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EDUCATIONAL CONCEPT MAPPING METHOD BASED ON HIGH-FREQUENCY WORDS AND WIKIPEDIA LINKAGE

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ABSTRACT

We propose a computational method to support the learner's knowledge adoption based on concept mapping relying on three perspectives of learning scenario represented by learning concept networks: learner's knowledge, learning context and learning objective. Each learning concept network is generated based on a set of high-frequency words from a representative text sample that are connected based on the shortest hyperlink chains between corresponding Wikipedia articles. The learner explores ranking-based routings connecting learning concept networks by expanding a concept map in two complementing learning modes: assisted construction and assistive evaluation, with focused and contextualized emphasis. Based on the method we have implemented a prototype of an educational tool and its preliminary testing indicated that the method can well support personalized knowledge adoption.

KEYWORDS

intelligent tutoring system, knowledge acquisition, vocabulary, context-awareness, concept map

1. INTRODUCTION

Successful learning requires systematic introduction of new concepts to the learner so that they can be carefully associated with previous knowledge [1]. The collaboratively edited Wikipedia online encyclopedia (http://en.wikipedia.org) currently contains over 3,6 million articles in English. Each article defines a concept denoted by its title and the hyperlinks between articles define directed conceptual relationships. We think that enabling learners to explore hyperlink network of the Wikipedia pedagogically can provide sufficient coverage in core educational contents about many typical curriculum, especially in primary school and with challenged learners. Relying on the knowledge structure of the Wikipedia, we propose a new computational method to support personalized adoption of knowledge by creating the closest mappings between *learning concept networks*. We define a learning concept network as a conceptual network that contains a tailored collection of concepts and their relationships about a certain learning topic with a certain perspective. We think that for any topic it is possible to define a variety of alternative learning concept networks each one addressing a specific perspective and being based on a unique collection of concepts, called as a *key vocabulary*, and specific relations determined between these concepts. Some important features for collective intelligence systems are possible individual user actions, system state, as well as community and individual objectives [2]. Motivated by previous results, we suggest generating learning concept networks for three complementing perspectives: the learner's knowledge, the learning objective and the learning context. *Learner's knowledge* refers to a personally flavored entity of knowledge and perspective about a certain learning topic acquired by the learner. *Learning objective* refers to a compact yet thorough entity of widely agreed knowledge describing a learning topic. *Learning context* refers to a diverse collection of everyday knowledge and collectively shared perspectives surrounding a learning topic induced by the members of the learner's community.

Motivated by convincing learning results based on high-frequency word lists [3], in our method key vocabularies are identified by selecting a set of concepts with the highest frequencies in a representative text sample. A text sample for learning objective is gained by retrieving a Wikipedia article whose title matches with the topic. A text sample for learner's knowledge is gained by asking the learner to write a short improvised essay explaining her current conceptualization about the topic. Alternatively, the learner may just provide a list of few essential key concepts describing the topic, or draw a simple concept map representing key concepts and their relationships. A text sample for learning context is gained by collecting an extensive set of essays (or lists of key concepts or concept maps) from various learners in which they collectively describe their cumulative conceptualization about a variety of everyday topics. In our method, each learning concept network is built by connecting concepts of the key vocabulary based on the shortest hyperlink chains between corresponding Wikipedia articles.

2. METHOD

We have implemented the proposed method in a prototype relying on a relational MySQL database storing learning concept networks in compact text format and a Java application enabling to visually edit and browse concept maps based on Java Database Connectivity interface (JDBC API). We used online database "Six degrees of Wikipedia" to make queries about the shortest hyperlink chains between any given two concepts in the English edition of Wikipedia, based on article collection dating from 3 March 2008 [4]. According to this web site, for each article the distances to all other articles were summed up and then divided by the number of reachable articles. This gave the closeness value of the article enabling identification of the shortest hyperlink chains between each pair of articles. Since longer hyperlink chains tended to reveal some interesting indirect relatedness but also to introduce ambiguousness, we decided to consider only chains containing one hyperlink or two hyperlinks with a requirement that the intermediate concept also belongs to key vocabulary. Based on occurrence distribution in collection of all the shortest hyperlink chains, our method creates two rankings: *concept ranking* for concepts belonging to key vocabulary and *hyperlink ranking* for hyperlinks existing between pairs of concepts belonging to key vocabulary. We think that these rankings can represent the hierarchy of pedagogic value concerning concepts and their relationships belonging to learning concept network. Based on comparative initial experiments we considered the following specific formulations to be effective. Concept ranking is a weighted sum of three factors: the most frequent concepts in a chain of one hyperlink, the most frequent start or end concepts in a chain of two hyperlinks and the most frequent middle concepts in a chain of two hyperlinks. Hyperlink ranking is a weighted sum of six factors: hyperlinks belonging to a chain of one hyperlink, hyperlinks belonging to a chain of two hyperlinks, pairs of hyperlinks going into opposite directions, hyperlinks belonging to pairs of chains of two hyperlinks going into opposite directions, the most frequent hyperlinks in chains of two hyperlinks, and hyperlinks in chains of two hyperlinks that have the most frequent hyperlinks going into opposite directions.

The method builds a learning concept network based on representative sets of concepts and hyperlinks that have reached the highest rankings and introduces a *three-level pedagogic hierarchy* to indicate pedagogic value of concepts and hyperlinks. The method first adds the highest-ranking concepts and better half of them belong to first level while the others to second level. Then the method adds the highest-ranking hyperlinks and better half of them belong to first level while the rest to second level. These hyperlinks can connect already existing concepts or alternatively additional concepts need to be added which belong to third level. Finally, the method aims to connect still separate segments of the network into one entity by gradually adding new hyperlinks and possibly new concepts based on the remaining ranking list of hyperlinks. In this last phase both concepts and hyperlinks belong to third level. By comparison, the method tries to find shared vocabularies, i.e. concepts that are shared by each pair of learning concept networks, called as *learner–context vocabulary, context–objective vocabulary* and *learner–objective vocabulary*. They enable to define a minimal collection of the shortest hyperlink chains that connect all concepts belonging to a pair of learning concept networks, called as *learner–context routing, context–objective routing* and *learner–objective routing*.

When the shortest hyperlink chains include parallel chains of equal length, higher priority will be given to those chains that have concepts and hyperlinks belonging to a higher level in three-level pedagogic hierarchy. Some of the shared vocabularies and thus also routings may turn out to be empty. All three routings together enable creating the closest mappings between the concepts of three learning concept networks. Learning concept networks are illustrated to the learner as personalized adaptive concept maps, called as *learner's knowledge map, learning context map* and *learning objective map*. To avoid excessive cognitive load, these concept maps are typically shown to the learner only partially step by step along the learning scenario. Our proposed method aims to support learning basically with two complementing modes that can be also mixed together: assisted construction and assisted evaluation. In both modes, despite the actual direction of hyperlinked concepts each hyperlink can be traversed in both directions.

In *assisted construction mode*, the method recommends what hyperlinked concepts could be next added to learner's knowledge map to gradually approach concepts belonging to learning objective map. Two complementing approaches are available. In *focused approach*, the learner is recommended to traverse hyperlinks along learner–objective routing to reach concepts of learning objective map. In *contextualized approach*, the learner is first recommended to traverse hyperlinks along learner–context routing to reach learner–context vocabulary in learning context map. Next, the learner is recommended to traverse in learning context map the shortest hyperlink chains connecting learner–context vocabulary and context–objective vocabulary. Then the learner is recommended to traverse hyperlinks along context–objective routing to reach concepts of learning objective map. In both approaches, the learner is finally asked to traverse the shortest hyperlink chains connecting all concepts of learning objective map. Focused approach aims to emphasize the learner's personal perspective and specific conceptual details in acquisition of new knowledge whereas contextualized approach tries to emphasize collectively shared perspectives in her community and conceptual structures on a broader scale.

Based on the recommendations, the learner is expected to explore conceptual structures hyperlink by hyperlink and meanwhile to expand gradually the learner's knowledge map by adding new hyperlinked concepts to represent her knowledge acquisition process. In each step, the method shows two updated ordered lists of the currently most recommended hyperlinks to traverse next for both focused and contextualized approach, sorted in decreasing order of significance. The orderings of the lists are generated to guide the learner to proceed in the parallel hyperlink chains of routings in an order similar to breadth-first graph search algorithm. Hyperlinks that diverge from routings are also recommended but with lower rankings. Beside the hyperlinked concept, each row in the list shows a condensed relation statement extracted from the text defining the hyperlink in corresponding Wikipedia article (verb and some adjacent words nearest to the hyperlink anchor in this article). According to her needs and intuition, the learner can alternate between the two approaches and decide which one of the new recommended hyperlinks to traverse next from the currently active concept. When the learner has selected a hyperlink, the learner's knowledge map becomes expanded by adding a node labeled with the hyperlinked concept and a directed arc labeled with its relation statement pointing from currently active concept to new hyperlinked concept. In this process the learner is expected to encounter and become exposed to conceptual structures that pedagogically relate her previous knowledge to new knowledge about the learning topic. If the learner is unfamiliar with a concept recommended by the method, she is provided with a definition by showing a Wikipedia article with a corresponding title. Depending on the desired educational level, the article can be retrieved from English edition, Simple English edition or Wikipedia Selection for schools. The learning process remains relatively self-guided in all steps and it typically ends when the learner self considers that all essential hyperlinked concepts have become explored and their conceptual meanings and relationships sufficiently adopted by her.

In *assisted evaluation mode*, the learner is provided with the learner's knowledge map but without recommendations based on routings concerning what hyperlinked concepts could be next added. Two alternative types of browsing can be used. In *targeted browsing*, the learner is provided with a list of all concepts belonging to learning objective map and she is asked to expand learner's knowledge map gradually until reaching these concepts. In *open browsing*, concepts belonging to learning objective map are not revealed to the learner and she is simply asked to expand learner's knowledge map gradually until she considers that it covers the most essential concepts in the learning topic. Targeted browsing aims to emphasize learning towards predefined goals whereas open browsing tries to emphasize learning with learner-driven goal-setting. In both types of browsing, the learner is allowed to add only such a hyperlinked concept that there is a corresponding Wikipedia article directly hyperlinked from/to another Wikipedia article corresponding to a concept currently belonging to learner's knowledge map. The learner is asked to mark concepts that she considers to represent everyday knowledge or collectively shared perspectives with a label "contextualized" and concepts that she considers to represent more specific knowledge or personal perspectives with a label "focused".

The learner can freely browse various alternative hyperlink chains while trying to build a compact conceptual network that covers sufficiently the learning topic. As in assisted construction mode, the learner is expected to become pedagogically fruitfully exposed to conceptual structures about the learning topic and to adopt new knowledge while reading Wikipedia articles that define concepts previously unfamiliar to her on request. When the learner has decided to finish, the method compares how much the gradually added hyperlinked concepts, both "contextualized" and "focused", correspond to exploring the routings based on the recommendations of the assisted construction mode with contextualized and focused approaches respectively. The amount of overlap between added hyperlinked concepts and the routings is used to measure the quality of the learner's learning efforts and the method reports the matching parts to the learner as an outcome of evaluation. The learner can now still try to complete unmatching parts or directly check the recommended routings in full detail.

3. EXPERIMENT

To evaluate the educational value of the proposed method we performed preliminary testing based on simple learning scenarios about children aiming to adopt basic vocabulary used in everyday life. The key vocabularies of learner's knowledge and learning objective consisted of the highest-ranking 10 percent of the nouns in text samples provided by the learner and the Wikipedia article respectively about selected topics. The key vocabulary of learning context consisted of 100 highest-ranking nouns used by English speaking children queried from Oxford Wordlist [5] for combination of early educational levels denoted by "Rec/Prep/K" (http://www.oxfordwordlist.com/pages/search.asp). Type and size of key vocabularies were chosen based on comparative initial experiments aiming to balance compactness and coverage.

Figure 1 illustrates learning context map (a), learning objective map (b) and learner's knowledge map (c) in one of the learning scenarios concerning learning topic "child". Arc labels were omitted from the figure to preserve clarity. To indicate three-level pedagogic hierarchy for concepts, the first level has bold font, the second level normal font, the third level italics font and concepts added in the final connecting phase an asterisk. To indicate three-level pedagogic hierarchy for hyperlinks, the first level has bold arcs, the second level normal arcs and the third level dotted arcs. In the shown case, learner–objective vocabulary and learner–objective routing turn out to be empty and thus the focused approach cannot be used but contextualized approach is still applicable. Learner–context vocabulary contains concepts Father, Game, School and Sibling, and context–objective vocabulary concept Time. Between these concepts the shortest hyperlink chains in learning context map rely on the following hyperlink chains: Father<-Family->Sibling, Family<-Party->School, Family<-House<-Toy<->Game, Toy->Food->School, Party<-Holiday<->Day<->Time and Game<->Play(activity)<-Play(disambiguation)<-Party. Figure 2 shows in user interface how the learner, currently at concept Family, explores conceptual structures leading from learner's knowledge map to learning objective map, following hyperlink by hyperlink the recommendations given by the method. The method shows sequentially lists of the currently most recommended hyperlinks to traverse next and in contextualized approach these include for example (given here in preferred traversing direction that may go against the actual direction of hyperlinks): Sibling<-Family, Father<-Family, Family<-Party, Party<-Holiday, Holiday<->Day and Day<->Time. The learner is also recommended to explore hyperlinks that diverge from routings and which cross-link concepts of vocabularies. We think that even this small sample gives convincing emphasis on essential conceptual structures about learning topic "child" and indicates educationally valuable resource for adoption of new concepts and overall conceptualization of the learner.

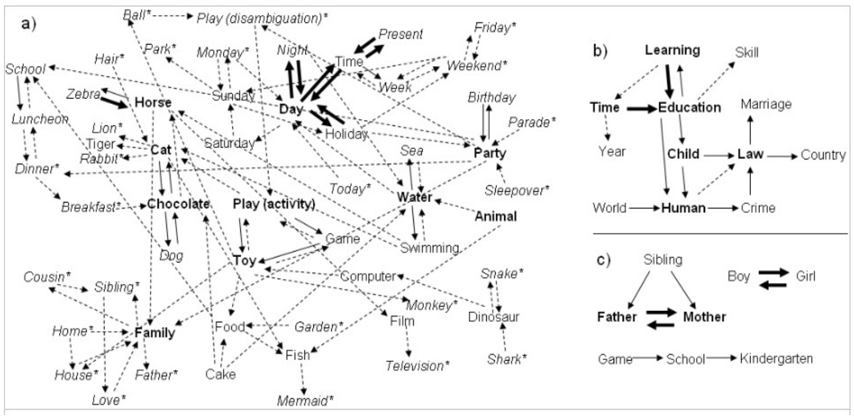

Figure 1. Learning context map (a), learning objective map (b) and learner's knowledge map (c).

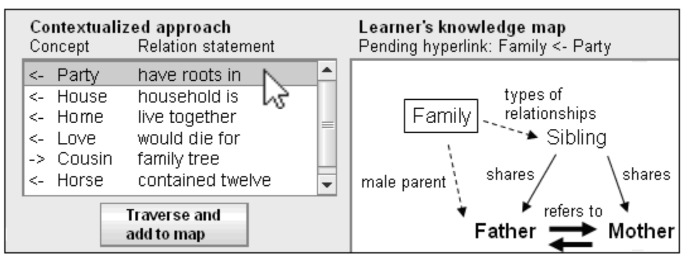

Figure 2. User interface (an excerpt) of the prototype in assisted construction mode.

To verify the suggested pedagogic value of knowledge acquisition with the proposed method we gathered an extensive collection of concept maps drawn without assistance by 102 learners describing their flow of association covering diverse pedagogic topics and containing 1827 conceptual relationships. We compared these non-automated exploration patterns to corresponding automated exploration patterns in learning concept networks containing 1601 conceptual relationships generated with the method. In statistical comparison, we found positive correlation among the highest-ranking conceptual relationships between automated and non-automated exploration patterns in various topics with overlap ranging up to 60-70 percent, thus indicating that automated method can fruitfully guide the learner's exploration along paths that are intuitively preferred in non-automated learning. With resembling positive results, we found convincing overlap even when comparing automated exploration patterns of younger learners to non-automated exploration patterns of older learners thus indicating that the method can enhance maturing of learning process. Similarly, the method seemed to enhance how individual conceptual relationships agglomerated and concept maps matured along the exploration. It thus seems that the method can support learning with recommendations based on traversing hyperlink chains to form the closest mappings between all concepts of the learning concept networks. Supplementary empirical experiments also indicated that persons representing different collaborator roles based on Competing Values Framework produced distinctive exploration patterns in collective concept mapping as suggested in our earlier work [6]. (For more details, see the author's web site: http://www.cs.hut.fi/u/llahti/publ/lahti_2011b_data.pdf.)

4. RELATED WORK

Supporting knowledge acquisition faces typical challenges of decision-making and creative problem solving. Due to complex dynamic nature of human learning, processes are hard to predict and evaluating solution candidates is costly. We think that educational methods can get useful influence from various domains, such as strategic planning, game theory and stochastic network models. Important results are that Muller games having winning condition relying on states visited infinitely often are optimally determined with finite-memory strategies [7] and that winning conditions for parity games played on pushdown graphs can be realized also by pushdown automata [8]. Some games, such as concave games and games with regret minimization, tend to converge to a Nash equilibrium [9][10]. Associations involving short time windows have been effectively modeled with artificial neural networks but for learning longer temporal relationships specific memory structures have been proposed [11]. With hidden Markov models Boyer et al. [12] automatically extracted human tutoring modes having significant correlations with student learning outcomes. Duran and Monereo [13] identified sequences of activities governing the exchanges present in peer tutoring of written composition task. Hou et al. [14] identified sequential patterns present in asynchronous discussions used for problem solving and knowledge construction.

Tetchueng et al. [15] propose learning systems with generic context-aware scenarios to deal with problem-based learning based on a didactic model and community of practices. Lee and Kwon [16] suggest an expert system supporting collective decision making relying on fuzzy cognitive mapping with dynamic weighted graphs. Osmundson et al. [17] showed that collaborative concept mapping helps learning scientific and principled information and reaching inter-connectivity between systems of the learning topic. Suthers et al. [18] showed that collaborative problem solving based on concept mapping outperformed threaded discussions and suggested a protocol for studying asynchronous collaboration. Gurlitt and Renkl [19] represented how different concept mapping tasks lead to a variety of cognitive processes, learning outcomes and perceived self-efficacy. Chujo [20] measured vocabulary levels in educational texts with a high-frequency word list based on the British National Corpus and identified a diverse set of partially shared and constantly evolving vocabularies. Hilpert and Gries [21] suggest methods for interpreting temporarily ordered stages of corpora and studying language acquisition. They argue that vocabularies and conceptual relations have different configurations for each individual, group, developmental stage and context.

Graph theoretical brain network analysis has gained promising attention and small world topology has been observed in human brain networks under various structural and functional conditions [22]. Goldstone et al. [23] argue that in dissemination of innovations in a social network, small world networks are beneficial when solving a difficult problem. Auber et al. [24] suggest that relevant information on the network can be deduced from a hierarchical decomposition into small world sub-networks and the hierarchy can be efficiently used to navigate the network. Zhao [25] demonstrated a documentation process enabling to construct and visualize small world network models and to establish the paths within the models by searching the related Web pages. Zaidi et al. [26] suggest a clustering method to identify hidden community structures and to facilitate browsing Web pages in scale-free small world network. Due to previous results and since the Wikipedia holds scale-free small world properties [27], we think that the Wikipedia's hyperlink network can inherently provide relatively optimal structure for exploring educational knowledge. In previous work we presented a concept mapping method for educational exploration in the hyperlink network of the Wikipedia based on generated lists of recommended hyperlinks for the desired learning topic [28]. Promising earlier results motivated us to develop support for acquisition of new knowledge and evaluation of learning progress with a method that enables to emphasize specific or everyday knowledge with personal or collective perspective on request.

5. DISCUSSION AND FUTURE WORK

Consensus is missing for a general learning theory and many pedagogic theories are hard to implement computationally. Despite theoretic advances, there is a lack of educational tools letting the learner to construct interactively her learning path in the light of expressive sequential model, relying on for example strategic planning, game theory or stochastic network models. To address this, we suggest one possible generalizable method to support various personalized and contextualized learning tasks and pedagogic games, currently offering guidance for complementing learning modes of assisted construction and assisted evaluation with two variants. The method also enables finding shared understanding with peers or teacher. Our method can be seen as an effort to agglomerate and synthesize parallel emerging ontologies that represent complementing perspectives of educational knowledge. We do not know any similar previous proposal. To keep our method computationally and pedagogically fluent and transparent, we used relatively simple criteria to form a learning concept network by connecting high-frequency concepts in text samples based on the shortest hyperlink chains between corresponding Wikipedia articles. As an alternative and supplementing the Wikipedia linkage the shortest paths can be retrieved from a collection of concept maps drawn by learners. The method is independent from Six degrees of Wikipedia and Oxford Wordlist. Besides retrieving learning objectives from Wikipedia articles, the method can be also applied to explore directly concept maps drawn by teacher and learners, to support reaching complementing consensus.

The current model based on learner's knowledge, learning context and learning objective could be augmented with components addressing for example types of personality, community and education. Concept ranking and hyperlink ranking schemes could take into account desired semantic relatedness measures and maturing of the Wikipedia. High-frequency concept lists and rules of conceptual chaining could be modified according to personal needs. To assure pedagogic gain, quality of text samples and exploration patterns could be socially annotated. Besides nouns, other conceptual classes could increase the pedagogic and expressive value of the method. Since small world networks seem to bind brain functions and the Wikipedia, we suggest developing related models for educational tools. Besides the Wikipedia, we expect our method to be applicable to other small world networks, such as wikis, the World Wide Web or even real-life social networks at schools. The learner could have different learning context networks defined for different school activities, collaborator roles, educational levels and so on. By comparing how different learners rely on contextual recommendations one could identify common learning challenges and match collaborators best complementing each other. Extensive further research and experiments in real educational setting are needed to augment models and make pedagogically verified tools. Since literacy is a crucial for self-sustained development for all children, we hope that future research can develop powerful sequential models for guiding the learner's exploration with any context and objective to balanced adoption of new knowledge.

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