Analysing Learner Behaviour in an Ontology-Based E-learning System: A Graph Neural Network Approach

Adam Wynn[1], Jingyun Wang[1], Zhongtian Sun[1], Atsushi Shimada[2]
[1] Durham University, UK, [2] Kyushu University, Japan
adam.t.wynn@durham.ac.uk

ABSTRACT: Despite the prevalence of e-learning systems, there is a lack of support for learners to identify and compare new knowledge with existing cognitive structures. Therefore, an ontology-based visualization support system was previously introduced which offers two modes: cache-cache, where relations are initially hidden and the learners are encouraged to create those relations, and receptive, where learners can view expert-generated topic maps. In this study, we aim to analyse learner behaviour by representing user behaviour as graphs and utilising a heterogeneous graph convolutional network. Two graphs are constructed for each student to capture behaviour before and after system use. Results indicate significant differences in mean embeddings between learners in receptive and cache-cache modes. Further analysis, considering pre-test performance, shows no significant differences in the receptive and cache-cache groups but highlights a considerably smaller mean for high prior performers in the cache-cache group.

Keywords: Meaningful learning; discovery learning; ontology; topic-map; graph neural network

INTRODUCTION

Learning strategies that support the organisation of knowledge within a hierarchical cognitive framework is highlighted by the hierarchical nature of knowledge significantly increases the learning performance of learners (Tsien, 2007). Understanding and making connections between new material and pertinent concepts are key components of meaningful learning, which is described as the substantive integration of new concepts into pre-existing cognitive frameworks (Ausubel, 1963; Ausubel et al., 1978). Despite having started to replace traditional textbooks with digital ones, existing e-learning systems lack support for learners to identify and compare new knowledge with existing cognitive structures (Wang et al, 2019a; Wang et al, 2020).

In Wang et al (2020) the authors introduce an ontology-based visualization support system designed for e-book learners, fostering both meaningful receptive learning and meaningful discovery learning. The system has two learning modes: (1) cache-cache mode where to begin with, all information regarding relations is hidden and the learners are encouraged to discover them, and (2) reception comparison mode where learners can see complete versions of expert generated topic maps. In this paper, we aim to analyse the behavioural differences among students when using cache-cache mode and receptive modes by using ontology data and log data obtained before and after the learner used the system in an existing computer science course. Analysing the learner data can reveal how the different learning modes in the system enable more effective learning of new concepts and how students explore the relationships between concepts during learning.

METHODOLOGY

This work proposed representing the user's behaviour as a graph and input into a heterogenous graph convolutional network (Wang et al, 2019b) using PyG (Fey and Lenssen, 2019) to take advantage of the multiple node and edge types. Two graphs are constructed for each student: one which represents their learning behaviour before using the system, and one for their behaviour after using the system. As shown in figure 1, each graph has page nodes which represent each page in the book, knowledge point (KP) nodes defined as "a minimum learning item which can independently describe the information constituting one given piece of knowledge in the content of a specific course" (Wang et al, 2020), and their upper concept nodes. There are edges linking each page node if the student moved to that page and stayed between 4 and 1200 seconds where the edge weight denotes the number of seconds spent on the previous page. Each page is linked to a KP if that KP is found on the page, and each KP is linked to an upper concept if the KP belongs to that upper concept.

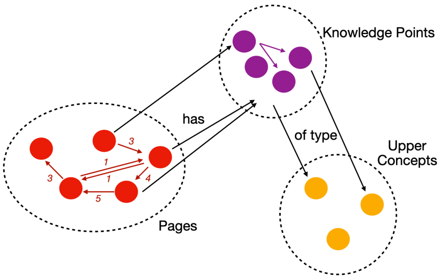

Figure 1: Representation of the graph constructed for each student

After the graphs are constructed, the model is trained on the task of link prediction between page nodes using Adam Optimizer (Kingma et al, 2014) and binary cross entropy loss. After training, three types of embeddings are derived from the last hidden layer which act as mathematical representations of each type of node in the graph. These embeddings represent how students interact with the e-books and capture nuances in their learning behaviour. Each student has two sets of page, KP, and upper concept embeddings representing their behaviour before and after using the system.

RESULTS

To analyse the effectiveness of the system, embeddings for each student before and after using the system, as well as the embeddings for the cache-cache and receptive modes are compared. In this study, we focus on comparing the average page embeddings of each student, as they best capture the behaviour of students compared to other node types. Embeddings are passed through a multilayer perceptron to be reduced to one dimension. Figure 2 shows the distribution of these embeddings.

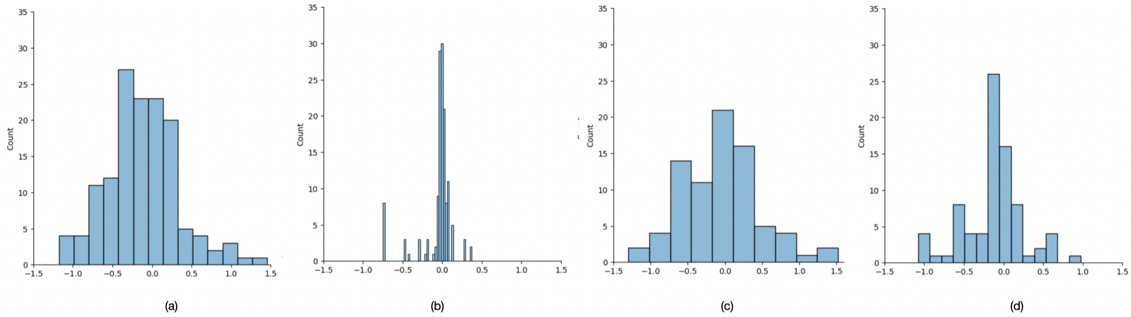

Figure 2 – Distribution of page embeddings for (a) Receptive Mode Before, (b) Receptive Mode After, (c) Cache-Cache Mode Before, (d) Cache-Cache Mode After

In Figure 3, it can be seen that the embeddings which represent learner behaviour after using the system are more clustered around the centre compared to the embeddings before using the system which are more spread out. More specifically, the "Receptive After" nodes are more clustered than the "Cache-Cache After" nodes. This could suggest that learner behaviour is more consistent with each

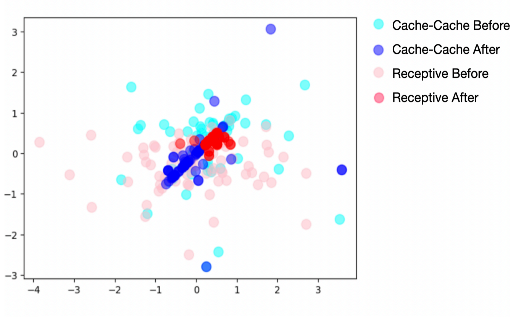

Figure 3 – Plot of Page Embeddings

other after using the system, especially for receptive mode indicating the system potentially helped students converge their behaviour on effective learning strategies.

Furthermore, a Mann-Whitney U test was performed to evaluate whether the behaviour differed by modes. The results indicated the mean page embeddings were significantly different (z=-2.582, p= 0.01<0.05) between learners in receptive mode and in cache-cache mode. Page embeddings were also analysed grouped by previous knowledge determined by pre-test. For the receptive group, the group with high performance (Mean = 0.057, S.D.= 0.212) and the group with low performance (Mean = 0.061, S.D. = 0.182) do not show significant differences. (F(1,78)=0.010, p=0.919), and for the cache-cache group, the group with high performance (Mean = 0.038, S.D. = 0.348) and low performance (Mean = 0.112, S.D. = 0.299) also do not show significant differences (F(1,78)=1.042, p=0.310), but the mean for the group with high performance is much smaller than the group with low performance.

CONCLUSION AND FUTURE WORK

In summary, this study demonstrates how log data and ontology data can be used as an input to a graph neural network to produce graph embeddings which can represent learner behaviour. Currently, page embeddings are analysed by considering the mean embeddings for all pages for each student and by reducing them to one dimension, therefore, some information in the data may be lost. In the future, we will analyse page embeddings together with KP and upper concept information in more detail by considering individual embeddings for each page.

ACKNOWLEDGEMENTS

This work was supported by JST CREST Grant Number JPMJCR22D1 and JSPS KAKENHI Grant Number JP22H00551, Japan.

REFERENCES

Ausubel, D. (1963). The psychology of meaningful verbal learning. Grune & Stratton.

Ausubel, D., Novak, J., & Hanesian, H. (1978). Educational psychology: A cognitive view. Holt, Rinehart & Winston.

Fey, M., & Lenssen, J.E. (2019). Fast Graph Representation Learning with PyTorch Geometric. ArXiv.

Kingma, D. P., & Ba, J. (2014). Adam: A Method for Stochastic Optimization. arXiv.

Tsien, J. Z. (2007 July). The memory. Scientific American, pp. 52–59.

Wang, J., Shimada, A., & Okubo, F. (2019). E-book learner behaviors difference under two meaningful learning support environments. ICCE 2019 - 27th International Conference on Computers in Education, Proceedings (pp. 342-347).

Wang, X., Ji, H., Shi, C., Wang, B., Ye, Y., Cui, P., & Yu, P. S. (2019). Heterogeneous graph attention network. In The world wide web conference (pp. 2022-2032)

Wang, J., Shimada, A., Oi, M., Ogata, H. & Tabata, Y. (2020). Development and evaluation of a visualization system to support meaningful ebook learning. Interactive Learning Environments