field	not explicitly for learning	not specified		
	Other	music institutions digital library	learner with special needs educational curriculum	conflict resolution	social inclusion

APPENDIX B: LIST OF REVIEWED PROJECTS

Project reference	Acronym	Title
507740	CALIMERA	Cultural applications: Local institutions mediating electronic resources access
506811	AMI	Augmented Multi-party Interaction
507835	UNFOLD	Understanding Networks of Learning Design
1765	ACEMEDIA	Integrating knowledge, semantic and content for user-centred intelligent media services
507457	BRICKS	Building resources for Integrated Cultural Knowledge Services
508013	AGAMENON	Pictures from the past: A wireless network of magic digital cameras and palmtops for archaeological travels through the time
510166	COHERENT	Collaborative holographic environments for networked tasks
507826	LEACTIVEMATH	Language-enhanced, user adaptive, interactive eLearning for mathematics
507128	TELCERT	Technology enhanced learning certification - European requirements and testing
507844	CONNECT	Designing the classroom of Tomorrow by using advanced technologies to connect formal and informal environments
2205	E-LEGI	European learning GRID infrastructure
4337	CALIBRE	Co-ordination action for libre software engineering for open development platforms for software and services
4293	AKOGRIMO	Access to knowledge through the grid in a mobile world
511592	MICOLE	Multimodal collaboration environment for inclusion of visually impaired children
4778	ENABLED	Enhanced network accessibility for the blind and visually impaired
516895	PAPERWORKS	PaperWorks : Interweaving Paper and Digital Documents
28025	CALIBRATE	Calibrating eLearning in schools
28051	EMAPPS.COM	Motivating active participation of primary schoolschildren in digital online technologies for creative opportunities through multimedia
27168	ICAMP	intercultural learning campus
26883	I-MAESTRO	Interactive Multimedia Environment for Technology Enhanced Music Education and Creative Collaborative Composition and Performance
27607	MGBL	Mobile games based learning
27952	VEMUS	Virtual European Music schools
27087	TENCOMPETENCE	Tencompetence: Building the European network for lifelong competence development
27728	ARGUNAUT	An intelligent guide to support productive online dialogue
27529	ATGENTIVE	Attentive agents for collaborative learners
27073	COOPER	Collaborative open environment for project-centred learning
28027	LEAD	Technology-enhanced learning and problem-solving discussions: Networked learning environments in the classroom
27391	LT4EL	Language technology for eLearning
26751	RE.MATH	Representing mathematics with digital media
27611	AETHER	Self-adaptive embedded technologies for pervasive computing architectures
27020	ACCESS-EGOV	Access to e-Government services employing semantic technologies
27039	ARISE	Augmented reality in schools environments
27866	ELU	Enhanced Learning Unlimited
28038	PALETTE	Pedagogically sustained adaptive Learning through the exploitation of tacit and explicit knowledge
27451	LOGOS	Knowledge-on-demand for ubiquitous learning
27023	APOSDLE	Advanced process-oriented self-directed learning environment
27656	ECIRCUS	Education through characters with emotional-intelligence and role-playing capabilities that understand social interaction
27986	ELEKTRA	Enhanced learning experience and knowledge transfer
27149	LUISA	Learning content management system using innovative semantic web services architecture
33572	CASPAR	Cultural, artistic and scientific knowledge preservation, for access and retrieval
34545	A-WARE	An easy way to access GRID resources

34567	GRID4ALL	Self-* Grid: Dynamic Virtual Organizations for schools, families, and all
34549	AGENT-DYSL	Accommodative intelligent educational environments for Dyslexic learners
34778	EU4ALL	European unified approach for accessible lifelong learning
33860	QALL-ME	Question Answering Learning technologies in a multilingual and multimodal Environment
216837	ATRACO	Adaptive and trusted ambient ecologies
215064	IMPACT	Improving access to text
215893	REFLECT	Responsive flexible collaborating ambient
215434	GRAPPLE	Generic responsive adaptive personalized learning environment
216267	LIWA	Living web archives
217141	SOCIALNETS	Social networking for pervasive adaptation
212578	LTFLL	Language technology for lifelong learning
215918	80DAYS	Around an inspiring virtual learning world in eighty days
216199	IDSPACE	Tooling of and training for collaborative, distributed product innovation
216356	MATURE	Continuous social learning in knowledge networks
215098	PERSIST	Personal self-improving smart spaces
224047	REPLAY	Gaming technology platform for social reintegration of marginalised youth
224044	INCLUSO	Social software for inclusion of (marginalized) young people
222107	NIW	Natural interactive walking
231551	DL.ORG	DL.org: coordination action on digital library interoperability, best practices, and modelling foundations
231717	TARGET	Transformative, adaptive, responsive and engaging Environment
231266	COSPATIAL	Communication and social participation: collaborative technologies for interaction and learning
231590	INTELLEO	Intelligent learning extended organisation
225938	OPPORTUNITY	Activity and context recognition with opportunistic sensor configurations
231396	ROLE	Responsive open learning environments
257639	ALICE	Adaptive Learning via Intuitive/Interactive, Collaborative and Emotional systems
257886	ARISTOTELE	Personalised Learning & Collaborative Working Environments Fostering Social Creativity and Innovations Inside the Organisations
257872	METAFORA	Learning to learn together: A visual language for social orchestration of educational activities
257617	MIRROR	MIRROR - reflectionive Learning at Work
257566	HEATTRONICS	Innovative Technologies for an Engaging Classroom
258114	NEXT-TELL	Next Generation Teaching, Education and Learning for Life
258453	SIREN	Social games for conflIct REsolution based on natural iNteraction
257831	IMREAL	inmersive reflectionive Experience-based Adaptive Learning
257493	SOCIETIES	Self Orchestrating CommunIty ambiEnT IntelligEnce Spaces
257410	TERENCE	An Adaptive Learning System for Reasoning about Stories with Poor Comprehenders and their Educators
270001	DECIPHER	Digital Environment for Cultural Interfaces; Promoting Heritage, Education and Research
271578	ETOILECASCADESIDEAS	Enhanced Technology for Open Intelligent Learning Environments
288578	TARDIS	Training young Adult's Regulation of emotions and Development of social Interaction Skills
288587	MASELTOV	Mobile Assistance for Social Inclusion and Empowerment of Immigrants with Persuasive Learning Technologies and Social Network Services
288596	LITERACY	ONLINE PORTAL FOR E-LEARNING AND SUPPORTING SOCIAL INCLUSION OF PEOPLE WITH DYSLEXIA
296229	EUCLID	Educational curriculum for the usage of Linked Data
318803	ILEARNRW	Integrated Intelligent Learning Environment for Reading and Writing
318496	INTUITEL	Intelligent Tutoring Interface for Technology Enhanced Learning
317964	JUXTALEARN	Juxtapositioned reflectionive performance enabling science and technology learning
318499	WESPOT	Working Environment with Social and Personal Open Tools for inquiry based learning.
318299	WE.LEARN.IT	European schools enhancing creativity, exploration and science

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- What version do I use?
- How do I upgrade applications?

Portability

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- What is being used?
- How much does it cost?

Auto-Scaling

- Can my application auto-scale?
- How do I configure auto-scaling?

Disaster Recovery Planning

- Can my application tolerare faults?
- How do I recover my system?

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Automation

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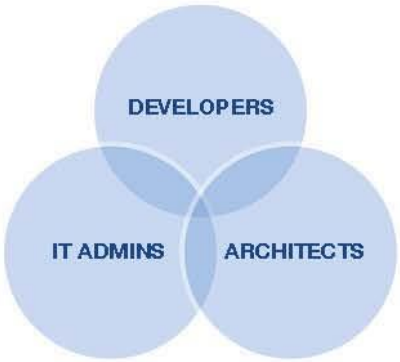
- ✔ Automatic Configuration
- ✔ Disaster Recovery

Runtime Environment

- ✔ Application Scaling
- ✔ Fault Tolerance
- ✔ Resource Clean-up
- ✔ Replication



Framework Design

- ✔ Architecture Policies
- ✔ Versioning
- ✔ Platform Management

Infrastructure Control

- ✔ Cost Analysis
- ✔ Policy Management
- ✔ Traceability

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