Assimilative Learning with the Aid of Cognitive Maps

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Abstract—Assimilative learning is understood as integrating new information into existing knowledge or cognitive structures without restructuring the current schema. If new information causes inconsistencies, cognitive efforts are necessary to reorganize or to accommodate the old knowledge. Thus, assimilative learning is more efficient and economic. Nonetheless a stable and most notably a correct memory representation which "spans" the knowledge space is essential. The current article highlights the logic of assimilative learning and shows how building elaborately a basic structure as well as the assimilative integration of new information can be eased with the aid of cognitive maps. Such a didactical scenario can be easily implemented in the field of eLearning and thus, is adaptively and automatically supporting the learning process.

Index Terms—Assimilative Learning, Cognitive Maps, Cognitive Structures, Nonmetric Multidimensional Scaling (NMDS), Procrustean Transformation, Psychopathology Taught Online

I. THEORETICAL BACKGROUND

A. *Learning is Structure Building: Assimilation / Accommodation*

Our mind is well organized. This fundamental insight of cognitive psychology is one of the most important paradigms for modern concepts of instruction. And despite the increased digitalization and enhancements in the field of information systems, it has not lost any of its relevance for theory building and practical implications. For instance, in the field of information retrieval, there are increasing attempts to close the conceptual gap between memory representations and database organization. Perceived elements of our environment are always structured as internal network representations, which form on every level of knowledge a meaningful connectivity (i.e. they are organized in reasonable interrelations, refer to each other, are the logical consequence or part of something etc.). Even very restricted knowledge provides people with a feeling of accuracy and completeness as long as it is consistent with current experiences. Only if an individual is unable to relate the semantics of new experiences to existing knowledge, an uncomfortable feeling of non-understanding will emerge.

When it comes to learning, people try (as a default) to integrate new experiences into the existing knowledge without restructuring the current schema. Our mind looks (automatically) for similar situations or perceptions in the past and tries to interpret new information from this perspective. New information will be assimilated and, in the end, will be part of the knowledge structure. As long as this "assimilation" [1] works, people can semantically match "old" and "new" and define accurate relationships between them: New information can be integrated into existing cognitive structures without reorganizing the old knowledge.

In certain cases systematic inconsistencies will arise between new experiences and previous knowledge. In these cases the previous representations of actually relevant sections of our world seem to be inadequate. For the purpose of integrating new facts in a proper way, our mind has to reconsider the knowledge about this section of the world. Piaget calls this process "accommodation" [1]: Accommodation describes a change, an adaptation or expansion in the former knowledge schema making it consistent with new experiences. This process is well described for example for the development of the view on science which children have at different age.

Accommodation in the sense of a fundamental reorganization is an exceptional case. It mostly happens while gaining expertise in a certain field, when the learning process is more accidentally and uncontrolled. The best case would be, if a person learned a new knowledge field in such a way, that this "basic structure" was accurate and additional information could simply be assimilated. This would be the most straightforward and the most efficient way: Because every assimilation schema (another term introduced by Piaget) comprehends the tendency to grow and to absorb new elements (information) [1]. On the other hand, every assimilation schema is forced to accommodate towards the new assimilated elements (p. 14 et seq.) in order to resolve the (slight) inconsistencies between old and new which have emerged during the learning process. These regulating compensations require cognitive resources. From a sequential point of view, assimilation always precedes accommodation: First, new information is added to existing structures and after that, inconsistencies emerge which have to be solved.

An important point to state is that starting from this model, during every interaction of an individual with the environment, previous knowledge is activated. Ausubel [2, 3] postulates acquisition, organization and storage of knowledge as three components of "assimilation". That means, that all the new and semantically meaningful information interacts with already known elements and, thus, will be assimilated into the previous structure. At the same time, (slight) changes or adaptations both of the existing structure and the new material take place.

Transferred to a functional way of learning, the theoretical statements above propose the existence of a correct and stable basic knowledge structure in order to achieve an optimal learning process. In such a case, a person can easily integrate additional information with very low cognitive costs. Unaided learning, however, often creates an inappropriate initial knowledge structure which has to be modified several times, making the entire learning process more or less inefficient. Hence, it is a pedagogical goal to implement a correct integration of given information from the very beginning: Concepts should not stand unrelated side by side, but refer semantically meaningful (not verbatim) to each other. A highly differentiated and complex knowledge structure allows deductive thinking and, thus, an adequate behaviour. To reach this goal, Ausubel [2] indicates in his so called assimilation theory the determination of previous knowledge of a person as the most important factor in learning. As soon as this has been done, the education can be adapted and shaped.

B. Cognitive Structures Based on Similarity

The practical implementation of these fundamental concepts of knowledge organization and of learning requires technical models of knowledge tracking. Cognitive psychology has explored diverse ways to map cognitive relations. Over the past decades, three paradigms have been proved as being very influential: propositional networks [4] are geared to SPO syntaxes of natural language as well as to propositions in logical systems. They map knowledge like "Peter gives Maria a necklace" or "Necklaces are examples of the category jewellery" and try to describe the knowledge of a person in this way. Schema theories [5] stress associative connections: Whenever a schema is selected, an individual instantly associates a set of typical situations or typical characteristics of an already known affair [6]. Production systems [7], which divide our environment into logical if-then-rules and their possible relationships, are mainly oriented towards the structure and language of computer software.

Furthermore, psychological research has developed its own measuring and mapping models for every form of such knowledge assets. Verbal interviews based on questionnaires (multiple choice, open questions etc.) remain mostly on the level of single facts and are not suited to highlight the important relational aspects between the knowledge elements. Current knowledge psychology on the other hand, tries to integrate the different basic models (as listed above) by measuring and mapping more complex knowledge representations. Technically, these approaches are characterized by different mapping techniques (the graphical depiction to map cognitive representation forms): Usually, they contain a set of symbols and geometrical forms to illustrate the logical relations which an individual uses to connect the different concepts in a knowledge area (for an overview of such techniques see [8]).

Surprisingly, little use has been made of these techniques in computer aided instructional systems (which could be adaptive when having a good representation of the knowledge of individual users). The fact that complex mapping techniques are much more spread in organizational psychology (where they are used in combination with interviews or group discussions) leads to the insight that an automatic semantic comparison of knowledge maps (allowing concrete conclusions about a discrepancy of a learner's current knowledge compared to the defined knowledge goal of an instructional system) is very difficult, if not impossible to achieve: The diversity of possible connections leads to such an unmanageable huge amount of individual solutions that comparisons among each other prove to be difficult. This difficulty increases as soon as knowledge representations possess a different level of complexity (this is often the case when experts and novices are compared with each other).

To resolve these practical problems, we propose a more general model of a "cognitive map" which is based on geographical representations [9, 10]. In such a cognitive map, a distance measure between the concepts is used to represent the general similarity which an individual sees between each object of a knowledge field. As the name "cognitive map" indicates, the resulting map stands for the internal representation of aspects or sections of the physical or social environment, which humans have developed based on their experiences and subjective interests [11]. In a more specific sense it means the mapping of the individually experienced similarity or dissimilarity between elements in our environment. These relations are calculated by Multidimensional Scaling, or, less frequently, by Correspondence Analysis or by Kohonen Networks and are visualized by means of geometrical maps. Using Multidimensional Scaling (as we will propose in part two of this paper), the model of a cognitive map requires no more than a matrix of paired similarity judgments for a set of objects.

II. THE CONCEPT

A. Knowledge Diagnosis Aided by Cognitive Maps

In the following, an innovative method to construct an adaptive learning tool to measure factual knowledge will be presented (we assume, for the first time in this context). The didactical scenario is based on a knowledge diagnosis using cognitive maps to compare the state of knowledge of an individual learner compared to the goal of an instructional process.

This method determines with simple numeric judgments how a person has structured a knowledge field. Appropriate measures are direct similarity judgments (SJ) between pairs of objects, because of their independence of the level of expertise. Humans are able, even with very little information, to give a rough judgment about the similarity between two things or persons whereas the judgments of an expert should be of better quality than those of a novice of course. Feelings of similarity evolve spontaneously. They take into account important features and characteristic dimensions and weight them depending on the individual cognitive organization [12]. Thus, SJ measure relational connections, integration and elaboration of a persons' knowledge structure and are independent of questionnaire formats and relational rules (like in other mapping-techniques). However, the resulting relational information of a single SJ is not obvious at all. Hence, it requires a complex mathematical analysis to reconstruct a semantically distinct structure out of a matrix of SJ.

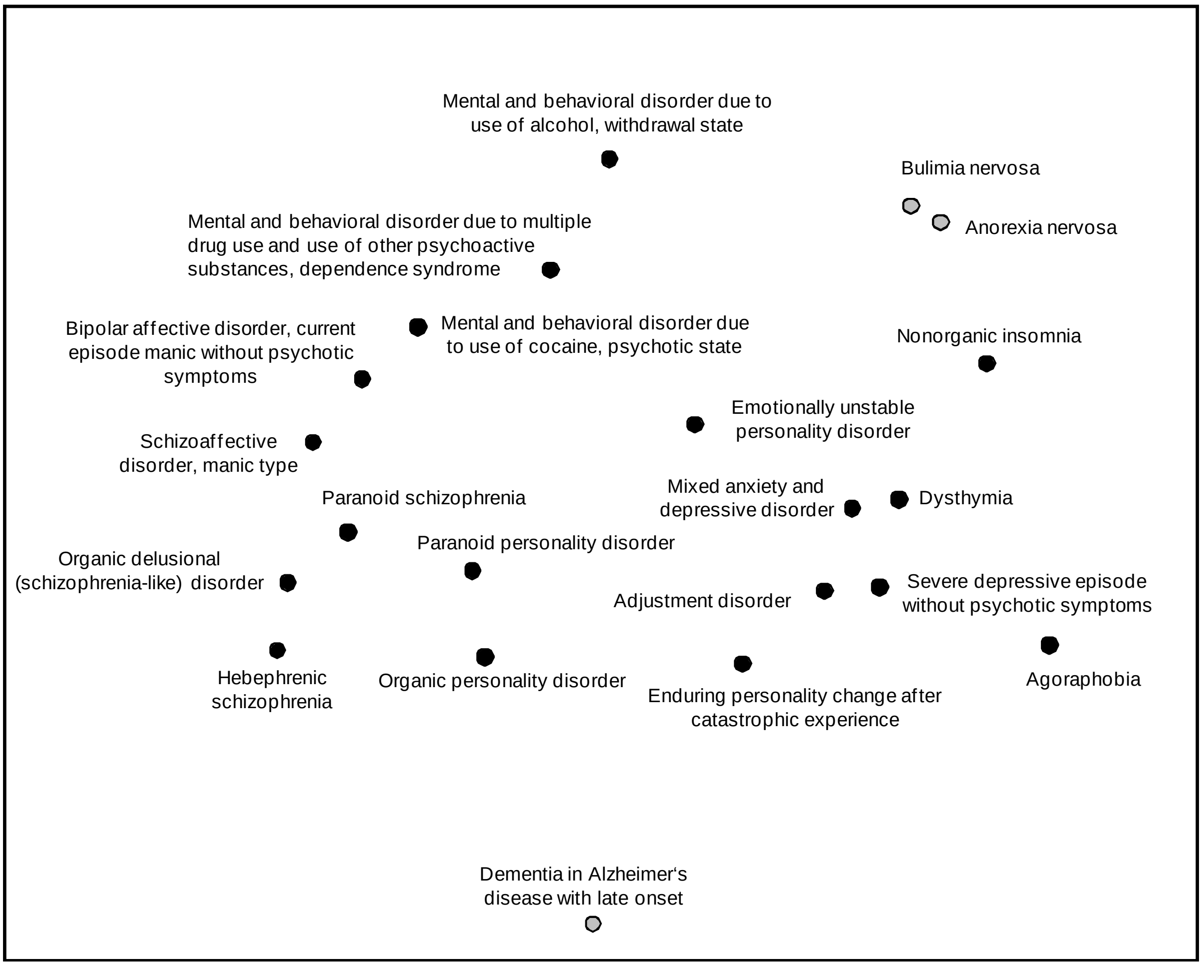

Figure 1. Two-dimensionally scaled NMDS map based on SJ about mental disorders. The dots represent the positions of the mental disorders from the point of view of experts). The gray dots represent the examples described in the text.

By Nonmetric Multidimensional Scaling (NMDS), an individual matrix of pairwise SJ (in our case SJ are rated on a 9-point-scale) can be transformed into a cognitive ("knowledge") map [13, 14, 15, 16, 17]. This geometrical representation visualizes the similarity which a person sees between objects as larger or smaller distances, allowing an easy interpretation of the semantic relations seen in a specific field of knowledge. At the same time, cognitive maps allow comprehending the knowledge about a specific object based on its position within the whole structure. Cognitive maps are widely accepted as an appropriate model for those cases of factual knowledge in which certain objects (which can be described by a set of features) exist side by side.

Figure 1 gives an example of such a knowledge map in the field of psychopathology, specifically mental disorders. Objects which are close together have been rated by experts as being rather similar, objects which are far apart as rather dissimilar. For instance, anorexia nervosa ("restricted eating") and bulimia nervosa ("binge eating and vomiting") are similar disorders and belong to the same category of the WHO classification system ICD-10 [18]. These two objects show only small discrepancies in terms of phenomenology, etiology, and other possible judgment criteria. The similarity, which was assessed to be very close, is reflected in the close position of these two disorders. Bulimia nervosa and dementia in Alzheimer's disease, on the other hand, show few similarities with regard to the potential judgment criteria (such as phenomenology, etiology, etc.). The pronounced non-similarity that is consequently judged is therefore reflected in far apart positions of the two disorders.

The subsequent assessment of the quality of knowledge is achieved by comparison of a learner map with the target/expert map by means of procrustean transformation [19]. The procrustean transformation is a procedure which finds the best orientation for one map to generate a maximum of similarity with a given map. In detail the procrustean transformation places two maps on top of each other and rotates, mirrors, shifts and scales the two maps until the maximal congruence between them has been found. In such a comparison, it is noticeable even without mathematical calculations which objects are well known by the learner (i.e. correctly positioned) and which ones are wrongly positioned (as an example, see figure 2). Of course, this distance information of the target/actual value comparison can also be expressed numerically. This is the basis for a fully automated analysis, which can be applied in computer-assisted education. The overall divergence of two maps is expressed as the AverageLoss (AvgLoss), which corresponds to the mean of the individual divergences (ObjectLoss) [14].

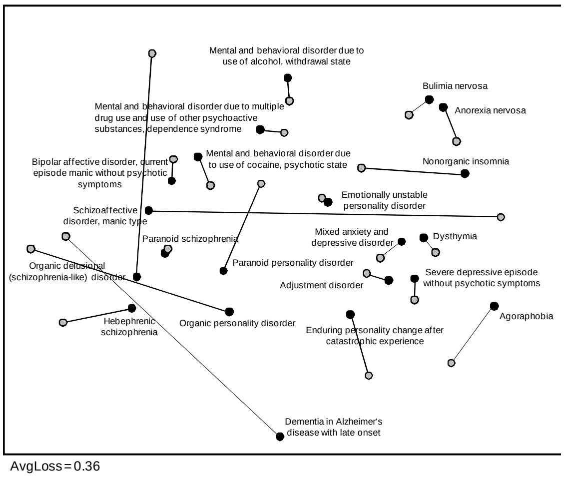

Figure 2. Result of a procrustean transformation of the knowledge map of a learner (gray dots) and the target/expert map (black dots). The overall divergence in this example corresponds to an AverageLoss of 0.36. The longer the line between the corresponding objects, the larger the (knowledge) divergence between learner and expert.

The AvgLoss indicates the degree of inaccuracy of the cognitive structure as a whole, and the single deviation values (ObjectLoss) estimate the degree of incorrectness of the knowledge of each single object.

B. *Didactical Scenarios for Assimilative Learning*

This result of the comparison of two cognitive maps serves as the feedback about the learner's knowledge with the objective of guiding the learner-structure towards a correct target-structure (expert map). If the structure of a learner-map differs eminently from the expert-map, the person has to be instructed to re-learn the fundamental criteria of the knowledge field in a first step. As soon as the positions of the majority of objects correspond to those of the experts (as in figure 2), the correctly placed objects can be used for an assimilative process for learning the incorrectly represented objects: Exercises are presented which specifically focus on a feature comparison by using one correctly placed (well known) object as an anchor for learning the features of the incorrectly represented object. Similarities and differences are specifically presented so that the person learns to better integrate the target object into the existing structure. This procedure can be implemented as an interactive process which iteratively leads to a correct representation of all objects.

Such a structure should contain the most important concepts of a knowledge field. However, it is not necessary to comprise all relevant objects. The purpose is rather to build a stable and correct anchor structure which can be filled by new objects during the second part of a computer-aided instructional system. The clear didactical advantage of a stable anchor structure is that a person will now be capable to integrate the new objects with no need of capacity-consuming accommodative processes: On the basis of the correct anchor knowledge, the new information can be linked with the existing (see figure 3). The quality of this integration process is monitored by similarity based inquiries (similarity judgments between the recently learned objects with objects from the anchor structure to allow the positioning of the new objects by a special version of NMDS). As soon as the position of a recently learned object sufficiently corresponds to the

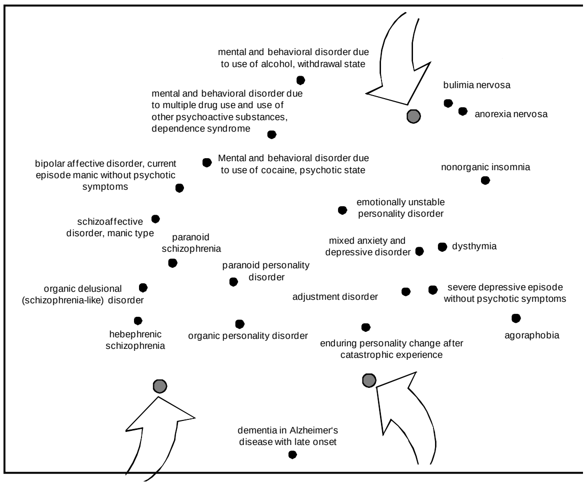

Figure 3. Illustration of the assimilative integration of new knowledge (gray dots) into the existing structure as an assimilative expansion of the knowledge space.

position the expert map provides for it, the learner has successfully assimilated the new information. Should that not be the case, the learner has to deal with his cognitive organization by re-learning the feature knowledge and by completing special similarity-based exercises (as specified above).

III. THE IMPLEMENTATION – ASSIMILATIVE LEARNING WITHIN THE ELEARNING ENVIRONMENT „PSYCHOPATHOLOGY TAUGHT ONLINE (PTO)“

This similarity based approach for assimilative learning has the technical advantage that it can be fully automated (a prerequisite for the implementation in virtual learning environments). The first practical application of the procedure is realized in the eLearning environment "Psychopathology Taught Online (PTO)" at the University of Zurich in Switzerland (http://www.pto.uzh.ch). Herein, the progressive differentiation of the cognitive structure and the assimilation of new knowledge of a learner are split up serially as described above. In a first curriculum, 20 mental disorders (e.g. paranoid schizophrenia, major depression, anxiety disorder) have to be learned and a basic and representative structure has to be accurately built up until a sufficient degree of approximation to an expert's map is reached. These 20 disorders cover the whole semantic space in a representative manner (figure 1) and have been selected by leading experts in this field. In a second curriculum, 32 additional mental disorders (also chosen on the basis of experts' rating of relevance) can then be integrated assimilatively (and learned with ease without restructuring the knowledge gained in curriculum 1). A third curriculum focuses on the ongoing assimilative integration of more complex and differentiated knowledge (those aspects of mental disorders which require a basic knowledge for a sound understanding).

When students start with the eLearning environment PTO, they may bring along diverse previous knowledge. Within PTO, they deal with the 20 basic lessons until they feel secure about the content (on the basis of pre-formulated learning goals, self-tests and case exercises). At this point, a similarity based diagnosis of the structural knowledge by cognitive maps provides a relational feedback by showing the individual knowledge map. If necessary, purposeful repetition recommendations and specific exercises (in which a student compares the features of a well known mental disorder with the features of a faulty positioned mental disorder) help to correct wrong representations. Thus, the student is capable of maximally tying in with existing knowledge and can iteratively construct a correct basic structure.

The subsequent expansion of the knowledge field with 32 additional mental disorders follows the path of assimilative learning and is controlled by an iterative similarity based knowledge diagnosis. If necessary, the learner receives adaptive and individualized feedback, namely purposeful learning recommendations and visualized feedback by means of his individual cognitive map [16, 17]. Furthermore, to support the assimilative process, the learning matter in curriculum 2 includes explicitly formulated cross references to corresponding contents in curriculum 1. By this aid, the learner receives implicit advices for providing a correct SJ.

The consolidation of a general and interindividually comparable basic structure is essential to avoid resource-consuming accommodative mental processes during curriculum 2 and 3. Providing an adaptive selection and order of exercises, the learner can efficiently and definitely integrate new information and expand his knowledge space without getting lost in the complexity and diversity of the learning content.

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