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USING CONSTRAINTS AND HYPOTHETICAL REASONING IN HYPERMEDIA EXPLORATION FOR EDUCATIONAL PURPOSES

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ABSTRACT: We present a hypermedia model for educational applications, addressing the problem of exploratory navigation into the hyperspace from the viewpoints of context establishment, assistance against disorientation and reporting on the learner's activities. We argue for the need to extend the conventional hypermedia framework with the introduction of constraint satisfaction and hypothetical reasoning. We focus on constraint programming techniques and abductive reasoning and we show how such an enhanced model can address the aforementioned problem for educational hypermedia applications.

1. INTRODUCTION

When the learner uses an educational application organised for exploratory learning ([2]), she is expected to formulate her own conceptual model ([7]) of the information offered implicitly or explicitly by undertaking initiatives, materialising and testing ideas, shortly by developing a critical thinking ([12]). This process requires the continuous supervision of and cooperation with the teacher. However, in many practical circumstances, notably in distant learning, the teacher interacts with the learner only periodically.

The examination results are a source of information on the learner's mental progress. However, the teacher needs more straightforward information on the learner's exploratory activities and on its interaction with the course subject. This information can only be provided by the material accumulated in the computer, which must hence be processed in a way appropriate for fruitful inspection by the teacher. We study this problem in the context of a hypermedia network enhanced with limited reasoning capabilities based on the abductive inference mechanism and the use of real-time constraints.

The hypermedia paradigm is very appropriate for explorative educational applications: the information space for many educational subjects can be organised as a hypermedia network, in which the nodes bear semantic information and the links materialise semantic relationships. The information space is usually explored in a navigational way, traversing links ([8,11,13]), whereby not only the visited nodes are of importance, but also the links crossed to reach them. Hypermedia navigation is itself educationally important, because it can free the learner from the "linear thinking" to which she is forced by the sequential form of an ordinary course/book,

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enabling "non-linear thinking" ([1]). Hence, hypermedia not only introduce new ways of learning but also insights to the *meaning of learning* ([10]).

In the following, we present a hypermedia model for educational applications. We address the issue of exploratory navigation into the hyperspace from the viewpoints of context establishment, assistance against disorientation and reporting on the learner's activities. We argue for the need to extend the conventional hypermedia framework with the introduction of constraint satisfaction and hypothetical reasoning. In particular, we focus our attention on constraint programming techniques and abductive reasoning and we show how such an enhanced model can address the aforementioned problems in the area of hypermedia for education.

2. VIEWS AND CONTEXTS OVER THE HYPERSPACE

Pragmatic considerations in the implementation of multimedia/hypermedia applications lead to the accumulation of information pieces into the application database, which exceed the needs and scope of any particular course, for which this information is envisaged. Rather, the material of such an application covers more than one --consecutive or independent-- courses, and can be studied from more than one perspectives, in much the same way as literature for teaching contains both introductory and advanced, informative and technical, descriptive and formalised parts for more than one courses. Thereafter, a course can be organised by establishing a *view* ([5]) containing only the material related to the specific course.

A view is by nature a static mechanism that may be customised by the teacher but should not be modified by the learner. On the other hand, it is imperative to provide the learner with a mechanism for the specification of a viewpoint or for the refinement of the view's content. Hence, we introduce the notion of the "context", as the collection of information pieces and/or links that satisfy specific requirements, related both to the properties of the information space and to the characteristics of the learner using it.

The distinction between view and context within a view lays at a semantic level: we observe the view as an overall collection of material to be studied, while the context forms a specific aspect of observing that collection. For example, let us consider a course on the geography of "our country" for pupils of a specific age. The country of interest can be specified as a static view by the teacher. If different viewpoints are considered, such as political and economical geography, these should also be specified as subviews. On the other hand, specifications such as the age of the learner and the duration of the course, which determine the detail presented to the learner, should rather be formulated as a context which the learner is allowed to further refine, according to her own interests and needs. For instance, the learner may decide to confine herself to the study of cities with more than a million inhabitants only or to traverse links of a particular type or into a given range of weights.

For the materialisation of contexts we propose the use of constraints, so that context resolution is performed by a constraint-solver. Although a view can also be implemented by a set of constraints, we observe a view rather as a passive filter over the hyperspace, while a context is established by active agents introducing constraints and testing the truth value of candidate elements. The agent's role is assumed by the teacher, the learner or the system itself.

In particular, the teacher can initially define statically some constraints that specify a certain context. This context can be further refined dynamically by the user at run-time while exploring the hypermedia subnetwork defined by the associated view. In addition, the system itself can assist the user in refining the constraints by proposing or enforcing new ones; this latter activity is achieved by the intelligent inference engine examining the log file (history) of the user's activities so far. What is important here to clarify is that, as it is happening with constraint-based programming languages, the additional constraints added by the user or the system should be consistent with the original ones. In other words, constraints are monotonically refined. This agrees also with the intuitive notion that the exploration path as was defined initially by the teacher should not be altered but only refined by the user. In fact, part of the system's responsibility is to detect any incosistencies between new constraints attempted by the user and the original ones set by the teacher.

3. DISORIENTATION IN THE HYPERSPACE AND ASSISTANCE FOR REORIENTATION

Although a view (and a context within it) constitutes a small fragment of the total hyperspace, the information pieces it contains and the number of links among them are generally still very large. This implies that the educational application must address the classic problem of disorientation, pertinent in most hypermedia applications ([11]).

The solutions to the disorientation problem are of either preventive or amending nature. Preventive solutions reduce the probability of disorientation by limiting the navigational freedom of the learner into the undertaking of guided tours or the move across predefined routes. As the freedom of exploration in the hyperspace is a fundamental principle of Interactive Learning Environments, we do not consider preventive solutions in this context. Amending solutions are based on the tracing of the learner's activities in the hyperspace. Amending approaches include the establishing of a history of visited nodes, a history of traversed links (especially in a hyperspace of several typed links connecting a pair of nodes), the identification of milestones - visited nodes of particular importance in the studied context, or combinations of the above.

The information that can be maintained in a history file or as a milestone´s list is limited, not only by the capacity of the storage medium, but also by the need to be tractable as an overview of the learner's activities. As reorientation cannot always be achieved by simply performing some backward steps over already visited nodes (or traversed links), the reorientation mechanism should rather provide the means of revisiting important nodes-milestones, and reestablishing chains of steps leading back to known information. Hence, the history of nodes/links visited thus far should be filtered into a tractable, concise list of meta-information pieces.

In [3] we have presented a mechanism for the manipulation of a history of nodes and milestones, used as a reorientation tool in a hypermedia network, while in [4] we have introduced an ordering mechanism for the classification of links, that can be used in filtering out less important links from a history in the favour of more important ones. Combining those two mechanisms, a compact resume of the learner's activities can be constructed by the system, which can itself recognise and filter out unimportant information.

This approach still has the disadvantage that the learner is cosidered the sole initiator of milestone declarations: the learner may be disoriented when declaring a node as a milestone, thus defeating the purpose of the whole reorientation mechanism. We propose to address this problem by enhancing the system with reasoning capabilities and by making it reactive to real-time constraints, thus allowing it to identify itself milestone nodes and to detect disorientation.

In particular, we propose the extension and enhancement of the system with a limited reasoning capability based on weighted abduction as defined for instance in [16]. The idea here is to have an inference engine running concurrently with the hypermedia system and filtering continuously the history information the system stores trying in the process to assess as to whether the user is still in control of what she intends to do, as this is expressed by the context within which she navigates, or is suffering disorientation problems.

In case of disorientation, the system may try to guide the learner in returning to a milestone, either one declared by the learner herself as such, or one declared by the system. System-declared milestones can be deduced by the inference engine according to the learner's behaviour: a frequently visited node, a node being the root of a specification hierarchy, a node from which excursions across different paths are undertaken, are good candidates for becoming milestones. The specification of rules according to which the system can recognise a node as being appropriate as a milestone, would relieve the learner from the necessity of declaring milestones herself during her navigation. Moreover, if the teacher considers the declaration of milestones by the learner as educationally important, the distinction between learner-declared milestones denoting semantically important nodes, and system-declared milestones intended solely for reorientation, would greatly enhance the teacher's evaluation of the learner's activities.

Time is an important factor in such an environment for a number of reasons. First of all, the inference engine must react as soon as it detects that it must intervene, i.e. in limited time, otherwise the user may be lost beyond salvation. In order to guarantee real-time system reaction the computational activity performed by the abductive inference mechanism should be minimal. Here we adopt the techniques of and restrictions enforced by "weighted abduction" ([16]) where assumption costs are introduced for any hypotheses that must be made and subsequently be proven correct, the idea being that the system uses the assumption costs to choose whether to simply assume something (which can be done in limited time but runs the danger of the assumption turning out to be false) or try to prove that it is true (which assures the credibility of the assumptions at the expense of increasing the system's response time). Second, the behaviour of the learner over time may be important itself; for instance, inactivity can often be attributed to inability in making the right choice. Here we use *temporal constraints* ([15]) to indicate the system's reaction under certain timing restrictions.

The reason why there is a need to introduce hypothetical reasoning is because nothing is really certain about a user's behaviour. Traversal of a particular link or move to a specific node - especially one declared as a milestone - may be performed because the user is disoriented and tries to go back to information pieces she knows, but it could also be the case that the learner's interest turned to some other issue. The purpose of the inference mechanism is therefore to try and make the right guess as to why the user has performed the specific operation.

4. REPORTING ON THE LEARNER'S ACTIVITIES IN THE HYPERSPACE

The history of visited nodes/links and the history of milestones do not serve only the reorientation goal. They can be used to formulate a summary report on the learner's activities in the hyperspace. This summary report should be *readable, tractable* and *correct*, so that the teacher's reaction and advices could be safely based on it. Readability implies that the report should appear in a format richer than a system log. Tractability indicates that the summary should be limited in size, while still providing an overview of the learner's navigation in the hyperspace. Correctness implies that the learner's activities should be processed in such a way that the removal of information does not lead to the wrong conclusions.

To ensure readability of the summary report, we argue that the report should actually take the form of path-marking over the visited nodes in the hyperspace: the path of traversed nodes and links is marked by a "visited" flag being set to TRUE. The learner's activities in the working context are indicated by the set flag value on the visited nodes and links; the nodes and links can be probably further enriched by information such as time of visit, direction of move during navigation, time spent studying the node's content, number of times a link was traversed per direction, etc. We denote this report as "navigation mirror" over the hyperspace. At the user interface level, the navigation mirror may be represented by assigning a different colour/shading to visited nodes and links when presenting the overview of the hyperspace.

Using the history manipulation mechanism proposed in [3], the history can produce a tractable navigation mirror. However, this mechanism removes information that is not necessary for reorientation but may be important for the teacher in evaluating the learner's exploratory attempts. In particular, the elimination of cycles within the hyperspace and the replacement of sets of connected visited nodes by a milestone node is allowed, and is even imperative, as part of the reorientation process, but produces a navigation mirror that indicates a smooth sequence of actions, which may mislead the teacher. Furthermore, as noted in section 3 the system may declare some nodes to be milestones, as the result of hypotheses it applies based on the learner's actions; such milestones should be distinguished from those declared by the learner as such.

The distinction between learner-declared and system-declared milestones can be effected by annotating the hyperspace nodes in the navigation mirror by the textual description of the hypothesis and the rules that have lead to the milestone declaration. Amending the elimination of information though requires a more complicated scheme, as follows:

Let N1,...,Nk be a sequence of visited nodes replaced in the history by a milestone node Ni, which may or may not belong to the sequence. Let the sequence index denote the order of visiting the nodes. We introduce a system-defined link type "Replacement" and connect the nodes of the sequence with directed links of this type enumerated by the sequence index; a link enumerated by zero emanates from Ni and points to N1, and a link enumerated by zero emanates from Nk and points to Ni. The user interface may make "Replacement" links visible or invisible within the navigation mirror ([14]).

Let N1,...,Nk,N1 be a sequence of visited nodes forming a cycle that has been visited m times. Let N1 be the earliest visited node, which also indicates the beginning of the cyclic move in the hyperspace. If the cycle has been retained in the navigation mirror, then no information is lost, because the nodes and links across the cycle are annotated with the number of times they have been visited. If the cycle has been eliminated altogether, then the "Replacement" links introduced above are used, where N1 assumes the role of node Ni. However, N1 is not necessarily a milestone: rather, it is declared as "cycle start" in its annotation, which further contains the number of times the cycle has been traversed.

It should be noted that the navigation mirror is not subject to the space limitations that force the elimination of information from the history of navigation: the history must be short because it is used for reorientation, while the navigation mirror must be short in order to be tractable. The above scheme allows the navigation mirror to be studied in a short and in a long format, depending on the level of information that is desired by the teacher.

5. CONCLUSIONS

In this study, we argue for the need to amalgamate hypermedia methods for distant learning support with constraint programming and hypothetical reasoning. We address the area of dynamic view construction, where the notion of context is introduced and materialised using constraint-solving techniques. We further study the issue of disorientation, where we suggest the extension of a mechanism for history and milestones manipulation with an intelligent mechanism based on abduction for the identification of milestones, and on (real-time) constraints to identify potential disorientation of the learner. Finally, we show how our history manipulation mechanism can be used to formulate a navigation mirror, intended as report on the learner's activities, on which the teacher's suggestions and advices can be based.

There is a further advantage in enhancing a hypermedia system with intelligent reasoning, if the system is a truly multimedia one in the sense that some hypermedia nodes point to multimedia objects other than simple text. If the inference engine can guess with reasonable accuracy the user's next move(s) then it may instruct the system to start the retrieval of large media objects (such as video clips) from secondary storage well before the user has actually selected them, thus enhancing considerably overall performance. Furthermore, if a particular piece of information selected by the learner can be represented in more than one formats, the inference mechanism may suggest (or even enforce) the "best" such format depending on issues like the context the user is within, system performance considerations, etc.

We are currently examining the implementation of the proposed framework as an interface between a hypermedia environment and a suitable inference engine featuring reactive abduction and real-time constraint solving capabilities and built on the top of a state-of-the-art concurrent constraint programming language system.

REFERENCES

[1] W.O. Beeman *et al*, "Hypertext and pluralism: from linear to non-linear thinking", *Procs. of Hypertext'87,* J.B.Smith, F.Halasz, N.Yankelovich, M.Schwartz, F.Weiss (eds.), University of North Carolina, Chapel Hill, 1987, pp. 67-81.

[2] A. DiSessa, C. Hoyles (Eds), *The Design of Computational Media to Support Exploratory Learning*, Springer Verlag, NATO-ASI series, (in press).

[3] G. Gyftodimos, M. Spiliopoulou, "Ariadne´s Cordas a Reorientation Tool for the Exploration of a Hypermedia Network", *Proc. of 3rd Panhellenic Conference of Computer Science*, Athens, May 1991, vol. 1, pp. 298-312 (in greek).

[4] G. Gyftodimos, M. Spiliopoulou, "Knowledge Construction and Acquisition in a Hypermedia Environment Customized for Learning Purposes", *Cognitive Psychology and Computers in Primary Education*, S. Vosniadou (ed.), Springer Verlag, NATO-ASI Series 1992, (in press).

[5] F.G. Halasz, "Reflections on NoteCards: Seven Issues for the Next Generation of Hypermedia Systems", *CACM*, vol. 37(12), pp. 73-84.

[6] B. Harvey, "Symbolic Programming vs. SoftwareEngineering - Fun vs Professionalism - Are These the Same Question?", *Procs. of the 4th European Logo Conference*, Georgiadis *et al* (eds.), Athens, Greece, 1993, pp. 359-366.

[7] P.N. Johnson-Laird, *Mental Models*,CUP, Cambridge, 1983.

[8] M.R. Kibby, J.T. Mayes, C. Knussen, "Hypertextas a Medium for Interactive Learning", *Procs. of 6th CanadianSymposium on Instructional Technology*, Halifax, Nova Scotia, May 1989, pp. 321-324.

[9] C. Kynigos, "Programming as a Means of Expressing and Exploring Ideas: Three studies situated in a directive educational system", in [2].

[10] J.T. Mayes, M.R. Kibby, A. Anderson, "Learning about Learning from Hypertext", *NATO Conf. Designing Hypertext for Learning*, Rothenburg, Germany, July 1989.

[11] J. Nielsen, "The Art of Navigating through Hypertext", *CACM*, vol. 33(3), 1990, pp. 296-310.

[12] S. Papert, "Computer Criticism versus Technocentric Thinking", *Educational Researcher*, vol. 16(1), 1987, pp. 22-30.

[13] E. Rivin, R. Botafogo, B. Schneiderman, "Navigating in Hyperspace: Designing a Structure-based Toolbox", *CACM*, vol. 37(2), 1994, pp. 87-96.

[14] M. Sancar and M.H. Brown, "Graphical Fisheye Views". *CACM*, vol 37(12), pp. 73-84.

[15] V. A. Saraswat, "Programming in Timed Concurrent Constraint Programming", *Constraint Programming*, Springer Verlag, NATO ASI Series, 1994.

[16] A. Waern, "Weighted Abduction for Reactive Diagnosis", SICS Research Report R92:11, 1992.