Beyond the Basics of the Adaptive Learning

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Abstract. The definitions, methods, implementations and realizations in the field of the adaptive learning, explained in our previous researches, pointed out new directions in the studying of this kind of learning. Although during and after the process they were considered in general as more adequate than the ones from the existing adaptive learning systems, the question was asked whether theirs theoretical background could be effective for the best realization of an adaptive learning environment. In this paper, considering the found flaws in, we go beyond these rules of knowledge representation in order to increase the possibility of constructing an improved adaptive learning environment.

Keywords: Adaptive learning – AL, adaptive learning environment – ALE, adapted learning environment – IALE, learning mechanism – LM, test set – TS, concept - C, in-concept - IC, basic adaptive learning - BAL, partial learning – PL, sufficient concept – SC, sufficient set - SS

1 Introduction

Considering the fact that our model of adaptive learning in electronic form - Awareness, was developed as a result of the new view towards the AL theory, it greatly relied on approximations and idealizations of the terms like ALE, IALE, LM, TS etc. Although those idealizations were needed to prove the justification of this kind of representation of the integral parts in the process of adaptive learning, it felt like the real cases needed correction as well as introduction of new terms and strategies so that this model can take a new step further from the experimental towards everyday usage. The lack of detailed comparative analysis with the current situation in the field of AL, as well as the modern AL systems, can be explained with the completely different approach of the AL related problems.

2 Basic Adaptive Learning

In order to make a distinction between the adaptive learning expressed in [1] – [5] and the changes made further in this paper, we will address towards one part of the initial AL rules as basic adaptive learning.

2.1 Definition

[1] contains a description of the AL process based on the definitions of concept, ALE, IALE, LM and TS. Key part of the AL process is the ALE structure itself because it determines the way of knowledge delivery towards the learner. In addition, it determines the allowed learning order [6] of the concepts, or more specifically, it influences the delivery stream of the concepts with the learner as destination.

The ALE itself, defined as a set of concepts and their relations, accurately expresses the dependency of one concept towards the other. If at least one of the in-concepts of a certain concept represents a learning candidate, then it is not allowed that concept to be omitted from the instantiation process.

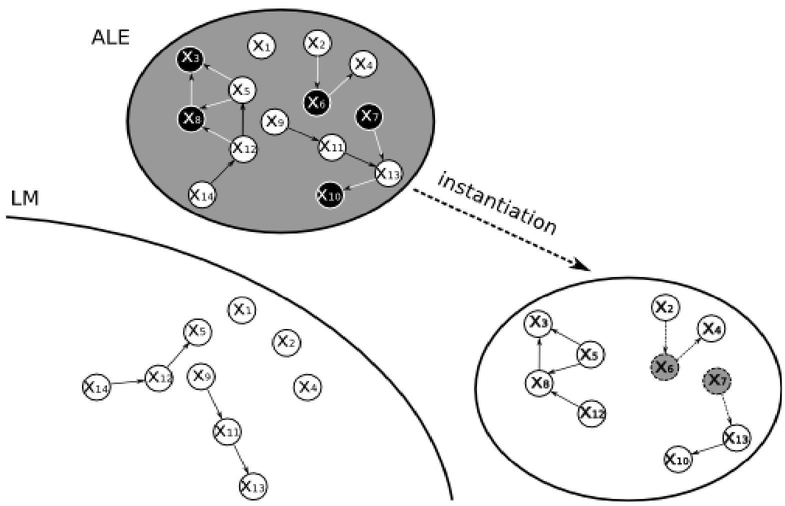

Fig. 1. Instantiation in BAL, using the method of unknown concepts.

A similar treatment of the connections between the concepts exists in the representation of the learner's LM, too. When it is determined that the learner is aware of a certain concept, it is also regarded that the learner has knowledge about all of its in-concepts, appropriately to the in-concepts of the same concept in ALE, considering the ALE's idealization expressed by $V_{LM} \subseteq V_{ALE}$ [1], [3].

As a result of the instantiation process of adapted learning environment from ALE, we can keep a certain number of in-concepts[1] for which can be considered that they are not included in LM, then in the IALE itself one concept can be learned only if its in-concepts are learned before.

The strictness of the defined dependency of the concepts can be clearly seen on Fig. 1. The process of forming the IALE using the method of unknown concepts is given as an example. Although by this method it is determined that the concepts x_3, x_6, x_7 and x_8 are not found in the learner's LM, the second and the third concept become unnecessary in IALE because the situation “the learner to know about x_4 and x_{13} , but not x_6 and x_7” is simply impossible.

Def 1: basic adaptive learning (BAL)

The adaptive learning during which the concepts are learned only in case when all of their in-concepts are already learned, is referred to as basic adaptive learning.

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The adaptive learning according to this rules of the concepts in ALE, LM, IALE and similar knowledge structures, will be referred to as basic adaptive learning (Def. 1).

2.2 Implementation

For BAL implementation in Awareness, a representation of the knowledge graphs for ALE, LM[2] and IALE is used ($G_{ALE}(V_{ALE}, E_{ALE})$, $G_{LM}(V_{LM}, E_{LM})$ и $G_{IALE}(V_{IALE}, E_{IALE})$ appropriately) [9]. By using it, the sets of concepts and the relations between them allow to be realized as a relational database. If we exclude the supporting tables in which additional data about ALE's concepts and the existing databases matching the adapted learning environments are held, the implementation of that connectivity among the concepts comes down to the following:

- grouping of the concepts with equal structure [1];
- initializing a table for every group of concepts with equal structure;
- estimating a number of columns for every table, equal to the number of in-concepts for every concept found in the table;

Besides the introduction of the term “concepts with equal structure”, during the implementation of the instantiation, the terms “sub database” and “sub table” are also introduced in order to express the features of the other concepts from the tables in the IALE database – their number of columns to be less than or equal to the number of columns of the appropriate concepts in ALE database.

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1 This is also applied for the concepts in ALE which can appear in IALE.

2 Unlike ALE and IALE, LM does not figure physically as a data structure in Awareness, instead it is integrated in the program code using similar data structures (arrays and matrices).

This implementation proves the exact dependency between the concepts. For one concept to be learned from the IALE's tables, all of the concepts found as values in the rest of the columns from the appropriate row have to be passed. Although the number of columns representing the in-concepts which have to be learned before is less than the number of columns of the appropriate concept from ALE and varies depending on how many of them exist in LM, this number for a given simulated learner is always constant. Variation of this number occurs only when there is a different LM present in the AL process.

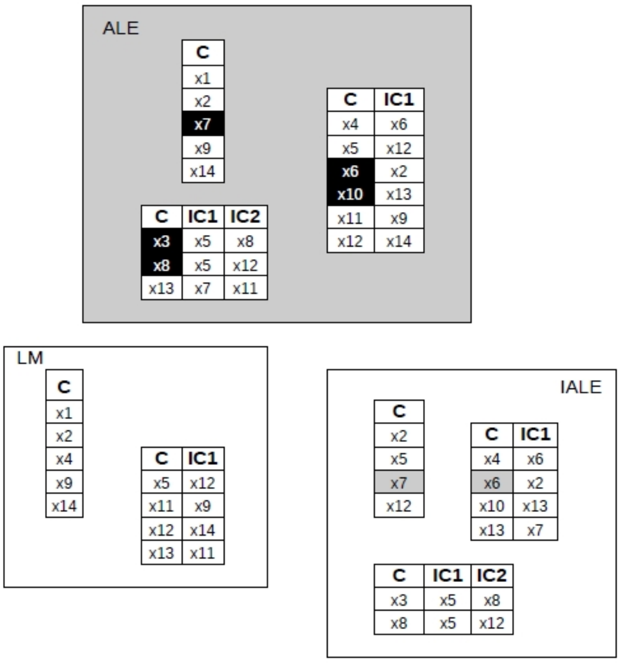

Fig. 2. Example of instantiation in BAL during the implementation, using the method of unknown concepts.

On Fig. 2 it can be noticed again that the rows for the concepts x_6 and x_7 can be omitted without any problems in IALE, since they are found in ALE as ICs for the concepts x_4 and x_{13}, respectfully, which on the other hand are found as concepts in LM.

2.3 Problems

The simplicity of BAL in the knowledge representation through the concepts is a great advantage during the simulation of AL with different models of learners, as it can be seen in [1] and [4]. The representations of ALE, LM and IALE are suitable for adapting towards other forms of representations according to the learner's type, as well as doing different mathematical operations on them.

The simple rules of BAL, although a source of many advantages, comes with several flaws which result from the limited representation of the dependencies between the concepts. The following are pointed out as two major problems:

- construction of ALE – every concept must have single in-concepts i.e. to be learned only through a single set of concepts (Fig. 3);
- limit of LM – only in-concepts from ALE are treated;

$$f(x_1, ..., x_n) = f'(x'_1, ..., x'_{n'}) \Leftrightarrow n = n' \bigwedge x_1 = x'_1, ..., x_n = x'_{n'}. \quad \textbf{(1)}$$

The concept's function definition [1], shows why BAL does not allow omitting of the uniqueness in the relations between the concepts and their in-concepts (1). According to it, in order to correctly preserve the construction of ALE, single equality of two functions determining two concepts can be achieved only if the function (concept) is compared with itself. It means that for the left example of Fig. 3 it is true that $x_2 = x_7 \bigwedge x_5 = x_9$ or $x_5 = x_7 \bigwedge x_2 = x_9$.

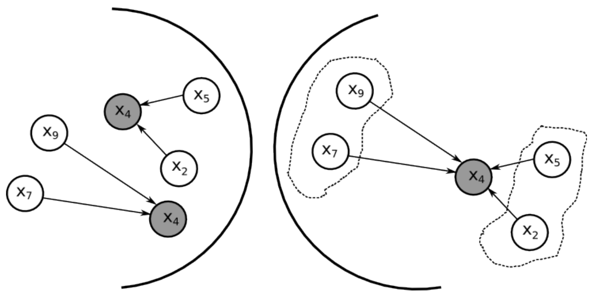

Fig. 3. Problem of unique representation of the ALE's concepts in BAL.

During the ALE's construction, almost always there is an encounter with the hesitation – which in-concepts should explain the concept. In case a decision has to be done, a question rises whether the chosen set of ICs will influence AL positively or not. On the other hand, if all the IC sets have to be included, then for every set, a particular concept is formed in order to preserve the rule of uniqueness. For the left example on Fig. 3 to be possible, the two x_4 concepts must be treated as different, which implies that one of them must have a different marker (x_i, $i \neq 4$). If during the inclusion of all IC, the forming of special concepts for every set is missed (Fig. 3, right), then we risk more complex explanation of the concept x_4. Considering this complex explanation, it can happen that the ALE itself concludes that they are not enough for the learner, having knowledge about one such set, to be fully aware of the concept, unnecessary offering him the other set.

In reality, the learner's model expressed by its LM, includes large number of concepts not present in V_{ALE}. But in BAL, those concepts are not treated considering the lack of strategy for their exploit during the instantiation. Specifically, in LM on Fig. 4, the concepts x_{14}, x_{15} and x_{16} are considered as nonexistent.

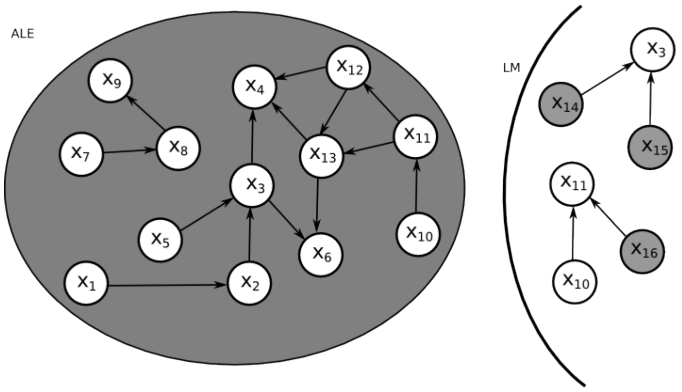

Fig. 4. Problem of limit of LM in BAL.

It appears that these two problems are distinctive, but with providing solution for the first one, we open the path for solving the second one as well, since there can be a possibility for representing the concept with alternative sets of ICs which will be known to the learner.

3 Elements of the Advanced Adaptive Learning

In order to bridge the two main problems in BAL, we will define new type of AL, where the restrictions which caused them will be allowed. Part of the rules for ALE's construction will suffer changes with the help of several newly introduced terms, not treated in BAL.

3.1 Sufficient concept

According to BAL, every concept is learned through the ICs. This way of explanation of the concept in some cases can be unique, but it does not have to. It means that the same concept can be presented with different groups of ICs.

Remembering the feature of De Bra and Brusilovsky [1], [7] about the relation between two concepts, let us assume that a single concept in one case can be learned only by a single IC and in other cases by more than one IC (Fig. 5).

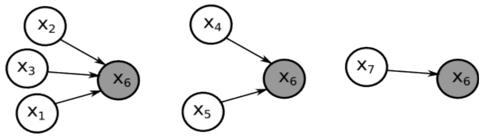

Fig. 5. Examples of different IC sets for a single concept.

Considering Def. 2, it can be concluded that SC for the concept x_6 in the example on Fig. 5 is the concept x_7. If the concept x_7 happened to belong to at least one of the other IC sets, $\{x_1\ x_2\ x_3\}$ and $\{x_4\ x_5\}$, then it would not be considered as sufficient. The SC guarantees the shortest possible way of learning the concept to which it provides knowledge.

Def 2: sufficient concept (SC)

The in-concept which can express the concept to which it provides knowledge, by itself, and also does not belong to any of the rest of the IC sets which express the same concept in other cases, will be referred to as sufficient concept.

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The representation of the different IC sets cannot be done on the same way as in BAL. In the terms of BAL it means that all ICs from all sets are required to express the actual concept (Fig. 3, right). For that purpose, a unique marking of those sets must be done, during the ALE's construction. Fig. 6 shows the marking by indexing of I on the example on Fig. 5.

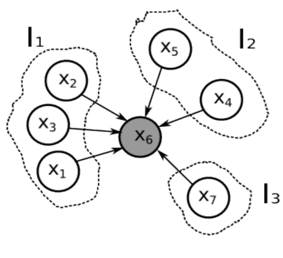

Fig. 6. Representation of IC sets for a single concept in ALE.

The sufficient concept cannot appear for every concept in ALE. There will even be situations when it will not exist, because there are often more pre-knowledge requirements needed to explain a single concept. However if we need to find replacement for the SC, we will look for it among the IC sets which have the smallest number of elements and they will be known as sufficient sets of ICs (Def. 3).

Def 3: sufficient set of in-concepts (SS)

The IC set with the smallest number of elements among the IC sets for a certain concept, which is not a true subset of any of the rest of the IC sets, is referred to as sufficient set of ICs.

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On Fig. 6, if the concept x_7 is omitted as in-concept for x_6, then I_2 becomes an SS for the concept x_6.

3.2 Partial Learning

The choice of the SC (if it exists) from the IC sets, is not always good. Although one of the AL's goals is the concept to be learned on shortest possible way, when it comes to ALE in general, choosing other IC set can often prove better. The reason for it lays in the fact that some of the ICs from the other group can explain other concepts as well, so their choice increase the chances of learning more than just one concept.

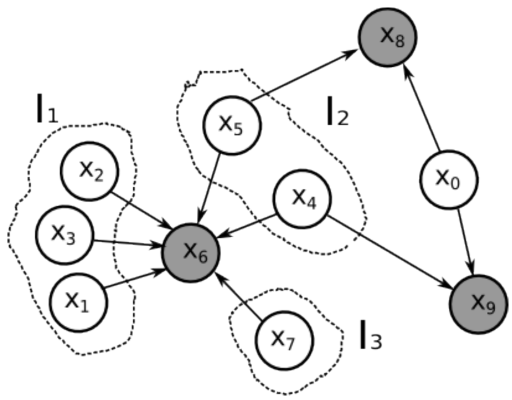

Fig. 7. Example of elements of IC sets, providing knowledge to more than one concept.

Fig. 7 shows two ICs from I_2 set, providing knowledge for the concepts x_8 and x_9. If we assume that x_0 was learned before, then by choosing I_2 we open the possibility of two potential concepts to be learned through two in-concepts. Because the choice of x_7 which gives opportunity to learn one potential concept through one IC, does not guarantee that through some following ICs we will gain new potential concept for learning, it becomes clearer that the choice of I_2 is better.

Def 4: partial learning (PL)

> Learning of the concept during which it is allowed not to gain knowledge about every IC set previously, is referred to as partial.

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The partial learning (Def. 4), is a base of a new AL strategy, which makes strict choice from the IC sets so that the learning of the goal concepts is done in the shortest possible way. In the near future we attend to fully develop such a strategy with the best possible efficiency.

4 Impact on the Learner Models

The changes made to the representation of the relations between the concept and its in-concepts involving SC and PL, means that besides ALE's construction, there will be altering of the simulation of LM and instantiation of IALE, too. This is logical because LM needs to match the ALE's representation for the instantiation to be performed according to the strategies we will develop in near future since the ones in BAL are considered obsolete and inadequate.

	A_1	A_2	A_3	A_4	A_5	C
e_1	x_1	0	0	0	0	c_1
e_2	0	x_2	x_3	0	x_6	c_2
e_3	x_1	0	0	0	x_7	c_3
e_4	0	0	x_3	0	0	c_3
e_5	0	0	x_4	0	0	c_2
e_6	0	x_2	0	x_5	0	c_4

Fig. 8. Propositional rule learner with repeating class values

In [4] we studied the behavior of several artificial learners in chosen ALE's by simulating their learner model. We started with one of the simplest, the propositional rule learner [4], [8] since it was easier to describe it in BAL terms. However the nature of this learner does not have any restrictions when it comes to learning the same class value with different sets of attribute values. Fig. 8 shows two such class values (c_2 and c_3).

The decision tree learner [4], [8] differs from the previous learner by its graphical representation so the feature of repeating the class value applies to it as well. In the case of relational rule learner [4], [8], additional column is required in the table relation in order to express the IC set the in-concept belongs to.

When it comes to neural networks as learners [8], no matter the type (including our quasi neural network experiment [4]), for the target vectors of the concepts having multiple IC sets (2), the number of input vectors will always be equal to the number of IC sets, a scenario which is not possible in BAL.

$$\text{set of input vectors } \{[x_{11}, \ldots x_{1q}, \ldots, x_{1n}]^T, \ldots, [x_{m1}, \ldots x_{mq}, \ldots, x_{mn}]^T\} \quad \textbf{(2)}$$

$$\text{for the m x 1 target vector } [0, \ldots, t_p, \ldots, 0]^T$$

Since every learner model we experimented with in BAL allows its output values to result from more than a single set of input values, there isn't any real obstacle left for simulating an LM and transforming the IALE's representation into understandable content, in the terms of the advanced adaptive learning.

In everyday life, individuals suffering from dyslexia might become good candidates for using the advanced adaptive learning methods. The reason for this lays in the fact that a model of a learner with dyslexia syndrome understands some concepts using quite unexpected in-concepts, which means that for this learner model there is a higher probability for another IC set for a single concept to be added.

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