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ABSTRACT

This paper presents a framework for producing learning environments (LEs) on the World Wide Web that improves productivity and quality at a reduced cost for both designers and learners. The resulting LEs are germane to fractals. Changes in scale are likened to levels in LEs; each level expresses a given viewpoint on knowledge. Self-similarity establishes a classification from which to derive a grammar. Texts and activities are highly fragmented, and interfaces rely on the fractal structure to provide for "spatial" landmarks. The LEs are adaptive with respect to learners' objectives, background, and cognitive style and are agile with respect to design, implementation, and maintenance. The fractal design and the underlying grammar set up the formal grounds required to code procedures that generate LEs, extend them, manage updates, and maintain the site. Topics discussed include: the hypotheses underlying the design; the fractal structure that is at the heart of the systems; how to take advantage of this structure from the standpoint of the learner to adapt the LE to his/her needs and cognitive style, and from the point of view of design and implementation; how the hypermedia structure can provide agility to production; benefits and drawbacks observed from in situ utilization of the LEs; and future works and conclusions. (Author/AEF)

Adaptive and Agile Interactive Learning Environments on the WWW

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Abstract Continuous education helps people to cope with an ever changing labor market, while distance education reaches them where they are, keeping them at work. We designed a framework used to producing learning environments (LEs) on the WWW. The resulting LEs are germane to fractals. First, we liken changes in scale to levels in LEs. Each level expresses a given viewpoint on knowledge. Second, self-similarity establishes a classification from which to derive a grammar. Third, texts and activities are highly fragmented. Fourth, the interfaces rely on the fractal structure to provide for "spatial" landmarks. The LEs are *adaptive* with respect to learners' objectives, background and cognitive style and are *agile* with respect to their design, implementation and maintenance. The fractal design and the underlying grammar set up the formal grounds required to code procedures that generate LEs, extend them, manage updates, and maintain the site.

1 Introduction

Nowadays people cannot afford to stop working in order to update their education. At the same time, the fast evolution of technology and an ever changing labor market impel them to keep their knowledge up-to-date. Distance education offers a satisfying solution to issues related to continuous education by reaching peoples were they are, keeping them at work and helping them to cope with a changing world. Since the mid 70s, Tele-university has produced pedagogical material for learning at a distance including texts, videos, exercises, exams, teleconferences, assistance, and other options. All these elements define what we will call a learning environment (LE). But producing high-quality pedagogical LEs is a long and costly process. This paper presents a framework that improves productivity and quality at a reduced cost for both the designers and the learners.

On the design side, the framework provides solutions to the reuse and maintenance of pedagogical material. It defines procedures for updating the pedagogical material in order to take into account the evolution of knowledge, and also gives a methodology and the means to tailor a course or part of a course for customized training. On the learner side, an LE has to interact with a variety of learning styles. Our framework enables one to produce LEs where a learner is free to select the part of knowledge he learns, free to choose the way she explores the pedagogical material, and free to choose the place and the time she studies.

Hence, the LEs generated by the framework are adaptive with respect to a learner's needs, background and cognitive style while they are also agile with respect to their design, implementation and maintenance. We used this framework to design and implement two hypermedia LEs on the WWW:

- INF6550 LE, called *Methods and Tools for Problem Solving*, is intended for undergraduate students having a background in business;

- TEC6200 LE, called *New Information Technologies and Cognitive Development*, is intended for graduate learners having a background in education.

Hypermedia is the cornerstone of our LEs' agility and adaptiveness. The WWW provides means for real-time modifications of their hypermedia structure.

In this paper, we detail this framework by explaining how we designed these LEs and how we exploit their adaptiveness and agility. First, we explain the hypotheses underlying our design, especially since they provide the basic assumptions that pointed out the supporting tools we implemented. Second, we sketch the fractal structure that is at the heart of the systems. Third, we show how to take advantage of this structure from the standpoint of the learner to adapt the LE to his or her needs and cognitive style. Fourth, we switch to the point of view of design and implementation. We show how the hypermedia structure can provide agility to production. Fifth, we discuss the benefits and drawbacks we observed from in situ utilization of the LEs. Finally, we sketch future works and draw concluding remarks.

2 Towards Constructivist TeleLearning Environments

Tele-university is devoted to distance education. Since its creation, courses have incorporated a variety of media. More recently, telelearning environments broke learner isolation and provided means for distributed learning. Besides giving access to knowledge, these environments help learners to manage their learning process, or to communicate with their peers. Collaboration then takes the form of discussion, virtual teamwork, or asynchronous assistance by the tutor. The information highway reveals as the latest challenge to Tele-University: how to produce fully computer-mediated learning environments. We claim that the INF6550 and TEC 6200 LEs lay down the basis of the answer.

Learning is unquestionably a complex phenomenon. Many elements and processes are interwoven. To be efficient, an LE must integrate them smoothly; even we could say that it should provide for some sort of symbiosis. To help us to get a clearer view, let's put them in a three-orthogonal axis:

- *static elements*: they consist mainly of texts, pictures, sounds and videos that explain theory, give examples, describe exercises and point out tools which the learner can use;
- *dynamic processes*: while learning, a person undertakes many actions which reflect the learning process by itself;
- *assistance*: when stuck on a problem, a learner searches for help; at Tele-university a telelearner gets support from a computer-mediated support system that achieves asynchronous communication between individual learners, networks of learners, and tutors to ease truly cooperative telelearning [Pierre & Hotte, 96]; in a near future, advisor information systems will provide first-line help [Giroux et al., 96].

So the challenge was to mediate these three aspects and generate a complete Web-based LE. Even better, we aimed at taking advantage of the flexibility and interactivity the Web offers (e.g., the hypermedia structure) to give a learner complete freedom on the knowledge he chooses to learn and on the manner he learns it. The latter is often referred to as a constructivist approach to learning.

In building an LE, static elements, dynamic processes and assistance raise their own set of issues. Static elements settle the playground. How should we structure and present contents and activities in a Web-based LE? What are the (html-)pages to produce? Dynamic processes correspond to the way a learner uses static elements. How are the static elements used? How does constructivist learning express itself? How could an LE support each person's learning process idiosyncrasies? Remote assistance is crucial in distance learning. How would an LE support learners that are free to choose their progress? Which are the help resources that are relevant and appropriate?

At first sight, these questions seem unrelated and consequently one could expect to solve each one on its own. But they are deeply intertwined. For instance, the freedom a learner has is intimately linked to the content and format of the documents. Longer documents leave less room to freedom since the learner usually has to read them all, thus putting more constraints on the order knowledge is acquired. We thus ought to uncover the relations existing between static elements, dynamic processes and assistance.

Our stance over Web-based LE is summarized in the following hypotheses that link contents, learning, assistance and learners' freedom:

1. Constructivism approach focuses on the learner. Constructivism requires that the LEs give complete autonomy and freedom to a learner's thought process. Such freedom especially implies that the learner should be able to interact with the LE according to his or her own cognitive style.
2. Hypermedia can provide such freedom to the learner.
3. To ensure coherence within hypermedia learning system, it is compulsory to establish a symbiosis between contents (knowledge), form (documents and activities) and though processes (cognitive progression and assistance).
4. To build constructivist hypermedia learning system, it is possible to lean on the symbiosis between contents, form and though processes.
5. The learning process (and thought process in general) is reflected by the navigation of the learner in the static elements.
6. It is possible to develop supporting tools, especially tools that render explicit the learner's route and progress in constructivist hypermedia LE.
7. To support constructivism, tools that render explicit the learner's route and progress are required.

For any feature in the LEs, one can report to some of these hypotheses. For instance, assumption #3 is underlying the complete design of the hyperstructure. Tracing tools were implemented in light of assumptions #6 and #7.

3 Elements of Adaptive Telelearning Environments

Indeed, we are looking for telelearning environments on the WWW able to adapt to a learner's objectives, background and cognitive style. The hypermedia structure underlying the WWW provides the basis for the kind of adaptation we are interested in. In this section, we first point out the need for design principle in the realm of hypermedia. Then we describe the principles .fractals. that rule the structure of the LE we implemented. Once the fractal structure is set, we know both which documents to write and what is their content. The hyperlinks can then be derived based on the fractal structure. The fractal structure is also used to design the interface. Once the static part is defined, the stage is set to study the dynamic processes and tools are designed to support the learner's cognitive processes. Finally we show how the design-produced documents, i.e. WWW pages, enable a learner to adapt the LE to his or her own cognitive style just by the way he navigates through them.

As the supporting medium for LEs, the WWW has many advantages regarding agility for distance education (e.g., distribution, real-time modification and notification). On the other hand, this medium imposes severe constraints. Learners have to work using a usually small computer screen. Linearity in thought and texts rapidly becomes quite boring. Consequently, designing pedagogical material for the WWW is far from writing a textbook. In textbooks the unit of division is, roughly speaking, the section. The structure is linear. When an author writes a section, he usually assumes that the reader will have knowledge of the preceding section. Books have been written for centuries, and today there are guidelines to achieve such a process. For instance, tables of contents are part of the conventions guiding the organization of books.

The WWW is a very young media, and there are no universally accepted guidelines. On the WWW, the unit of fragmentation is the page which, we believe, should be no longer than two computer screens. The structure is hypertextual, so the author cannot predict which path will have lead the learner to the page he is writing. Thus, a page should address one micro-idea. Due to the medium, a small computer screen and relatively low-bandwidth for communication, documents must be kept short. Finally, documents ought to be self-explaining. But these guidelines are not sufficient. A WWW author needs also guidelines to provide answers to the following questions:

1. What are the pages he has to write down? What content and knowledge should each page address? ;
2. How should contents and activities be linked to obtain LE in such a way that the learning process remains open?.

The answer comes from the very nature of hypermedia: fractals!

Hypermedia provide a very powerful and flexible mean to present knowledge to the learner [Jonassen, 86]. But as the WWW reminds us every day, it is quite easy to get lost in such fragmented universes. So we sought for an organization of didactic material that could ensure coherence throughout the material. Fractals possess the qualities required to organize highly fragmented universes such as those found on the WWW:

"A fractal is a rough or fragmented geometric shape that can be subdivided in parts, each of which is (at least approximately) a reduced-size copy of the whole. Fractals are generally self-similar and independent of scale" [Stepp, 96].

We believed (and we observed afterwards) that a structure inspired by fractals can help to ensure coherence between the various hypermedia fragments by defining a sort of spatial relationship. The spatial structure obtained gives landmarks to learners to help them avoid getting lost. The issue then is to organize pedagogical material into self-similar levels of interrelated fragments. On the one hand, we liken changes in scale to levels in LEs, each level expressing a given viewpoint on the same knowledge. On the other hand, self-similarity establishes a classification. We used this classification to derive grammars and to provides formal grounds for a methodology and for automation. Let's see how it is achieved.

An LE is made up of pages. A page content may be theoretical (description of theory), pragmatic (description of activity), or related to the LE by itself (for instance, pointers on help resources). The fractal structure of an LE focusses on pages that either describe the theory (models, examples...), or activities (exercises, homework...). We call each page a *fragment*. Even if fragments describe independent micro-ideas, they are linked to each other. Then, the links between the fragments create a network. Whatever complex the network is, some nodes, usually a few, are fundamental and the rest of the network can be interpreted as examining these nodes from a different perspective or as a finer grain view of them.

Besides the network of fragments, there is another network implied in an LE. Knowledge addressed in it could be modeled as a rich semantic network. We called it the knowledge model [Fig. 1, left]. Any fragment, theory or practice handles some portion of the knowledge model. The trick to get to a fractal structure of the LE is to find a mapping between fragments and the knowledge model. The viewpoints on a subject determine the levels, while the central nodes of the knowledge model define the main part of self-similarity [Fig. 1, right]. The other elements defining the grammar and completing self-similarity are the type of the fragments .theory or practice. and the subtype of the theoretic fragments .presentation, model, examples.. Thus, levels and self-similarity provide the guidelines needed to determine which documents to produce and define a standard way to fragment knowledge and to ascribe a topic to individual fragments. Even better, levels and self-similarity define the foundations of a grammar that indicate the documents that have to be produced.

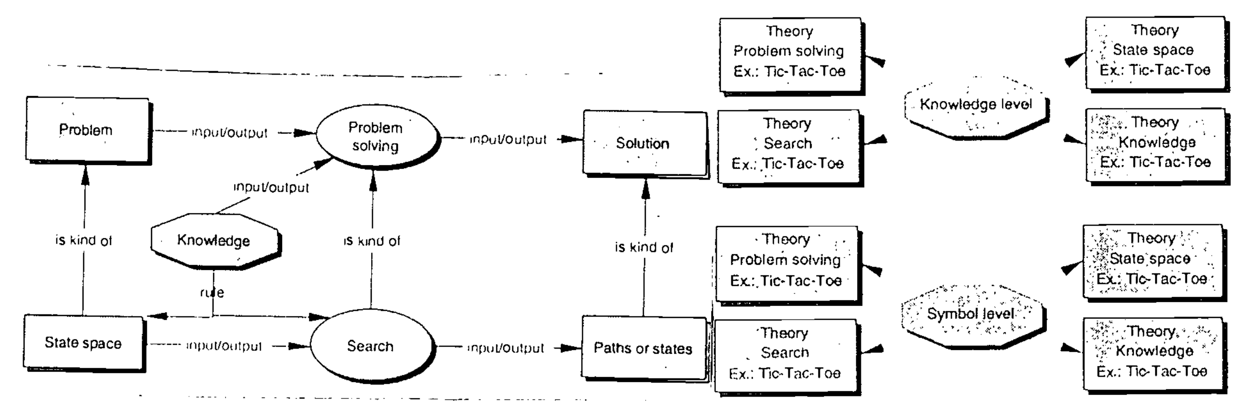

Figure 1: Left) The knowledge model of the course INF6550: to solve a problem is to perform a search in a state space; the search is directed by knowledge [Newell and Simon, 76]. Right) Self-similarity between levels is derived in part from the knowledge level.

Once fragments are written, they have to be linked. Since knowledge is at the heart of the LE, knowledge is the main criterion used to define a coherent hypertextual structure. The problem consists in identifying for each fragment the fragments that are semantically the closest. Such information is made explicit by the fractal structure, based on the knowledge model, the levels, and the pedagogical nature. Since this information is encoded in the name of the fragment, the computation of the semantically closest fragments can be done on the fly. This property enables one to distinguish in the interface two types of links according to their semantic. Links with a strong semantic connotation are implemented with the help of a contextual navigator [Fig. 2]. Links with a weak relation to the discourse, as references, are implemented as usual.

For instance, in the INF6550 LE, the contextual navigator can be thought of as a hypercubic structure based on :

1. the axis of the knowledge model: `problem-solving` (S), `knowledge (C)`, `search (R)` and `state space (E)`;
2. the levels: objectivation, knowledge, symbol and expertise. The forefront plane correspond to the current level;
3. the pedagogical nature: theory and practice. The theoretical fragments are associated to the upper halves of the small squares, whereas the practical ones are associated to the lower halves.

Other elements as the example name is not described explicitly by the contextual navigator. The shaded part indicates the semantic of the current fragment. The contextual navigator indicates that the fragment is about the state space from a pragmatic approach (lower part is shaded) at the symbol level. Finally, some other contextual elements are made explicit through links established beforehand: knowledge models, examples list...

In order to manage its learning process, the learner must be able to locate himself among a bulk of knowledge fragments. Besides the information made available by the contextual navigator, other indicators have been incorporated in the interface[Fig. 2]. Very quickly, learners notice that the level of fragment is identified by a specific color stripe : blue for problem-solving, yellow for search, pink for knowledge and green for state space. At the upper left corner of the document, there is always an icon to indicate the level. Finally, each document has a title providing further information. Conventions govern title wording. From now on, the hyper-stage is set, and the learner can come in.

In a constructivist approach, learning processes need to be observed and taken into account [Chambreuil et al., 94]. To manage her learning, the learner must know what she learned and what rests to be learned. To give her feedback on its learning process, we implemented a trace mechanism. The trace indicates which fragments have been visited, and to what extent they are understood or completed. The trace uses a six-steps scale: introduction, planning, beginning, entry, strengthening and complement. A color is associated to each step. The progress of the learner is estimated automatically, but the learner can always indicates to the system what its real progress is.

The trace is displayed either on a fragment-per-fragment basis or on a synthetic map. In the first case, an arrow on the scale at the upper right of each fragment indicated the inferred or real degree of understanding. In the latter case, a global cognitive map gives a synthetic view of the LE's fragments, level by level. Fragments are represented by cells whose color indicates the learner's progress. The synthetic map also helps the learner to appraise how many fragments there are for each level, as well as how many are theoretical or practical.

There are many ways to navigate within an LE. We have already explained the contextual navigator which points on the fragments that are semantically the closest. The contextual navigator can be used to follow a line of thought. But there are times when the learner may want to stop investigate an idea and jump to another one. She can also navigate through the hypermedia LE using: the synthetic map, a menu at the bottom of the fragment , or specific items pointed out in the current level.

Now the learner has at hand LEs that are highly fragmented while still remaining well-structured. There are clear division between theory and practice, and the essential features in the knowledge model are highlighted. There are also contextual maps, synthetic maps, and trace recordings to give her a view on her learning process. But what about this learning process? How could she navigate through the LE according to its cognitive style? A free translation of the Myers-Briggs type indicator can provide some hints [Krebs, 85]. People may be either theoretic or practical, synthetic or analytic... For instance, the theoretical one will consult the theoretic fragments first; then he will do the exercises, while the analytical one will choose a theme and will follow it throughout all the levels. The LE is sufficiently structured, flexible enough, and will provide the right tools to enable a learner to adapt it to his own cognitive style. Finally, asynchronous transactions between tutors and students are privileged in the LE. So the learner remains free to choose the time and place most suited to its life-style.

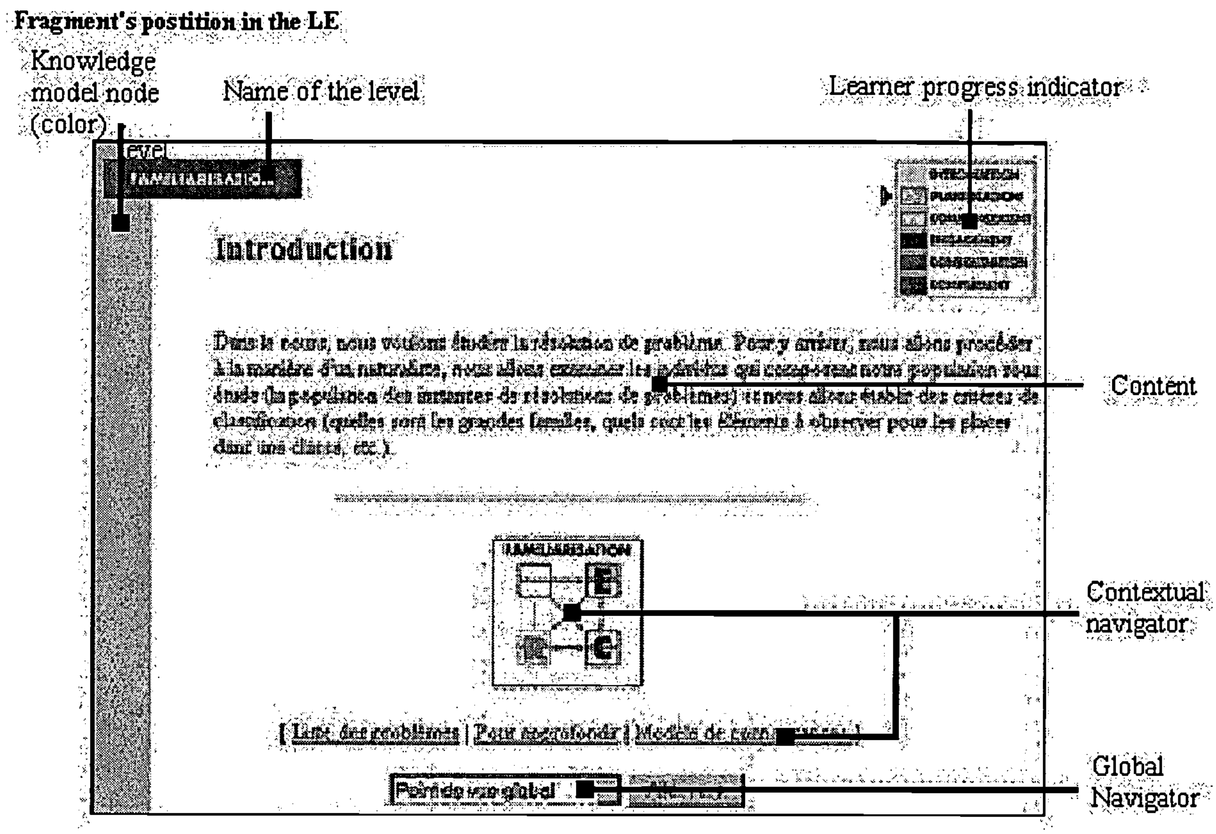

Figure 2: A view on a typical fragment.

4 Reusing and Maintaining Courseware: Agile LEs

In the preceding sections, we showed how the fractal structure of an LE can be used by a learner to adapt it to her cognitive style. In this section we show how such fractal LEs are *agile* with respect to their design, implementation and maintenance. Fragmentation into small pieces enables to tailor quickly them for specific purposes. The fractal design and the underlying grammar set up the formal grounds required to code procedures that generate LEs, extend them, manage updates, and maintain the site. Obviously, such properties have tremendous impact on costs.

The TEC6200 course addresses topics that are quite similar to those of INF6550. So we decided to reuse and extend the INF6550 LE to produce the TEC6200 one. First, we reused many fragments from the INF6550 LE. Since fragments were self-explaining and already contained information used by the contextual navigator, the process was easy and almost automatic. Then we extended the set of fragments of INF6550 LE by the addition of a new level respecting the self-similar structure on the one hand and by the addition of new peripheral fragments on the other hand. In the latter case, the grammar was extended to incorporate the new semantic knowledge components. We have also reused the interfaces of INF6550 LE with little modifications and 80 percent of INF6550 contents for two main fragments of TEC 6200 LE. Its two other fragments need complete processing on contents and visual aspects. We estimate that the reuse of INF6550 amounted to 28 percent saving on production, mainly because there was not been any prototype. On the other hand, improvements on the assistance infrastructure of TEC6200 will be injected into INF6550, so the savings will be more important.

Now that the INF6550 has been used by real learners, we have been able to verify that the site is effectively easy to maintain and to update in real-time. Fractal principles together with the grammar provide a principled way to update an LE and keep it a coherent. They enable one to code procedures that manage changes and maintain the site. To update an obsolete document, add information regarding a precise point, adding or retrieving an example, we just need to put or retrieve the files on the site, since the appropriate hyperlinks are dynamically computed. The LE is thus reacting dynamically according to the information available on the site.

5 Conclusion

In this paper we outlined a framework we used to design and implement two learning environments on the WWW. Respecting the spirit of the WWW leads to highly fragmented documentation and activities. The fragments are assembled to produce an LE. Principles governing fractals .self-similarity and 'infinite' decomposition. guided the fragmentation of knowledge and ensured coherence of the LE's overall organization. Such coherence is compulsory to help the learner navigate through the knowledge and activities. Self-similarity also established a classification from which a grammar has then been derived. These LEs can ease the learning process and adapt to a given learner in the following ways:

- The fractal organization defines clues used for spatial orientation throughout the knowledge and the LE.
- The network structure and the fragmentation permit a learner to explore knowledge and activities according to its very own cognitive style. Its navigation can be interpreted in terms of the Myers-Briggs type indicator.
- Fragmentation and fractal design enable a learner to explore just the part of knowledge needed in a coherent way.
- Examples can be dynamically chosen according to the learner background.

These LEs are agile with respect to their design, implementation and updates in the following ways:

- *Reuse* : Fragmentation into small pieces enables to tailor rapidly an LE for specific needs, context and backgrounds.
- *Extensibility* : The fractal design sets up the rules for coherent extension of an LE.
- *Maintenance* : Fractal principles together with the grammar provide a principled way to update a LE and keep it a coherent. They enable one to code procedures that manage changes and maintain the site.

An advisor system using the learner's trace, the grammar and the Myers-Briggs type indicator is the next enhancement planned for these LEs.

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