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Swarm-based wayfinding support in open and distance learning

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ABSTRACT

Open and Distance Learning (ODL) gives learners freedom of time, place and pace of study, putting learner self-direction centre-stage. However, increased responsibility should not come at the price of over-burdening or abandonment of learners as they progress along their learning journey. This paper introduces an approach to wayfinding support for distance learners based on self-organisation theory. It describes an architecture which supports the recording, processing and presentation of collective learner behaviour designed to create a feedback loop informing learners of successful paths towards the attainment of learning goals. The approach is presented as an alternative to methods of achieving adaptation in hypermedia-based learning environments which involve learner modelling.

INTRODUCTION

Open and Distance Learning (ODL) gives learners freedom of time, place and pace of study, putting learner self-direction centre-stage. Brocket and Hiemstra (1991) define learner self-direction as the learner's assumption of "primary responsibility for and control over decisions about planning, implementing and evaluating the learning experience" and Hiemstra (1994) notes learners' preference to take on responsibility for their own learning. However, taking on new responsibilities is not without its challenges. Brookfield (1985) notes that although self-directed learning "has connotations of autonomy, independence and isolation", investigations have highlighted that "adults would like more, rather than less, assistance in their learning pursuits". Similarly, Candy (1991) writes that self-directed learners are often challenged to assume certain responsibilities, and that when deciding how to approach learning tasks, the self-directed learner is "confronted with the problem of how to find a way into and through a body of knowledge that is unknown at the outset. Without the benefit of any explicit guidance, a self-directed learner is obliged to map out a course of inquiry that seems appropriate, but that may involve a certain amount of difficulty and disappointment that could have been averted." Candy's description calls to mind the image of the distance learner as navigator, charting a course through educational waters, following Darken and Silbert's (1993) definition of navigation as the "process of determining a path to be travelled by any object through any environment". In subsequent work, Darken and Peterson (2002) use the term 'wayfinding' to refer more specifically to the navigator's decision making process. We use the term "Educational wayfinding" to describe the cognitive, decision-making process carried out by self-directed learners as they assume responsibility for choosing and sequencing their learning events. The wayfinding decisions with which learners are faced arise from the freedom offered to them by learning providers on their way to the attainment of particular goals. In some highly constrained situations, both the choice of learning events and their ordering may be fixed by a learning provider. More likely, learners may be permitted to select and order modules, perhaps to accumulate credit points towards a certificate. In this context, we note Yorke's (1999) warning that "as the unitization of curricula spreads through higher education, so there is a need for greater guidance for students to navigate their way through the schemes". This provides the background to this chapter: difficulties in the educational wayfinding process can lead to learners not reaching their goals, or taking unduly long to do so. The rationale for our work is that self-directed learners can benefit from support in the educational wayfinding process, and we describe a new approach to supporting the educational wayfinding process which has the potential to address the drawbacks of existing approaches found in the literature. We examine a number of alternatives to the provision of such support, and introduce our approach to issue, which builds on self-organisation theory.

APPROACHES TO WAYFINDING SUPPORT IN ODL

There are a number of approaches to wayfinding support used today in ODL in addition to those identified in ODL research but not yet widely implemented.

The first approach involves fixing routes though materials in advance of their delivery, creating curricula or content plans to be followed by learners thereby reducing navigational choices. However, this pre-planning limits the possibilities for learner self-direction, and Evans (1994) notes that the didactic models used in open and distance education are often "founded on highly didactic models which provide [the students] with little control over their own learning … and the students are left with little option but to adhere to the curriculum". This observation suggests the need for a flexible, adaptive approach to wayfinding support.

Such flexibility can be realised through so-called "learner support services" (Simpson, 2000). Although capable of providing highly individualised advice, learner support services do not come without a price. Costs are likely to be variable with student numbers and be exacerbated by the less predictable, demand driven nature of ODL.

A significant amount of research has explored the creation of *educational hypermedia systems* (De Bra, 2002) as part of the Adaptive Hypermedia research area (Brusilovsky, 2001; Cristea & De Bra, 2002). Thus activity continues the research line established in the eighties in the area of Intelligent Tutoring Systems, and seeks to "build a model of the goals, preferences and knowledge of the individual user and use this through the interaction for adaptation of the hypertext to the needs of the user" (De Bra, Brusilovsky, & Houben, 1999).

User models are representations of a world outside the computational environment and may contain wrong, outdated or inadequate information (Fischer, 2001). A case in point is cited by Kilfoil et al. (2003) - the digital video recorder automatically recording programs it assumes its owner will like, yet based on an inappropriate assumption regarding the owner's lifestyle. As De Bra notes (2000), "bad guidance is worse than no guidance". Self (1987), writing over 15 years ago, noted the absence of a theory of learning which might be used to maintain learner models. In a later article (1990), Self describes the scope of the student modelling problem—"from computational questions, to representational issues, through plan recognition, mental models, episodic memory to individual differences – to encompass, it would seem, almost all of cognitive science". Concerns on the practical application of User Modelling continue to be raised (Atif, Benlamri, & J., 2003; Kay, 2001; Strachan, Anderson, Sneesby, & Evans, 1997).

This raises a research question for cognitively-informed systems: Is there an alternative approach to wayfinding guidance in ODL which might provide a cost-effective solution yet which does not rely upon learner modelling?

SELF-ORGANISATION AND WAYFINDING

The previous section reviewed three sources of wayfinding support—*course designers*, attempting to predict efficient paths, *learner support services*, providing flexible advice but at a price, and *adaptive hypermedia systems*, still challenged to prove their practical application. A fourth source can be found in the social context of learning, a point noted by Brookfield (1985) when he states that the "successful self-directed learners … place their learning within a social setting in which the advice, information, and skill modelling provided by other learners are crucial conditions for successful learning". This observation finds echoes in the information navigation literature, where the term *social navigation* (Höök & Benyon, 2003) has been coined to describe research reflecting the fact that "navigation is a social and frequently a collaborative process" (Dieberger, 2003). This point is also made by Forsberg et al. (1998) who state that "most information navigation in the real world is performed through talking to other people". However, we need to question whether learners would be prepared to support their peers in advice-giving dialogues given the pressures on their time.

In fact, social navigation does not always involve direct interaction. The field has been divided into two areas of research . The first, *direct* social navigation, sees actors as "co-present and in direct contact with one another" (Dieberger, Höök, Svensson, & Lönnqvist, 2001). In contrast, *indirect* social navigation exploits traces of interactions left by others (Shipman et al., 1996; Wexelblat, 1999). Applications of indirect social navigation can be found in the educational literature (Shipman, Furuta, Brenner, Chung, & Hsieh, 2000; Zeiliger, Reggers, Baldewyns, & Jans, 1997), although the focus has tended to fall on teachers or students pre-defining trails through information space for others to follow later. This approach brings with it a certain cost to the ODL learner who may not be disposed to investing time and effort to create a trail for unknown learners coming along later. The ideal approach would avoid anyone pre-creating wayfinding guides and have them somehow "emerge" so that learning processes, as it were, spontaneously acquire (sequential) structures or organisations. This is the language of self-organisation—"the spontaneous formation of well-organised structures, patterns or behaviours, from random initial conditions" (Soraya Kouadri et al., 2003). Indeed the "acquiring of spatial, temporal or functional structure" is seen as the essence of self-organisation by Hadeli et al.(2003), and is echoed by Heylighen and Gershenson (2003)—"a self-organizing system not only regulates or adapts its behavior, it creates its own organization. In that respect it differs fundamentally from our present systems, which are created by their designer."

Bonabeau, Dorigo and Theraulaz (1999) give ant foraging trails as an example of the spatiotemporal structures which emerge as a result of self-organisation. The ability of ants to find efficient (i.e. short) routes between nests and food sources suggests an approach to cost-effective, flexible and implementable wayfinding support. Paths identified by ants are not pre-planned, but emerge, spontaneously, as a result of indirect communication between members of an ant colony—a form of indirect social navigation. Dorigo and Di Caro (1999) describe how ants deposit a chemical substance known as pheromone which can be sensed by other ants. When a navigational decision has to be made, such as taking a left branch or a right one, ants make a probabilistic choice based on the amount of pheromone they smell on the branches. Initially, in the absence of deposited pheromone, each of the branches is chosen with equal probability. However, if one branch leads to food faster than the other, ants on their way back will select the shorter branch due to the presence of the pheromone they deposited on the forward journey. More pheromone is deposited, leading to more ants selecting the shortest path, and so on, creating a feedback loop which leads ants along efficient paths to their destination. This process of indirect communication exploited by members of ant colonies is known as *stigmergy*. In their overview article, Theraulaz and Bonabeau (1999) state, "The basic principle of stigmergy is extremely simple: Traces left and modifications made by individuals in their environment may feed back on them…. Individuals *do* interact to achieve coordination, but they interact indirectly, so that each insect taken separately does not seem to be involved in coordinated, collective behavior". Stigmergy, self-organisation and ant-colony algorithms are the subject of much interest in the computer science community for optimisation and routing problems (Di Caro & Dorigo, 1998; Dorigo, Bonabeau, & Theraulaz, 2000; Schoonderwoerd, Holland, Bruten, & Rothkrantz, 1996). The application of stigmergy is also being explored in the e-learning domain (Dron, 2002; Dron, Boyne, & Mitchell, 2001), albeit not in the area of wayfinding support.

In the educational arena, efficient paths are not defined in terms of distance, but rather time. We can imagine learners' interactions with learning resources being recorded automatically as they progress through a body of knowledge. The time-stamping of these interactions allows sequences to be identified which can be processed and aggregated to derive a given "pheromone strength" favouring paths which are faster to complete. This information can be fed back to other learners, providing a new source of navigational guidance indicating "good" ways through the body of knowledge—a self-organising, stigmergic approach to wayfinding support. Such an approach seems to provide an answer to ODL needs in this area. It is cost-effective, since trail creation occurs unnoticed as a side effect of learner interaction with e-learning systems, it is flexible, able to emerge from and adapt to different circumstances, and holds the prospect of being implementable, since its adaptivity (Cristea & De Bra, 2002) does not depend upon learner modelling. Indeed, such an approach abstracts entirely from the characteristics of individual learners, relying instead on the collective behaviour of the swarm of learners to identify efficient paths.

The next section introduces an architecture which supports the feeding back of collective learner behaviour to support learners in reaching their educational goals efficiently.

A SOFTWARE ARCHITECTURE FOR WAYFINDING SUPPORT

Our work on ODL wayfinding support is being carried out within the context of a larger R&D programme, designed to help the creation of flexible learning facilities that meet the needs of learners at various levels of competence throughout their lives. We refer to these network facilities for lifelong learners as “Learning Networks” or LNs (Koper et al., 2004). Learning Networks support seamless, ubiquitous access to learning facilities at work, at home and in schools and universities. Learning Networks consist of learning events, called Activity Nodes (ANs) in a given domain. An AN can be anything that is available to support learning, such as a course, a workshop, a conference, a lesson, an internet learning resource, etc. Providers and learners can create new ANs, can adapt existing ANs or can delete ANs. An LN typically represents a large and ever-changing set of ANs that provide learning opportunities for lifelong learners (“actors”) from different providers, at different levels of expertise within the specific disciplinary domain.

Wayfinding support in LNs relies on the following concepts:

- The learner’s *goal* is a description of the level of competence a learner wants to achieve (for example, the bachelors or masters level in a particular discipline).
- A *route* is a plan to reach a goal, described as a series of selections and/or sequences of ANs. ODL providers offer programmes with curricula (i.e routes) by which individuals can reach their goals.
- A *Learning Track* is the sequence of ANs successfully completed by a Learner;
- The learner’s *Position* is the set of ANs which have actually been completed (i.e. the Learning Track) together with those which can be considered as completed, perhaps as a result of exemptions arising from previous study or work experience.

Position and goal equate to “you are here” and “there’s where I want to be”, respectively, and the wayfinding guidance which is fed back concerns effective ways of getting from here to there, based on the behaviour of previous learners along the available route(s).

The architecture we propose combines elements which record, collect, process and present collective learner behaviour. Andersson et al. (2002) use the phrase *Emergent Interaction Systems* to describe systems which “consist of an environment in which a number of individual actors share some experience/phenomenon. Data originating from the actors and their behaviour is collected, transformed and fed back into the environment. The defining requirement of emergent interaction is that this feedback has some noticeable and interesting effect on the behaviour of the individuals and the collective - that something ‘emerges’ in the interactions between the individuals, the collective, and the shared phenomenon as a result of introducing the feedback mechanism.”

The ‘something that emerges’ in our situation are paths through bodies of knowledge, rather like well-worn footpaths in forests. Our initial focus is on *efficient* paths, that is, those which minimise the time taken to reach a certain goal from a particular position. Subsequent research will investigate *attractive* paths, those rated highest by other learners, in line with work on recommender systems (Herlocker, Konstan, Terveen, & Riedl, 2004; Resnick & Varian, 1997).

Central to the approach are logs of learner information indicating what learners did and when. The use of internet technologies in e-learning has brought with it an increase in the level of standardisation of transmission protocols and data, and logging information is no exception. The World Wide Web Consortium has defined Common and Extended Log File Formats (World Wide Web Consortium, 1996) and a whole area of research is now dedicated to the processing and analysis of these files for various purposes, known as Web Usage Mining (Punin, Krishnamoorthy, & Zaki, 2001; Spiliopoulou, Pohle, & Faulstich, 1999; Srivastava, Cooley, Deshpande, & Tan, 2000). The techniques have also been applied in education (Sheard, Ceddia, & Hurst, 2003; Zaïane, 2001).

However, the events which are registered in these logs are extremely low level. This complicates their analysis, making it difficult to know which users are interacting (since only IP addresses are logged) and what they are doing (since only cryptic Uniform Resource Locators (URLs) are logged). Oberle et al. (2003) note that "an interpretation of URLs in terms of user behaviour, interests and intentions is not always straightforward … web usage analysis is not interested in patterns of URLs but rather in patterns of application events". The route to solving this problem taken by Oberle et al. is to enhance the logs with additional information drawn from a formal ontology. However, the characteristics of our domain suggest a different type of log is more appropriate, one incorporating a higher level of application event and which records not only which learner did what, but also whether or not this was successful (eg by including the results of an assessment).

Such a level of logging is available in the learner records data store described in the IEEE Draft Standard for Learning Technology — Learning Technology Systems Architecture (IEEE, 2001). This data store, specifically designed to cater for the nomadic nature of lifelong learners, is defined as a repository of "learner information, such as performance, preference, and other types of information. The learner records may store/retrieve information about the past (e.g., historical learner records), but may also hold information about the present (e.g., current assessments for suspending and resuming sessions) and the future (e.g., pedagogy, learner, or employer objectives)".

With these notions in place, the elements of an architecture for self-organising wayfinding support for learners can be introduced (Figure 1).

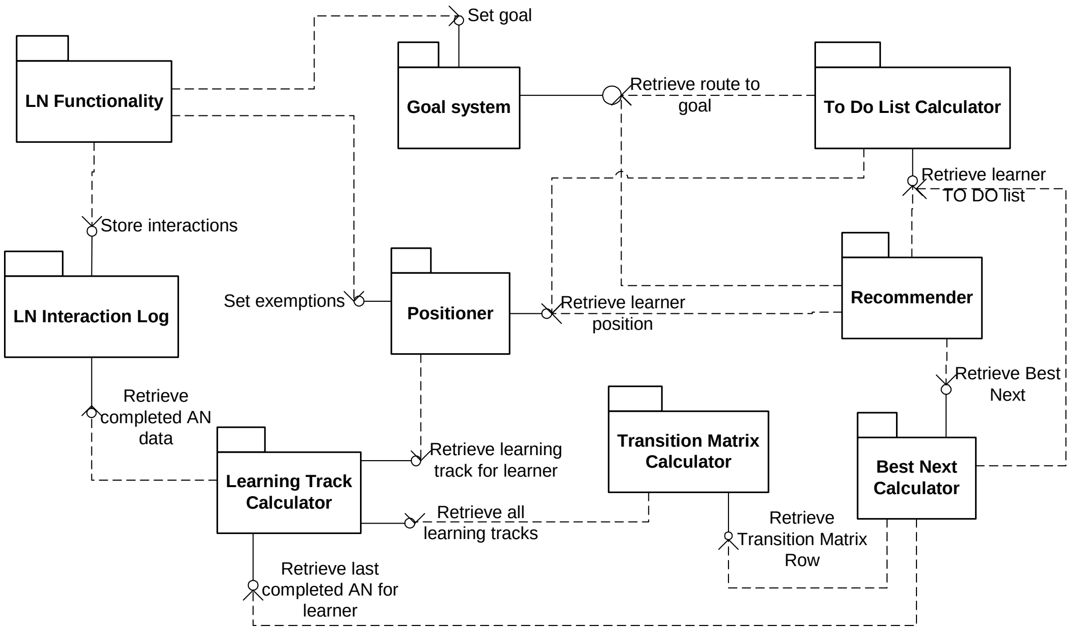

Figure 1. A software architecture for wayfinding support for learners.

Learners interact with the *LN Functionality* available in a learning network (Koper et al., 2004). Part of the functionality available allows learners to select from a list of the learning goals in a learning network (the *Goal system*), and thereby also identify the route to the goal. Learner interaction is stored in an *LN interaction log* (i.e. a Learner Record Store as described above), including information on the learner, the AN, a timestamp and an indication of performance (for example, pass or fail). This information can be processed to create sequences of ANs successfully completed by learners (done by the *Learning Track Calculator* – see Mobasher (2004) for an examination of the techniques involved). Using information on the tracks of all learners, a transition matrix (Deshpande & Karypis, 2004) can be calculated (by the *Transition Matrix Calculator*) over pairs of ANs, indicating, for each *from* node, how many learners have successfully progressed to the following *to* node (see Figure 2).

	A	**B**	**C**	**D**	**E**
{}	1	3	2	4	5
A		4	2	5	1
B	2		2	1	3
C	3	4		1	2
D	4	2	4		5
E	1	2	5	3	

Figure 2. A transition matrix showing learner transitions *from* ANs (rows) *to* other ANs (cols).

The *Positioner* deals with the maintenance of the ANs which have been completed by learners, or can be considered as having been completed. The former is straightforward to calculate, since it is the Learning Track for a given leaner. The latter, referred to as the Recognition of Prior Learning or Prior Learning Assessment (Breier, 2005; Starr-Glass, 2002), is considerably more complex (see Van Bruggen et al. (2004) for an examination of approaches to this problem).

The *To Do List Calculator* maintains the difference between the requirements expressed in the route associated with the learner's goal, and his or her current position. Using the transition matrix and the Learner's To Do list, the *Best Next Calculator* selects an AN to recommend based on the progress of the swarm of other learners. The algorithm used to select the AN from the candidates is that described by Koper (2005). Using the transition matrix shown in Figure 2, if we imagine a learner having just completed the AN labelled 'A' and *en route* to a goal which requires A, B, C, D and E to be successfully completed, a list is first drawn up of all the transitions made from A by all previous learners (i.e. 4 from A to B, 2 from A to C, 5 from A to D and 1 from A to E):

[B, B, B, B, C, C, D, D, D, D, D, E]

The recommendation is identified by drawing one item randomly from this list. The result is that the most frequently followed path has a higher probability of being selected (in this case A to D), although, to prevent sub-optimal convergence to this path, there is a chance that the other paths (A to B, A to C and A to E) will be selected. The use of randomness in the procedure follows the ingredients for self-organisation described by Bonabeau et al. (1999).

The final component in the architecture is the *Recommender,* which pulls together the various pieces of information to present a coherent picture to the learner, including information on the learner's goal, position, to do list and the recommendation itself. Figure 3 shows a prototype of the recommender, implemented in the open source Virtual Learning environment Moodle (Dougiamas, 2004).

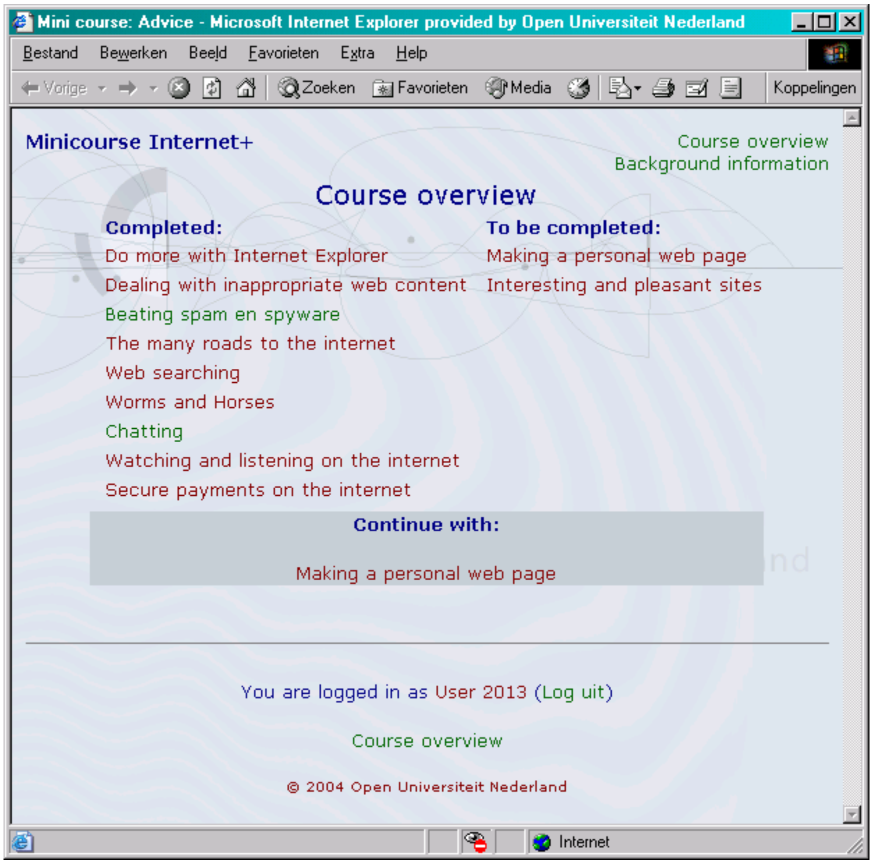

Figure 3. The prototype Recommender component

DISCUSSION

This chapter has described the rationale behind our research into self-organising wayfinding support, and described an architecture for its provision. Our approach is designed to adapt support for decisions on the sequencing of learning events not on the basis of a model of the individual learner but using information on the collective behaviour of the swarm of other learners.

We are currently carrying out experiments to measure the actual value of the approach using two groups of learners. One group of learners will receive feedback on how others have progressed to their shared target, the other group will be left to their own devices, and we will compare the numbers of learners who manage to reach the goal in a given time period. The results of the experiment will be used to determine whether to adopt the approach on a larger scale in our institution.

In conclusion, our work is intended to open a new source of information to help learners in deciding how to progress towards their learning goals using a feedback loop on how others with shared positions and goals have fared. The envisaged feedback loop has an advisory character, not intending to push all learners down a single path as quickly as possible but rather to allow learners to make informed choices concerning steps on their learning journey.

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