The Learning Objects Structure Petri Net

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Abstract

The Learning Objects Structure Petri Net, LOSPN describes the structure and mutual dependence of a set of learning objects, LOs. It allows to model the context of each learning object in terms of preconditions (prerequisites) and postconditions (learning objectives or learning targets). It is this property which makes re-use of learning objects in different courses and in different departments possible.

The LOSPN offers to derive the level of a learning object from the structure of the set of LOs. It allows to define different learn paths. If a student does not pass a certain LO the LOSPN (without further diagnosis) indicates which LOs should be recapitulated.

Our Notebook University project teleVISE provides many examples for LOSPNs: how to generate a LOSPN, how to represent it in XML within standards, and what potential LOSPNs provide.

Key words:

learning objects, metadata, re-use, standards, e-learning, Petri Nets, Learning Objects Structure Petri Net

1 Introduction

The importance of metadata as well as the difficulty of their acquisition and/or generation is widely acknowledged, as stated e.g. [1]:

"Once the metadata is available, it is relatively straightforward to use it (...). It is, however, much harder and more time- and resource-consuming to produce metadata in the first place. Even the quality of metadata generated by domain experts is subject to changes in domain knowledge. In practice, there are situations in which metadata are impossible to generate without an overall understanding of a large scale complex body of data."

Metadata play a crucial role when the re-use of learning objects is at a premium. Without metadata there is no re-use of learning objects in different contexts by different authors and for different purposes. Here we focus on the intricate interrelation between re-use and metadata, i.e. metadata modeling and metadata acquisition. To be explicit and concrete we use our blended and mobile learning tele-tutoring project teleVISE [2] as a source of examples as well as a case study: teleVISE [3] provides a large data base of problems (including sample solutions and links to relevant learning material like lecture notes or interactive documents) together with metadata and a data base of exercises, i.e. problems of the problem data base to work on. Students collaborate online in order to solve the problems posed in obligatory, weekly exercises, they hand in their solutions online for their tutor to assess their solutions, to give feedback and to help where needed. Students use the data base of problems to prepare for examinations. Lecturers use it to select problems for their lecture or as exercises for their students. Because teleVISE is a project run at different departments, the pool of problems only makes sense if problems can be re-used by lecturers in other departments and students in other degree courses.

Metadata modeling has to serve two masters: on one hand, it has to describe learning objects in enough detail in order to make it distinguishable from other learning objects when searching. On the other hand, all this metadata has to be specified. To be short, to model metadata means to optimize a cost value ratio where costs arise from metadata acquisition and benefit from re-use of that particular learning object. We present different standards for metadata and discuss the role of these standards in the modeling process. However, there is no guarantee that metadata adhering to these standards will serve the needs e.g. of teleVISE where re-use of learning objects depends on various contexts.

To this end we propose a Petri net model for interrelation and usage of learning objects and thus for the metadata describing them.

Once metadata is modeled, acquisition [4] in most cases will be a combination of automatic generation from content and of specification by mostly the author. Where applicable, metadata can also be obtained by observation of authors and learners behavior.

In order to assess the benefit of providing metadata to learning objects we discuss aspects of online search, of re-use in different contexts, and of data administration, i.e. content management.

The paper is organized as follows: In the next section we present the state of standardization focusing on metadata and re-use and give examples of e-learning standards and their ambit.

In the third section we briefly sketch our notebook university project teleVISE which has triggered the idea of the LOSPN and provides many examples.

In the next section we attempt to summarize the important shortcomings of traditional metadata.

The following section introduces the Learning Objects Structure Petri Net, LOSPN. We illustrate its features by teleVISE examples. This real world application reveals cost and benefits of the LOSPN best. We illustrate the potential of LOSPNs in areas other than mathematics by an example in the area of programming. Some remarks on implementation of LOSPNs within standards conclude the section.

In the last section we summarize the goodies of LOSPNs and weigh the benefits compared to the cost of setting up LOSPNs.

2 E-learning Standards

Analysis of the leading standards, e.g. IMS Global Learning Consortium standards [5], ADL standards, especially SCORM [6], IEEE LTSC standards, specially LOM [7], Dublin Core Metadata Initiative Recommendations [8], Resource Description Framework [9], American Mathematical Society, Metadata [10] reveals:

- Different standard proposals aim at standardizing how to satisfy the requirements of different tasks like authoring, development, deployment, (re-) usage of LOs by different user groups.
- This has led to numerous standard proposals. However, standardizing bodies try to harmonize their individual standards.
- More and more of the proposed standards allow extensions: experience has shown that one standard cannot cover all e-learning scenarios.
- XML-based implementations exist for many proposed standards.

Table 1: Examples of e-learning standards and their ambit

Type of Standard	Development of Content	Deployment of Content	Use of Content		
			Study	Search	Feedback
Notation: MathML, SVG	x		x		
IMS Question & Test	x				
AMS, DCMI, ...				x	
LOM, IMS Metadata		X		x	X
IMS Content Packaging		X			
SCORM		X	x	x	X

3 The Project teleVISE

The problems of teaching mathematics for engineering are ubiquitous, notorious and well known. To cope with these problems and to improve education in mathematics for students in engineering courses, the project "teleVISE" at Hochschule Bremen, University of Applied Sciences, has established a web-based service providing tutor-supported co-operative work on mathematical problems [11]. This service utilized by several departments of Hochschule Bremen enhances and complements class room teaching. teleVISE follows a problem-based approach which comprises modeling of real-world problems, application of mathematical procedures, computation and verification of both model and results. teleVISE consists of two parts: The first is a growing database of 700-plus mathematical problems indexed by metadata so that both students and lecturers can easily search for appropriate problems; the second is an online collaboration and tutoring environment. An electronic whiteboard integrated into teleVISE supports online discussions of students and tutors. Notebook computers with wireless connections allow for flexibility in time and space and graphics tablets for graphical input.

In order to realize these Web-based services we developed an e-Learning Management System (LMS) covering the needs of different user groups:

- *Authors* can easily add new problems together with sample solutions, links and references to the problem database.
- *Lecturers* can select exercises and assessments from the problem database. Therefore they must be able to search the data base according to their needs using various search strategies.
- *Students* get access to their exercises at the right time, they can ask for online support by tutors, online they hand in their solutions which are marked by the tutors. They can archive their solutions for examination preparation.
- *Tutors* support students working on their exercises via the Internet. If need be they mark the students solutions and give feedback to students and lecturers.
- *Organizers* and *administrators* maintain data bases for problems, exercises, users, courses, access rights etc.

Figure 1 depicts the architecture of this system combining a Course Management System with e-learning authoring tools.

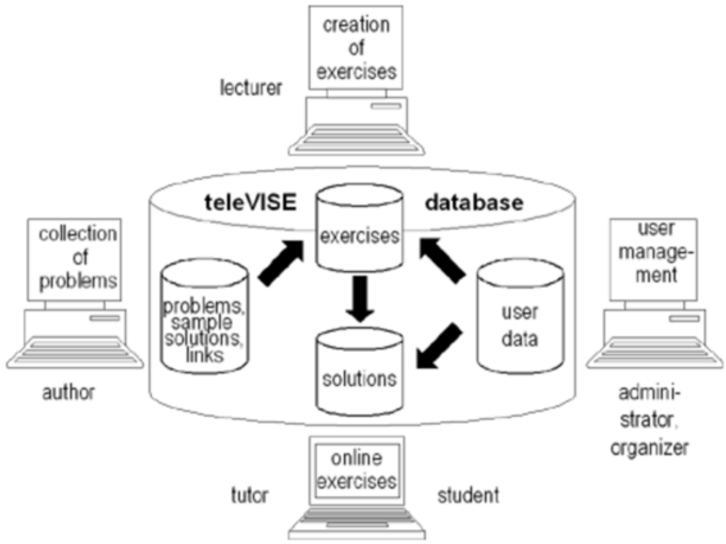

Figure 1: Architecture of the system teleVISE

The teleVISE system generates exercises and their presentations dynamically on base of user input.

- Lecturers need data describing each problem in the problem data base in order to select adequate exercises for their specific students. Based on the user data base the selected problems become 'personalized' exercises.
- Students need similar data in order to select problems for examination preparation. And based on the user data base they get access to 'their' exercises of the week.

In each case search results have to be presented depending on type of user and purpose, e.g. problem presentations with or without sample solutions, links, hints, references, etc.

In this sense, teleVISE provides an adaptive user interface.

3.1 Metadata in teleVISE

The teleVISE metadata concept has been set up with the very many existing e-learning standardization efforts [12] in mind. The teleVISE metadata adhere to the most established standards as much as possible.

To meet the online search needs of users various metadata are recorded, e.g.

- processing time
- type/didactical characterization of activities [13] (computing, modeling, ...)
- level (basic, advanced, experts)
- area (engineering, physics, chemistry, ...)
- topic (determinant, vector product, ...)
- AMS-Code [10]

Authors have to interactively input content related metadata.

Metadata standards like LOM and IMS Metadata are especially suitable to describe teleVISE problems, sample solutions and links. These standards cover to structure technical and organizational metadata but not to characterize content in that level of detail necessary in teleVISE. Striving for Best Practice emphasizes this necessity [14]. Thus, we need to develop sophisticated means to describe content and tools to acquire these metadata and to use these metadata to full capacity.

When designing the system we thought these metadata to be sufficient for comfortable searches. Here, we want to discuss basic problems like context dependency when using teleVISE metadata and possibilities to resolve these problems.

4 Shortcomings of 'Traditional' Metadata

Considering that there are experts in libraries, documentation centres and archives are striving to make a vast body of documents accessible to the public or other target groups it is not surprising that metadata is difficult to model, to acquire and to maintain.

Besides the immanent problems of key words, at least the teleVISE metadata

- is by no means to be acquired automatically, e.g. type
- is only to be estimated, e.g. duration, level
- provides no or only little additional information in queries of authors and students, e.g. AMS classification
- does not take different contexts into consideration, e.g. courses of mathematics in other departments

Summarizing, metadata were costly to provide but did not make the potential of 700 problems as accessible as desirable.

5 The Learning Objects Structure Petri Net, LOSPN

Guided by our experiences in the project teleVISE we will now model structure and mutual dependence of learning objects, LOs by a Petri net, the *Learning Objects Structure Petri Net, LOSPN*.

5.1 Structure and Mutual Dependence of LOs

As the case may be, our learning objects are learning units, problems or exercises. Each LO is characterized by preconditions and postconditions. All what is necessary to take a learning unit, to tackle a problem or to practice an exercise specifies the preconditions. Postconditions consist of all knowledge gained in a learning unit, experiences made in solving a problem or skills acquired by practicing exercises. And postconditions can be part of preconditions of other LOs.

Assuming that the LOSPN correctly models the mutual dependence of LOs, then, a LO can be completed successfully only if all preconditions are fulfilled. These relations can adequately be described by Petri nets [15] when LOs are modeled by places and preconditions and postconditions are modeled by transitions as shown in **Figure 2**.

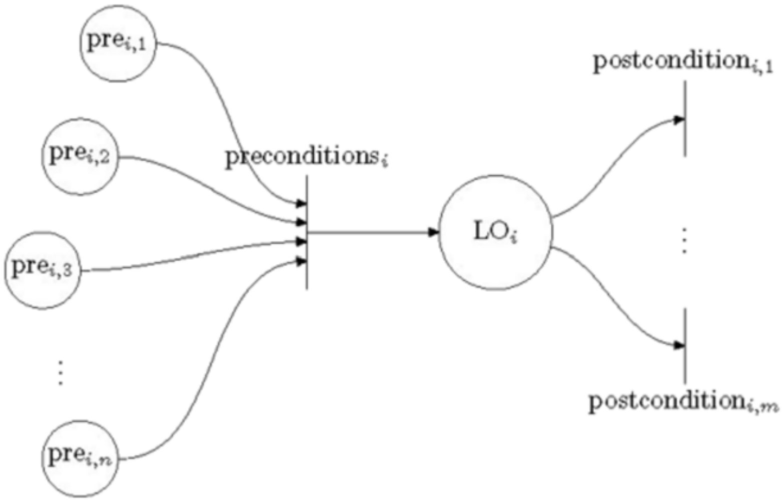

Figure 2: A LO in a LOSPN

Transitions correspond quasi to eureka moments which can go with the acquisition of new insights, experiences or skills.

5.2 Dynamic in LOSPNs

In a Petri net, places contain so called tokens. Transitions in a Petri net can only fire if at least one token is present in every input place. Then, firing consists of removing exactly one token from every input place and depositing exactly one token in every output place.

In our case, there exist sufficiently many, say infinitely many tokens in those places which are specified as preconditions of a whole learning unit. In this way the LOSPN represents the fact that knowledge, experiences and skills can be used indefinitely often.

For example, someone wanting to appropriate matrix transformations for generative computer graphics to oneself has to be able to multiply matrices, needs matrix algebra. Therefore, in the place Matrix-Algebra there are arbitrarily many tokens.

Figure 3: Places representing preconditions - like Matrix-Algebra - have arbitrarily many tokens

5.3 Context in LOPSNs

Generally, LOs exist in certain contexts. Context is defined to be knowledge, experiences and skills necessary to reach a certain educational objective or – in IMS slang – learning goal.

The context of a LO consists of knowledge, experiences and skills necessary for this LO. Context is target group specific. Context is modeled by a set of places with infinite many tokens.

An example from the pool of problems in the teleVISE data base illustrates the concept developed so far.

Problem A: *Name a near at hand parabola which approximates the cubic polynomial y=x3-x between the origin and the positive extremum. Reason about your choice.*

Problem A': *Name a near at hand one parametric family of parabolas which approximate the cubic polynomial y=x3-x between the origin and the positive extremum.*

Problem A'': *Consider a near at hand one parametric family of parabolas which approximate the cubic polynomial y=x3-x between the origin and the positive extremum, and determine that member of the family which approximates this cubic polynomial in the given interval best.*

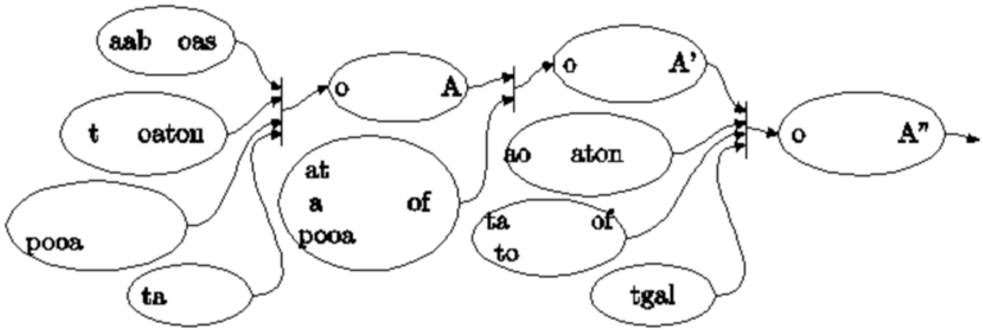

Figure 4: LOSPN for problems building on top of each other

5.4 Learn Paths in LOSPNs

By inserting additional places, so called control places, we can coerce certain learn paths.

Here it becomes clear that a LOSPN is dependent on the didactic concept: Obviously, in the above example LO A' builds on LO A and LO A'' builds on LO A'. If due to didactical considerations this relation is desired, if a corresponding learn path is to be specified then necessarily LO A has to belong to the preconditions of LO A' and LO A' to the preconditions of LO A''.

Besides contexts, a LOSPN reflects also learn paths and didactical intentions.

5.5 Resolution and Lumping in LOSPNs

Different contexts for different target groups can be taken into consideration only if the LOSPN models enough detail, i.e. if the resolution of the model is high enough. The more heterogeneous the self-conception of courses e.g. in mathematics, and the more divers the didactical concepts, and the more varied the educational objectives, the more detailed, explicit, and in-depth the LOSPN has to be specified.

On the other hand, lumping, i.e. comprising places and transitions to super-places and super-transitions respectively makes it possible to model different hierarchical levels. Along with lumping of the LOSPN goes building a hierarchical thesaurus of subjects as given as attributes of LOs.

5.6 Difficulty or Level of LOs Depending on a Context

Weighing transitions makes it possible to measure the difficulty or the level of a LO. Consider the example of a simple integration task.

In the following LOSPN let all places without input be context. With respect to this context, the effective voltage ueff of a sinusoidal voltage is to be determined.

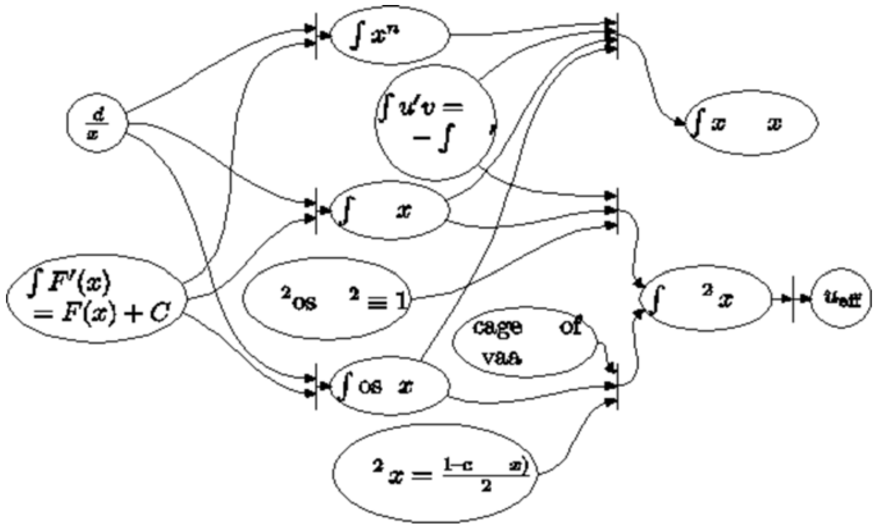

Figure 5: LOSPN for a problem with two solutions

There are two ways to compute o sin2x dx – a fact which the LOSPN models correctly.

A LO is the more demanding, the more demanding its preconditions are. If each transition is weighed by the number of its input places, then, the sum of all weights along the longest path from the LO to the context defines a context sensitive measure of its difficulty or level.

The difficulty or level of a LO is proportional to the sum of the weights of transitions along the longest path from the LO to the context.

5.7 Failing a LO in a LOSPN

If preconditions are modeled in detail and LOs can be passed in principle, then failing a LO indicates that some preconditions are not met. Without further diagnosis of the failure the only thing to do is to secure the context, i.e. to backtrack until all preconditions of the LO and its predecessors are met and then to proceed towards the said LO.

If an e-learning system keeps track of the learning history then this system can propose to the learner certain LOs which the learner already recapitulated and obviously had trouble with.

In a LOSPN to a given LO there are 'equivalent' Los, i.e. LOs which share the same context or LOs with the same set of prerequisites. An e-learning system can propose to the learner equivalent LOs to offer a possibility to overcome difficulties with a certain topic.

5.8 Search in LOSPNs

Students and lecturers have different interests when searching a set of LO.

- When exercising or when preparing for exams, students are likely to search for
    - LOs focusing on certain procedures, LOs of certain authors, LOs in certain application areas,
    - LOs with lower, equal or higher level, but similar to a given LO
- When preparing lectures or exams, lecturers are likely to search for
    - LOs as example in their lectures,
    - LOs as problems in their examinations,

i.e. LOs focusing on certain procedures, LOs in certain application areas which satisfy the needs of a certain target group.

These requirements can be met by LOSPNs if only they have been modeled with sufficient resolution and if the attributes of each LO like area and topic have been specified carefully.

5.9 Representation Power of LOSPNs

Another example dealing not with mathematics but with programming demonstrates that LOSPNs are not restricted to mathematics. The example shows how to program an application for user specified queries in a database. It is intended to illustrate how to step from designing an application with console input and output to an application with a graphical user interface.

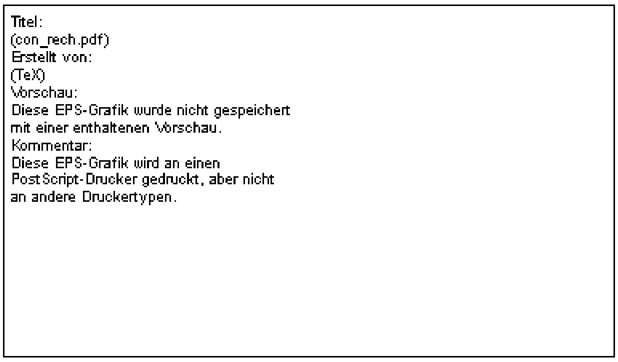

Figure 6: LOSPN to design database queries with console input and output

Extending the application by graphical user interfaces, GUIs, means to substitute the interface places by their graphical counterparts together with all the places representing the necessary apparatus.

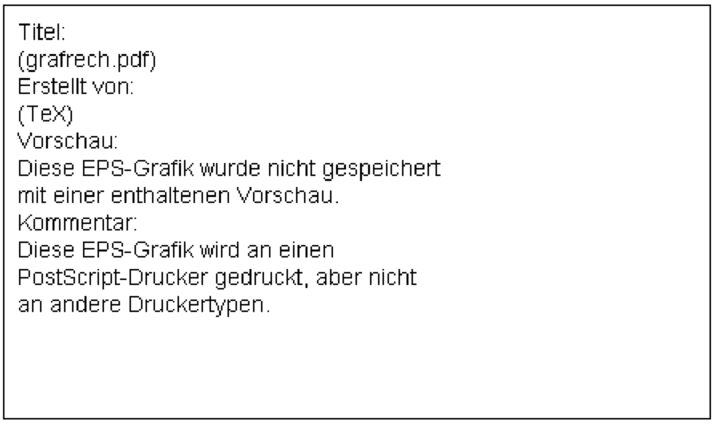

Figure 7: LOSPN to design database queries with graphical user interfaces

5.10 Implementing a LOSPNs in XML

A LO has 0..n preconditions. Therefore, in a LOSPN the corresponding place has 0..n input transitions. Hence, a LOSPN can be represented by one XML-type description element for each LO. So it is only necessary to combine an extension of the XML-Bindings for LOM with the description of the LOSPN which can be done by e.g. the Petri Net Markup Language, PNML [16].

This will be the base for the development of comfortable tools for the acquisition and utilization of LOSPN-based metadata of LOs.

6 Potential of LOSPNs

The examples so far show that LOSPNs in principle describe structure and mutual dependence of LOs adequately.

- On one hand, it is disadvantageous that the nature of LOSPNs prevents to generate LOSPNs automatically. In case of teleVISE, a LOSPN for some 700 problems has to be specified. Classifying a LO as having the same preconditions or the same postconditions as a LO whose metadata already have been specified can reduce this workload.

- On the other hand, a LOSPN is advantageous because it offers the possibility
  - to model the mutual dependencies of LOs,
  - to specify learn paths,
  - to map didactical concepts,
  - to take different contexts into consideration,
  - to determine the difficulty or level of a LO in dependence of any contexts,
  - to take failure into consideration and to model recapitulation or simply repetition,
  - to support different search strategies, and
  - to allow for stepwise refinement.

To sum up, LOSPNs seem to be a means to describe structure and mutual dependence of LOs. LOSPNs allow to specify metadata which in turn allow search for and re-use of LOs.

At least the example of 700-plus LOs in the teleVISE problem database indicates that in general also 'traditional' metadata cannot be acquired automatically – a fact which puts the same property of LOSPNs into the right perspective.

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