INFORMATION ARCHITECTURE OF FRACTAL INFORMATION SYSTEMS

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Abstract: The fractal approach has emerged as a promising method for development of loosely coupled, distributed enterprise information systems. This paper investigates application of information architecture in development of fractal information systems. Principles of designing the information architecture of fractal information systems as well as rules for analyzing the information architecture are developed. These rules are used to obtain problem-domain representations specifically suited for needs of individual fractal entities. The usage of the information architecture in implementation of the fractal information system for the university's study programme development problem is demonstrated.

1 INTRODUCTION

Modern enterprises operate in close collaboration with many other enterprises. Support for networking and collaboration has become a vital requirement for information systems (IS). That includes addressing heterogeneity of systems, dealing with conflicting objectives, accounting for dynamic changes in the network, information sharing, knowledge exchange, and providing different, specialized views of the system. Despite elaboration of various technologies (e.g. workflows, groupware, content and knowledge management, virtual enterprises) addressing some aspects of these issues, they remain of major importance in enterprise computing and software development. A fractal approach is also emerging as a promising technology for designing multiple-interrelated systems (Warneke, 1993; Hoverstadt, 2008). In the area of enterprise ISs, the fractal approach appears suitable for dealing with ISs development problems characterized by a relatively loose coupling among entities involved in solving of focused knowledge intensive problems without highly elaborated and structured workflows. Examples of such problems are operations of project consortiums, academic institutions and distributed product-design groups.

Fractal systems consist of self-similar, self-optimizing, goal-oriented fractal (independently acing organizational entities) arranged in a loosely coupled hierarchical network. They are continuously evolving and are characterized by rich information exchange flows inside fractal entities, between different levels of the fractal system and with external environment (Ryu and Jung, 2003). Goal-orientation allows balancing individual and system-wide interests of all entities involved. Self-similarity allows simplifying and structuring design of what might appear as a chaotic system. Self-organization allows finding ways for achieving goals without having predefined processes. Information flows supported by the fractal systems facilitate knowledge exchange.

Ryu and Jung (2003) and Kirikova (2008) discuss general aspects of development of Fractal Information Systems (FIS). This paper focuses on information structuring and management issues in FISs by means of elaboration of Information Architecture of Fractal Information Systems (IAFIS). Information Architecture (IA) describes the structure of a system, i.e., the way information is grouped, navigation methods and terminology used within a system (Barker, 2005). That is particularly important in fractal systems because a common, easily accessible information basis is necessary for fractal entities to achieve their and system-wide objectives. Additionally, IA defines information flows among fractal entities. From the ISs development perspective, IA is used to develop self-similar representations of the problem domain for entities involved in the problem solving and to trace information interdependencies.

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Thus, the objective of this paper is to elaborate methods for designing and analyzing IAFIS and to demonstrate application of IAFIS in development of FISs. It is assumed that each entity belonging to a fractal system has its own problem representation, which is based on a common goals and ontology of the fractal systems. This representation suits needs of a particular entity. IAFIS defines all Information Elements (IE) characterizing the problem domain and relationships among these elements. Analysis of IAFIS yields IEs relevant to the problem representation of individual entities. The contribution of this paper is elaboration of rules for analyzing IAFIS, as well as outlining of principles for designing FISs on the basis of IAFIS. These principles also can be applied in design of enterprise content management systems and portals, which are enterprise systems having limited support for formalized development. Design, analysis and application of IAFIS throughout the paper is presented by using a problem of ISs development for Study Programme (SP) development in Latvian universities.

2 FRACTAL IS

For purposes of this paper, the FIS is defined as a problem-oriented IS shared by a network of interrelated Organizational Entities (OE), where each entity has its own representation of the problem and information needs. Key elements of the FIS are shown in Figure 1.

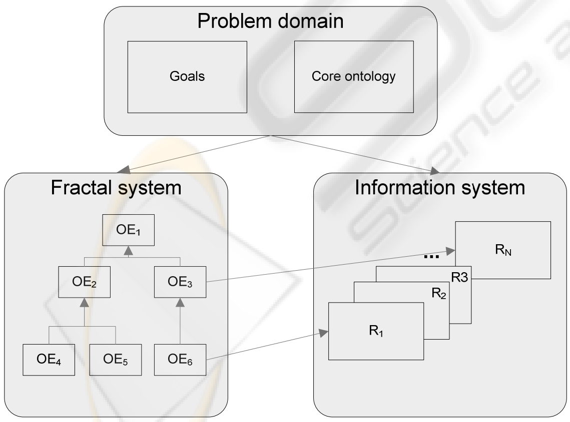

Figure 1: A fractal system and its IS. R_i denotes problem domain representation.

A FIS is created upon demand by a group of entities involved in solving a common problem. The common problem is defined by a set of goals and core ontology. The core ontology defines initially agreed concepts characterizing the problem domain (Kirikova, 2009). However, it is likely that each entity also has its own internal ontology, which to some extent deviates from the core ontology because usually it is not restricted just to the particular problem domain. Entities might be arranged hierarchically. However, they are relatively independent, and entities at higher hierarchical levels provide only problem-solving goals and general framework while the choice of sub-goals and particular problem-solving mechanisms is not strictly regulated. An IS supports problem-solving. It provides multiple views or representations of the problem domain. These representations are suited according to specific needs of each entity. At the same time, they use the common core ontology and common design principles. IAFIS is used to provide a systematic framework for developing and maintenance of these different representations.

3 IAFIS META-MODEL

In the FIS, an organization entity uses information to complete its activities and achieve its objectives. It either is an owner of this information or consumes information provided by other OEs. IAFIS defines Information Elements (IE) and relationships between these elements. It allows to identify information needs of each OE and to reason about change and knowledge propagation inside the fractal system. UML is used to describe IAFIS.

There are five types of nodes used to define IAFIS (Figure 2). The central element is `InformationElement`. It is used to describe any kind of information unit (e.g., document, record, file) relevant to a particular problem domain. `InformationElement` may contain multiple `Parameter` elements. The `Parameter` element identifies data items of the IE what either characterize this IE or have major importance in the problem domain. It can be represented either as a class or as an attribute. Parameters often are numerical values, which can be used to quantify and analyze the problem domain. IEs together form a problem representation suitable for a particular OE. Multiple OEs can share one representation. One organizational can have multiple problem representations. Definitions and meaning of IEs and parameters are provided in either the core ontology or ontologies owned by individual OEs.

Six types of relationships among IEs are defined. Association is used to describe general connections between IEs. A dependency relationship is used to

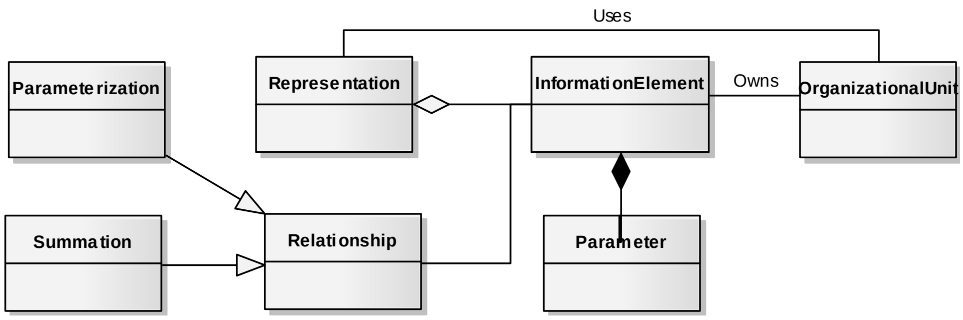

Figure 2: General representation of IAFIS.

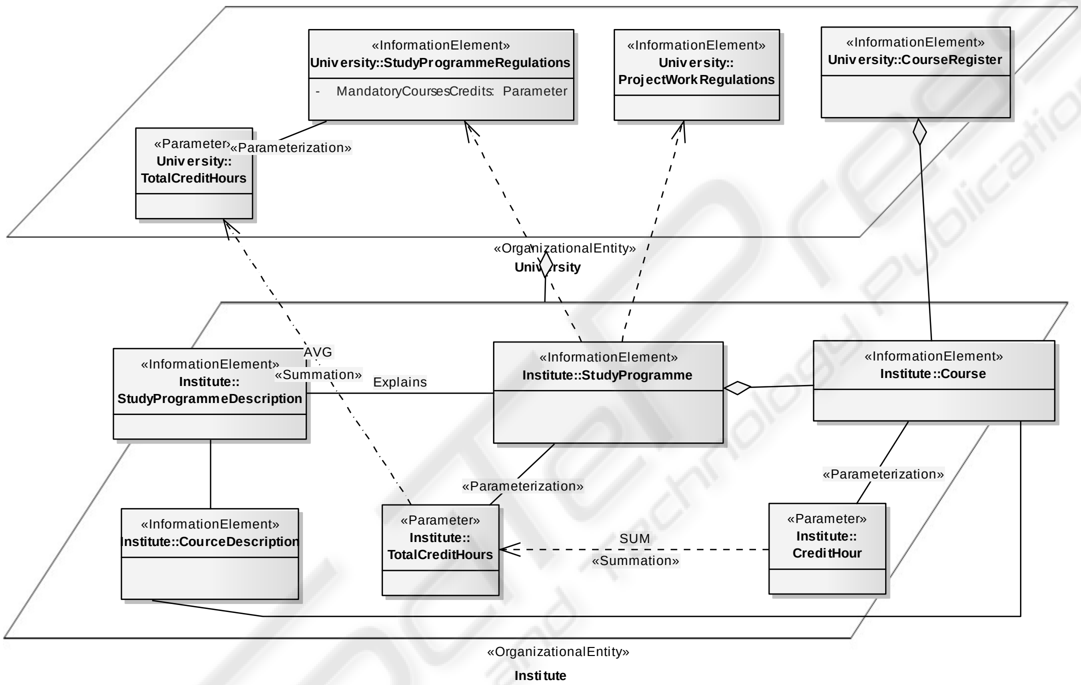

Figure 3: IA of SP development information system.

describe some kind of dependence of one IE upon other IE. It is particularly used to show that content of one IE is developed according to some requirements provided by another IE. Aggregation and composition relationships are used to describe that an IE consists of other IEs. A parameterization relationship indicates that a `Parameter` element belongs to the specified IE. A summation relationship is used to describe data transformation and aggregation relationships between different problem domain representation.. IAFIS is developed using the defined elements. A designer identifies fractal OEs and IEs, assigns the IEs to the OEs, parameterizes the IEs and establishes relationships among the IEs. Thereafter, IAFIS is analyzed and used in development of problem domain representations for individual OEs and for maintenance of the FIS by tracking change and knowledge propagation.

The example of study program development IS is used to illustrate IAFIS. SPs comply with general guidelines set by the law. The SPs are accredited by the Latvian Ministry of Education and Sciences. On the basis of these legal requirements, each university develops their internal regulations on development of SPs. These regulations are more detailed and include references to other administrative regulations and documents (e.g., course register). SPs are developed by university's faculties.

A fragment of IA for the SP development IS is shown in Figure 3. It consists of two OEs (depicted using parallelogram) – university and faculty (other hierarchical levels such are omitted). The SP development at the university is governed by "SP

Development Regulations" represented by the `University::StudyProgrammeRegulations` IE. There are multiple data items characterizing this IE, and these are presented using elements of type Parameter (only one parameter is shown for the sake of simplicity). For instance, the regulations mandate the total number of credit hours required in a SP. This is an important characteristic and therefore is shown as a parameter. SPs are developed by faculties, and IE `Faculty::Study Programme` belongs to the faculty. The dependency relationship is used to show that the SP is developed according to requirements provided by the SP development regulations. The SP also has a parameter characterizing the total number of credit hours. The summation relationship is used to describe information flows from one hierarchical level to another. In this case, it is shown that the University sets the bounds on the total number of credit hours and that the University averages total credit hours data received from faculties (this information can be used to analyzed structure of SP and to judge about necessary adjustments in regulations). The SP IE is also shown to depend upon `University::ProjectWorkRegulations` and indirectly upon `University::CourseRegister`. There are also IEs, which are unique to the faculty and do not directly depend upon IEs belonging to other OEs.

4 ANALYSIS OF ARCHITECTURE

IAFIS is analyzed in order to develop representations of the problem domain for each OE. The analysis yields several types of collections of IEs gathered from different OEs. These collections are aimed to contain all IEs and their parameters necessary for an OE to address the particular problem. The entity specific problem representations consist of properly arranged collections. IAFIS is also analyzed to understand information interdependencies, to identify isolated IEs as well as to investigate other features of fractal systems.

The most important task of the analysis is identification of required IEs for each problem representation. These IEs are grouped in collections. The first collection C_1 includes all IEs owned by a particular OE. The second collection C_2 includes all IEs, which are suppliers in a dependency relationship with IEs belonging to the first group. The third collection C_3 consists of all IEs, which are indirect suppliers of IEs. The fourth collection C_4 includes IEs, which have any other types of direct relationships with IEs belonging to C_1. These rules are formally specified using OCL (Object Constraints Language). Collections of IEs subsequently can be used during the implementation of the FIS for grouping and to establish hierarchy of IEs.

IEs in IAFIS are parameterized to highlight the most important characteristics of the problem domain. Relationships between parameters are shown using the summation relationship. The summation relationship is bidirectional. From a supplier to a client, it describes what kind of restrictions the supplier imposes on the client. From a client to a supplier, it defines the supplier-side processing of data provided by the client.

Parameterization and summation relationships are also analyzed. That includes finding all parameters characterizing a particular IE. For each OE, three groups of parameters are identified. The first group P_1 includes parameters characterizing each IE from collection C_1. In the FIS, these are displayed along the particular IE. The second group P_2 includes parameters directly or indirectly provided by clients in the summation relationships. These can be used as key performance indicators. The third group P_3 includes parameters directly or indirectly provided by suppliers in the summation relationships. These can be used as the most important problem-solving guidelines.

The analysis of IAFIS is also used to update the ontology of the fractal system. IEs and parameters used by OEs are matched against concepts defined in the core ontology. If these elements are not found in the core ontology, they are either identified as candidates for inclusion in the core ontology or inspected for correspondence to concepts already included in the core ontology. An OE specific problem representation contains only those elements deemed explicitly necessary to problem-solving though tracing capabilities also can be provided.

The analysis also is used to identify isolated IEs and isolated clusters of IEs. These collections are candidates for knowledge propagation and modification of the core ontology in the case of semantical inconsistencies.

5 UPDATING OF IAFIS

During maintenance of the FIS, IAFIS is updated both automatically and manually in response to changes in the fractal system and problem-domain. The updating is classified as change propagation and knowledge propagation. The FIS can be modified according to the changes made in IAFIS.

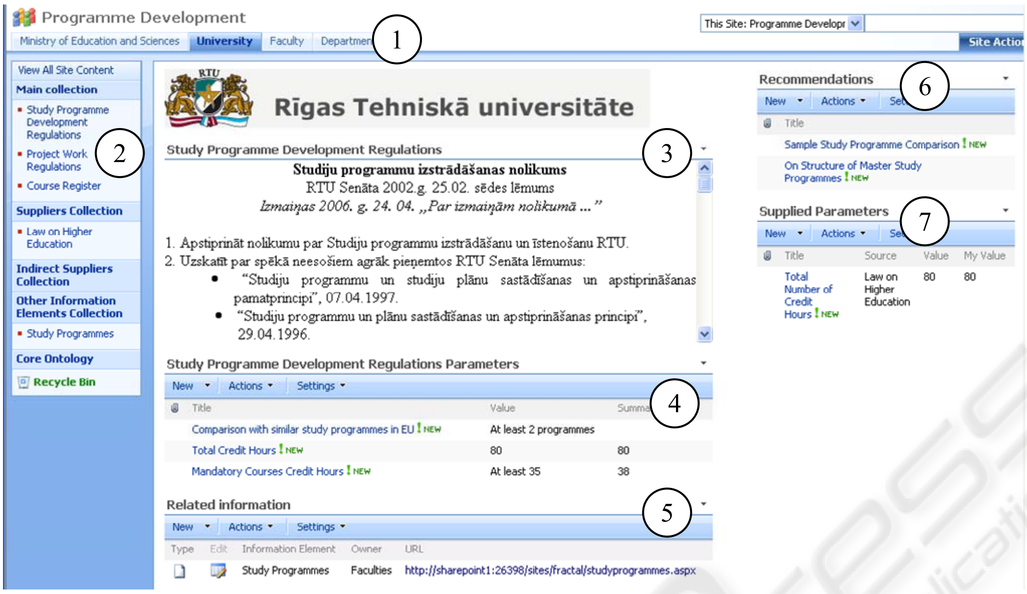

Figure 4: Sample implementation of SPDIS.

Change propagation deals with updating of IA in the case of changes in its elements or relationships. Three kinds of change propagation situations are considered: 1) updating in the case of added IE; 2) updating in the case of added parameter; and 3) updating in the case of added relationships.

In the case of added IE, relationships between the element and other elements owned by the particular entity are manually established. The ontology of the particular entity is also updated. If the element is added at upper levels of the fractal system, semantically related IEs belonging to lower level entities are searched in the core ontology, and the lower level entities are notified to consider updating of their representations. Adding an element at lower level entities often is performed in response to changes in upper levels and dependency relationships can be established. If the element initially is added for internal used, it is defined in the ontology of the particular entity and its further evolution depends upon rules of knowledge propagation.

In the case of added parameter, summation relationships are added to the IA. Initially, all parameters of directly or indirectly related IEs in all other representations are checked to identify semantically related parameters. The core ontology is used in the identification process. Summation relationships are established with semantically related parameters. If semantically related parameters are not found, a new parameter is added to related IEs, a new IE and its parameters are added or no action is taken. If new elements are added then summation relationships are also established. In the case of added relationships, there are no direct changes in IAFIS but the analysis rules are reevaluated and changes are resembled in the FIS.

Knowledge exchange is vital for fractal systems. Knowledge can be propagated from individual entities to the whole fractal system. Three types of knowledge propagation mechanisms are identified: 1) promotion of IEs with high level of cohesion (K_1); 2) best practice propagation (K_2); and 3) promotion of frequently used elements (K_3). From the IA perspective, an IE is of type K_1 if it is involved in many direct or indirect relationships what indicates that this element is important to the problem domain. In the case of human directed knowledge propagation, representations lacking elements of type K_1 are analyzed to check relevance of these elements. Automatically, elements from K_1 can be provided as recommendations (Montaner et al., 2003) for inclusion in the representation.

The fractal system adopts best practice processes, which have been successfully utilized by some of fractal entities similarly as described by Steckuka et al. (2008). IEs used in these processes are included in problem-domain representations for those entities adopting the processes. IEs of type K_3 are determined by monitoring usage of the FIS. The fractal system automatically recommends adding to the representation IEs frequently used by other OEs or IEs frequently requested using the trace function.

Similar knowledge mechanisms can also be applied for propagating knowledge about parameters.

6 SAMPLE IMPLEMENTATION

Application of IAFIS is demonstrated by implementing a prototype of the information system for the SP development problem (SPDIS). The IS is implemented on the basis of commercial collaboration and content management system according to IAFIS shown in Figure 3. Figure 4 shows the user interface of SPDIS of the university. Markers are used to indicate different parts of SPDIS. The first part refers to problem domain representations for different OEs (e.g., university and faculty). Part 2 contains links to IEs needed by the particular OE. These elements are collected and structured according to the rules established in Section 5.1. Part 3 contains the selected IE, in this case the regulations on SP development. Part 4 lists parameters of the selected IE. The list contains their title and value, and summation value, which is computed from data provided by clients in the summation relationship. Part 5 lists all IEs from the collection C_4. The recommendations part (part 6) demonstrates automatic knowledge propagation. The IEs in this part are included according to the rules K_1 and K_2 specified in Section 6.2. Part 7 shows parameters, which are used by the university in elaboration of regulations on SP development. The parameters are those included in group of parameters P_3.

7 CONCLUSIONS

The paper has proposed IA and its analysis rules as a tool for developing fractal systems. The problem representations specifically suited for particular OEs and built on the basis of IAFIS are self-similar what ensures consistency in the relatively loose coupled system and reduces systems development and maintenance cost. At the same time, they are adjusted to needs of particular OE, which have the sufficient information basis to complete their tasks with respect to common and individual goals. The set of rules for change and knowledge propagation enables updating of the FISs and facilitates knowledge sharing among fractal entities. To our knowledge, the proposed IA and its analysis rules provide the first systematic framework for information management in fractal systems.

Efficient utilization of IAFIS requires parameterization of IEs. Concept modeling and document mining techniques can be used for this purpose. The fractal system can be designed in either top-down or bottom-up manner. In the case of top-down approach, a lead entity develops its problem representation and this representation can be used as a template for developing self-similar representtations. In the case of bottom-up approach, fractal entities have their own problem-representations, which are continuously aligned during evolution of the fractal system. Another question for future research is integration of fractal systems with other ISs because IAFIS and implementation of FIS depends upon already existing models and systems.

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