Higher-Order Cognition in Personalised Adaptive eLearning

Victoria Macarthur and Owen Conlan
School of Computer Science and Statistics,
Trinity College, Dublin, Rep of Ireland
macarthv@cs.tcd.ie

Abstract: In nature, the Goby fish lives in symbiosis with the burrowing shrimp; serving as a watchman in return for a place to live. Current adaptive learning systems hold an ambiguous position that attempts to compensate for real-world interaction. This paper presents a novel symbiotic-dialog approach to abstract cognitive skill training. The approach is implemented within Goby, a third-party symbiotic service that will support the acquisition of a metacognitive repertoire, within the context of a host eLearning system.

Keywords: Metacognition, Adaptive Services, Personalisation, eLearning

Introduction

E-Learning is shifting towards the individual and towards personalisation [1][2][9]. Adaptive Learning Systems (ALS) support the acquisition of diverse types of knowledge and skills, using different conditions for learning which are mediated by stereotypical traits. Mostly, they deal directly with knowledge gain rather than education of learning skills. Systems that do promote cognitive skills implement it directly into the system itself.

This paper asks whether educational systems could not only promote the acumination of knowledge, but also foster learning and higher-order skills using the service-orientated approach. These skills are antecedents of the principal aspects of positive lifelong learning such as comprehension, communication, and metacognition. It is hypothesised this could be achieved through a novel symbiotic-dialog approach. This approach proposes a discrete service could work in collaboration with eLearning systems, while engaging in a dialog with the learner to support the acquisition of their abstract cognitive skill repertoire. This approach has been implemented in Goby, a third-party contextually-aware service that works with a host ALS. The following describes ALS, symbiosis and dialog within a service oriented approach, modelling cognition, and an example of use.

1. State of the Art

1.1 Adaptive Learning Systems

Adaptive Learning Systems provide an advanced learning environment that attempts to meet the needs of the individual rather than the many. The basic principle of an adaptive system is to collect data, both directly and indirectly, to infer abstract user characteristics and make assumptions about how best to change the course [2][9]. According to constructivist learning theories, how we interpret experiences and learn depends on what we already know. Personalisation is intended support the activation of appropriate mental models, resulting in deeper processing. A user model determines adaptation by identifying the learner's progress. It is represented as a set of information structures which infer assumptions about knowledge or skills, cognitive abilities, objectives, motivation, learning style, preferences, tasks and abilities [2][9]. Each system deploys assessment and adaptation decision-making [2]. Adaptive presentation techniques alter the multimedia, available content, structure and order [2][9]. Adaptive learning supports dynamic learning patterns that adjust to learners' preferences, goals or cognitive competencies [9].

Conventional ALS deal directly with knowledge gain rather than the acquisition of learning skills. However, there are a number of learning environments explicitly support cognitive development within a domain. They deal with such skills as monitoring, regulation, reflection, regulation and evaluation [4] with domains such as sciences and problem solving [6]. Previous approaches to measuring skill mastery use belief networks, Bayesian networks [3] and machine learning techniques [4]. This paper proposes that a learner's skills and traits are modelled in a fashion analogous to our own cognitive mental models and schemata. It is also proposed that the abstract cognitive support may be delivered as part of Service-Orientated Architecture.

1.2 Higher-order Cognitive Skills

Cognition refers to the mental activities and functions through which human beings acquire and process knowledge including learning, memory, and thought. It is mediated by biological, emotional, and social influences [11]. Higher-order cognitive skills develop from earlier complimentary skills. There are a multitude of higher-order skills that are similar in their importance to learning, yet difficult to quantify. Metacognition was identified as a candidate for the symbiotic-dialog approach as it is complimentary to learning, and may be understood in terms of the useful cognitive traits and activities [5][8]. Metacognition [5][11] relates to a multifaceted theory of the complimentary psychological functions, which actively monitor and consequently regulate cognitive functioning according to the current state of an individual.

2. The Symbiotic-Dialog Approach to Abstract Cognitive Skills Training

2.1 The Symbiotic-Dialog Approach

The purpose of the symbiotic-dialog approach is to support the acquisition of a particular cognitive competence that lies implicitly outside of the academic domain. When implemented within Goby, it is envisioned as a third-party service that offers advice and actively promotes higher-order cognitive skills while the learner engages in an ALS.

Service-Oriented Architecture dictates that one component need not control all functionality. Complimentary services are loosely coupled in order to function as a more complex system. The notion of a dialog represents an ongoing communication between entities to increase understanding and derive meaning. The dialog driven approach to symbiotic service development engages with the learner through a number or prompts or questions. Prompts implicitly update the conceptual schema, while answers to questions explicitly update it. A symbiotic service that works with ALS gathers implicit user model information in order to make inferences of its own. Such a service will actively engage in a dialog promoting abstract tasks and traits that are complimentary and contextually related to the successful completion of the eLearning course (See Fig 1).

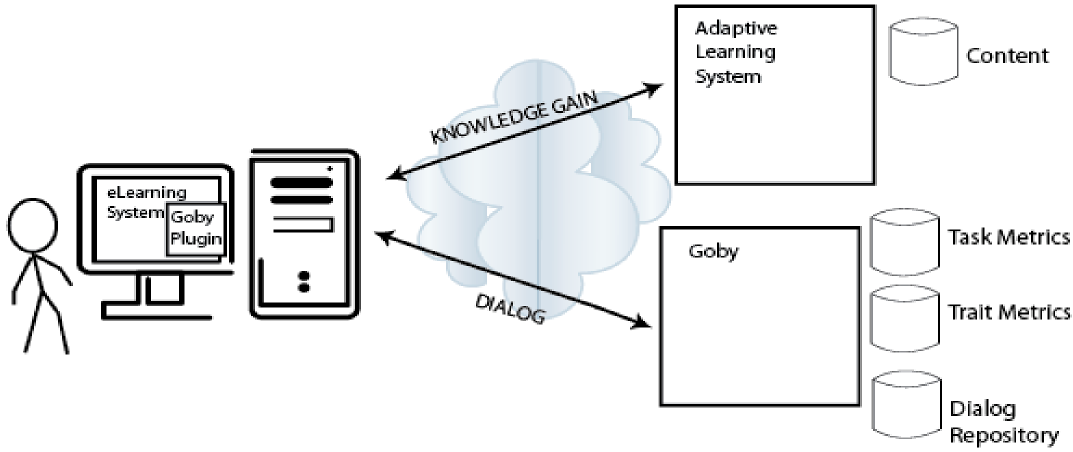

Fig 1. Goby System Diagram

2.2 Modelling Abstract Cognitive Skills

There are few generic models of higher-order cognition designed to use with eLearning systems [6]. Within the symbiotic-dialog approach, aspects of learners' cognition are described according to a generalised schema. In this case, the *schema* refers to generalisations about higher-order cognitive skills, derived from psychometric factor analysis [10] and research that organises and guides the processing of cognitive skill information [7]. The activation of schemata occurs as concepts are encountered, permitting predictions, inferences, and creates expectations.

Each cognitive skill is viewed as having both *traits* and *tasks*, which are described according to a schema or blueprint. These schemata express attributes including value, confidence in the value, and order. They also depict relationships with other elements. *Traits* represent dispositions, which when described on an inventory or test, are understood as a number of individual factors. A factor represents an individual item, whereas a trait is a complex characteristic. Similarly, a *task* refers to a general goal that is comprised of several activities. Each fact is distinguished by its value and a measure of confidence in the accuracy of that value on a 5-point Likert scale; its relationships or dependencies with other facts; and context in which it is activated or altered. The establishment of mental models result from complex networks of information necessary according to the learners' schema, task goals, and comprehension of performance. These mental models are represented as instances of facts that denote the current values of those attributes according to the current schema and the task.

Technologically each of these concepts is a representation as a number of rules and facts within a rules engine with a particular context. These facts are stored as persistent data in a database. On instantiation, the service builds initial facts about each individual factor. The learner is initially represented with stereotypical values for these factors, and a low confidence is given to these ratings. This confidence grows over time as the service engages in a dialog with the learner.

2.3 Implementing Metacognition within the Goby service

Metacognition has been divided as two classes: traits and tasks. The Metacognitive Awareness Inventory (MAI) [10] outlines metacognitive *traits*. It encompasses skills such as evaluation, debugging, comprehension, and planning. The categories within this inventory are representative of traits and the individual items as their relevant factors. This is a hierarchical relationship as each trait may have a number of factors, and factors belong to particular traits. The metacognitive *tasks* have been obtained from constructively responsive protocols identified as being successful for reading academic works [7]. For example, the task schema for 'Before you Begin' comprises of activities such as *constructing a goal* and *over viewing an activity*. Each of the component factors and activities describes attributes such as value, order, and a measure of confidence.

2.4 Technological Framework

In order to achieve the metacognitive learning that Goby brings, it is necessary to engage in a constructively responsive dialog with the learner, both directly and indirectly. This will grant the learner with a vocabulary of metacognition so that they may understand and describe their metacognitive processes. A series of operations within a rule engine determine the status of the learner schema and the data flow therein. These rules define how interactions are represented; the schema is updated; and dialog is contextualised.

The level of dialog with which the learner may engage with Goby varies. The learner may use the service as a reflection tool by accessing a visual representation of progress over time. They may receive prompts from the service, or answer questions about a particular fact. This may activate a particular factor or activity and implicitly or explicitly update the cognitive skill schema. At a functional level Goby is related conceptually to abstract-cognitive skills and their description within a schema as a series of traits with factors and tasks with activities. It is implemented as a discrete third-party service, written with Java, JBoss Rules, XML, and open-source native database technologies.

3. Hypothetical Example of Use

Suppose a learner is engaging in an introduction to Java learning scenario. In terms of the planning trait, important factors are: pace, thinking about learning, goal setting, self-questioning, strategy selection, reading instructions, and time organisation. The 'before' task that corresponds to the planning trait comprises seven activities such as *constructing a goal*, *over viewing a learning activity*, and *deciding to only do particular sections*. Initially, Goby derives values from stereotypical user groups.

The learner selects their topic: 'Java Objects' in the ALS. Goby implicitly understands that the first activity they should undertake is to 'construct a goal'. Goby identifies 'goal setting', and 'think about necessary learning' as candidate factors that support this activity. 'Goal setting' has a greater relative utility according to its importance. On initialisation, the value of 'goal setting' is set to the stereotypical value (three on the Likert scale) with a low measure of confidence (two on the Likert scale). As the measure of confidence is low, the learner is explicitly questioned: 'Have you set a specific goal before you begin your task?" Answering yes increases the value and confidence of 'goal setting'. Continued dialog with the learner and monitoring of their progress in the ALS builds a confident view of the trait facts and the tasks facts, which in turn directs future dialog.

4. Conclusion

State of the art of adaptivity within eLearning holds an uncertain position that attempts to ground eLearning technologies within cognitive and learning paradigms in order to advance knowledge gain. Goby implements a novel approach to cognitive skills learning as a service-based system. This new 'dialogic approach to symbiosis' is derived from literature on cognitive learning theories and adaptive eLearning. Goby embraces the notion that modelling higher-order cognition is too complex to easily discern. Instead, it views a learner's cognition according to the traits and tasks that have been identified, which are modelled as schemata. The aim is to enhance learning by incorporating abstract skills that are taught implicitly in the classroom but lie outside the traditional academic domain. Goby does this through engaging in a number of levels of dialog with the learner, from prompts to questions. It is implemented as a third-party service, which works in symbiosis with host ALS as this contextualises the abstract cognitive skill learning. At this stage it is necessary to evaluate the Goby *in vivo*, as a stand-alone service. Currently, Goby models the learner schema and selects prompts or questions according to the relative utility of factors and activities. Next, it will be integrated with an ALS. It is predicted that the contextualisation of the service will depend on the quality and availability of the ALS metadata. The results from this experiment will dictate future development and further understanding of cognitive interventions that are mediated by technology.

Acknowledgements

This work has been funded by the Irish Research Council for Science, Engineering and Technology: funded by the National Development Plan.

References

[1] Brown, E., Brailsford, T., Fisher, T., Moore, A., Ashman, H.: Reappraising Cognitive Styles in Adaptive Web Applications. In: WWW 2006. (2006), Edinburgh, Scotland

[2] Brusilovsky, P.: Developing adaptive educational hypermedia systems: From design models to authoring tools. In: Murray, T., Blessing, S. (Eds.) Authoring tools for advance technology learning environment. (2003) 377–409 Dordrecht: Kluwer Academic Publishers

[3] Conati, C., Gernter, A., VanLehn, K. (2002). Using Bayesian Networks to Manage Uncertainty in Student Modeling. Journal of User Modeling and User-Adapted Interaction 12: 371 – 417.

[4] Ferguson, K., Arroyo, I., Mahadevan, S., Woolf, B., & Barto, A. (2006). Improving Intelligent Tutoring Systems: Using Expectation Maximization to Learn Student Skill Levels. Intelligent Tutoring Systems 4053: 453 – 462.

[5] Flavell, J.: Metacognitive development. In: Scandura, J. and Brainerd, C. (Eds.) Structural Process of theories of complex human behaviour. (1978) Netherlands: Sijthoff and Noordhoff

[6] Gama, C. (2004). Metacognition in Interactive Learning Environments: The Reflection Assistant Model. ITS, 3220: 668 – 677.

[7] Pressley, M. Afflerback., P. (1995). Verbal Protocols of Reading: The Nature of Constructively Responsive Reading. Hove, UK, Lawrence Erlbaum Associates, Publishers.

[8] Pintrich, P., Wolters, C., Baxter, G.: Assessing Metacognition and Self-Regulated Learning. In: Schraw, G., Impara, J. (Eds.) Issues in the Measurement of Metacognition (2000) 43–98 Nebraska-Lincoln: Buros Institute of Mental Measurements

[9] Ruiz, M el P., Diaz, M. J. F., Soler, F. O., & Perez, J. R. P. (2008). Adaptation in current e-learning systems. Computer Standards & Interfaces 30: 62 – 70.

[10] Schraw, G. D., Dennison R. S. (1994). Assessing Metacognitive Awareness. Contemporary Educational Psychology 19: 460-475.

[11] Vygotsky, L.S.: Mind in Society: Development of Higher Psychological Processes (1978) Cambridge: Harvard University Press