„BABEŞ-BOLYAI" UNIVERSITY OF CLUJ NAPOCA
Faculty of Economic Science and Business Management

CONTRIBUTIONS TO USING DECISION SUPPORT SYSTEMS BASED ON "MACHINE LEARNING" TECHNOLOGIES IN BUSINESS MANAGEMENT

- PhD thesis summary -

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INTRODUCTION

The success of any organization depends mostly on the decision made at different leadership position levels, and given the current economic-social conditions, making the right decision has turned into a rather difficult task. If at first the decision-making process used to be considered in management theory an activity reserved exclusively to people, with the growth in the amount of data and in the difficulty levels to manage and process it, the decision-making process is now being developed using computer-based and communication technologies. This has lead to an interdisciplinary approach in decision study, to the decision computerization and to the emerging of computer-based decision support systems.

Decision support systems come into play to assist the manager in his tackle upon the complex environment and the circumstances formed around making a decision. An important step in accepting these systems, which has implicitly lead to their development in time, was understanding and embracing the idea that these instruments do not pursue to remove the decision maker, but bring support and assistance instead.

With the evolvement of the knowledge society and the knowledge-based organizations, the complexity of management problems has also increased, and the computer-based decision support systems have begun to realize themselves through solutions based on artificial intelligence technologies. The objective of the intelligent technologies approach in building decision support systems was set on using human ratiocination for the ability to come up with solutions for complex decision problems, as well as for determining a knowledge plus within the organization, thus increasing the quality of the management process.

This thesis aims to perform an investigation upon the decision environment and decision support systems, as well as intelligent systems and Machine Learning technologies and also how to use these to create an improved decision process. The theoretical research has determined the development of a decision software framework that represents a foundation for building complex decision algorithms. A highly expandable and reusable environment with a strong practical character has emerged, that allows the usage of algorithms that assist decision makers in solving high-complexity decision problems.

The thesis is structured into six chapters (figure *i*), beginning with a theoretical presentation of the basic notions and used concepts and continuing with a detailed description of the design and implementation of the proposed system.

In the conditions of our contemporary society, named the knowledge society, the organizations have to adapt their management to proactive thinking, to embrace the idea of rationality of computational and decision component in pursuit of becoming more and more competitive and obtaining high performance. A well-built software infrastructure together with computer-based decision support systems can supply an indisputable support for the decision makers confronting with a multitude of problems within the organization.

We seek to present a new approach regarding the development of decision support systems, emphasizing new directions in decision algorithms implementation through an expandable system designed with respect to advanced principles of software engineering. The proposed approach comes as a retort to trends imposed by the current software technologies and allows the implementation of decision support systems using new Machine Learning technologies.

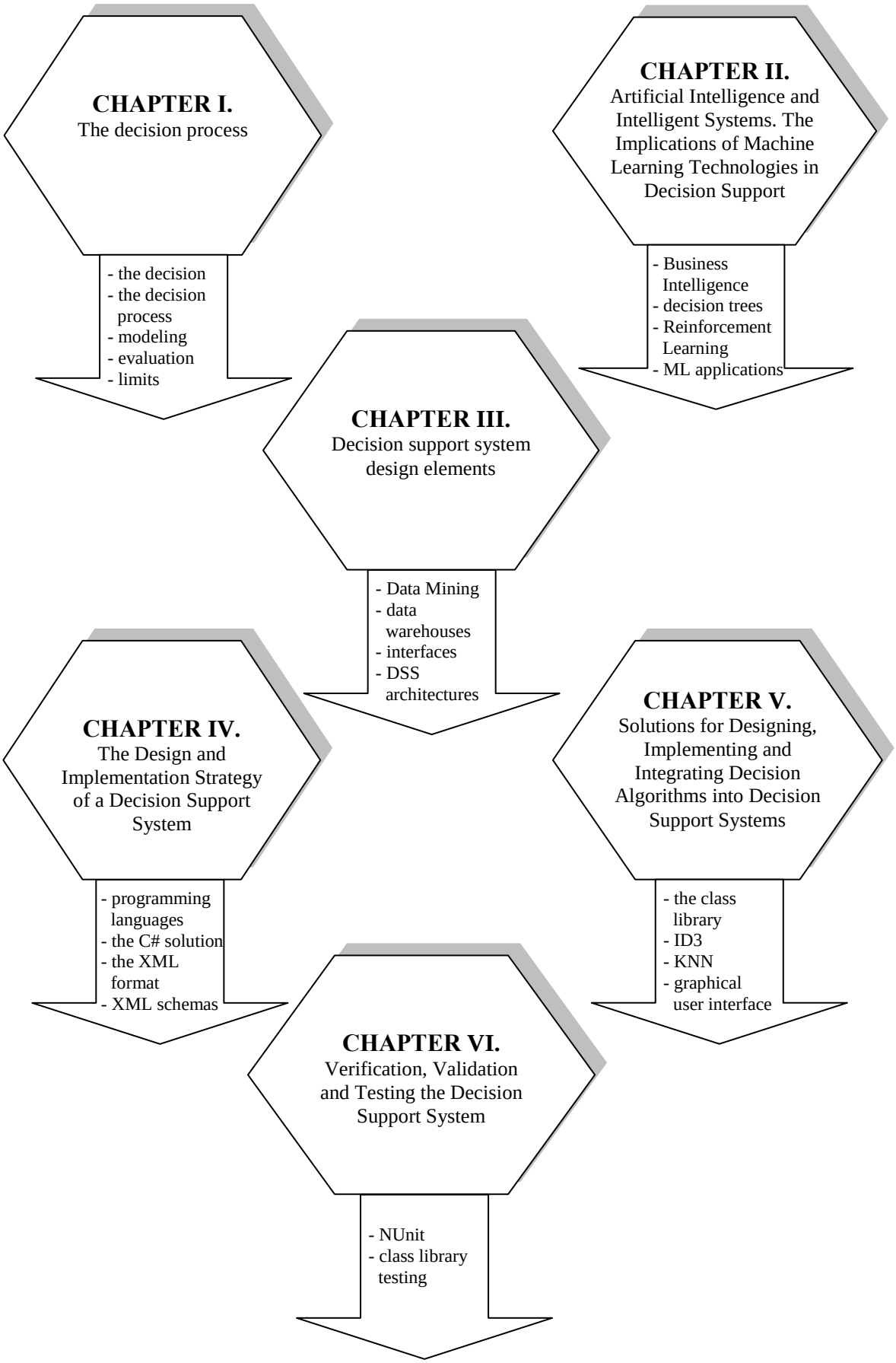

Figure i. *The structure of this thesis*

CHAPTER I. THE DECISION PROCESS

Chapter I describes the elements of the decision process, displaying the relationship between the computer-based system and the decision system which, as a result of the complex modifications that impacted the society due to information becoming the essential resource of the organization, evolved in a natural way. In order to completed illustrate the decision process we begin with detailing on the notion of decision, showing the decision characteristics and classification by a series of criterions, enouncing the definition of the decision maker and the decision circumstances. The structure of the decision process is established, this being composed in our vision from four steps: preparing the decision, picking out the optimal solution and making the decision, applying the decision and controlling the application, and finally, evaluating the decision results. Because selecting the optimal solution and adopting the decision is the most important step in the decision process, we have shown the primary techniques and means of finding the optimal decision, and have described the procedure for modeling the decision processes. In order for the decision process to prove its finality, its results are evaluated, thus establishing the quality of the entire process.

The end of the 20th century has been marked by transition, from the industrial society, within which the main resource of an organization was represented by assets, to the post-industrial society, also known as the information society, within which the most valuable resource is information and the base production is the intellectual one [Niţchi03]. This society is deeply influenced by the development of computer-based and communication technologies, which determine a substantial alteration of the informative process which structurally and functionally defines the computer-based system.

Like any other activity a human subject performs, management implies a chain of decisions which can be classified by a variety of conditions. The decision can be defined as a consequence of conscious activities of choosing and taking a path to follow, which also implies allocating resources for achieving the planned goal. Making a decision is justified by the following elements: the decision maker, the situation and the decision problem, the decision process.

The decision process emerges from a sequence of decision activities. This process is based on acknowledging a decision situation and collecting data, and then

proceeds to searching, projecting and modeling alternatives, choosing the accurate solution and finally, making the decision and evaluating the results.

The decision process spans upon more stages and phases and its structure results from the number and succession order of its stages. In our vision the decision process is composed of four main stages, each stage being divided in multiple phases (Figure 1.).

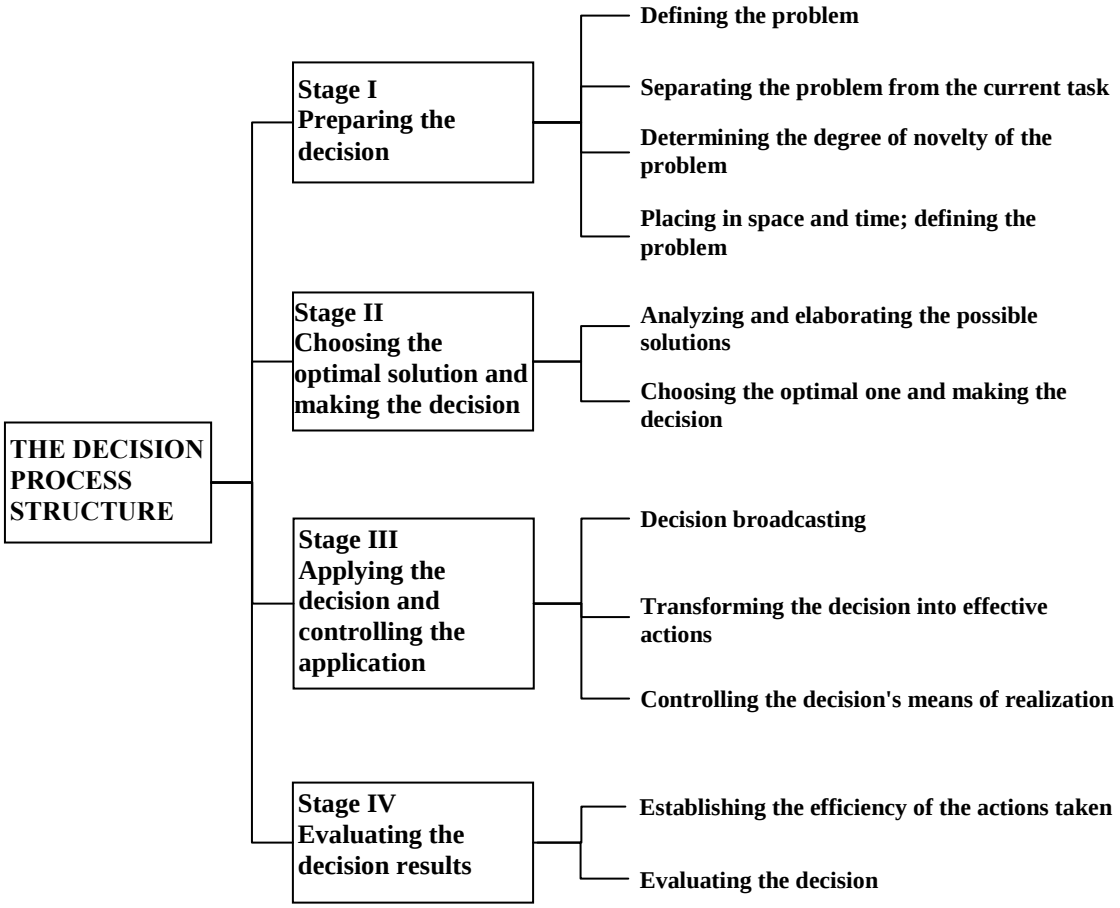

Figure 1. *The structure of the decision process*

Modeling the decision process will be achieved with respect to each stage its structure (Figure 1.). Therefore one or more models will be built for each decision activity, considering the modalities of development of these activities. It is noteworthy that the modeling process tends to be limited, imperfect, because even with a maximum level of attention when developing the model, it won't fully reflect the modeled object, consequently it can affect the quality of the perspective over the decision process.

CHAPTER II. ARTIFICIAL INTELLIGENCE AND INTELLIGENT SYSTEMS. THE IMPLICATIONS OF MACHINE LEARNING TECHNOLOGIES IN DECISION SUPPORT

Chapter II opens with the presentation of artificial intelligence concepts, accentuating the intelligent system perception, the involvement and usability of these kinds of systems in the economic domain. The different types of intelligent systems are displayed – artificial neuronal systems, intelligent systems based on genetic algorithms, fuzzy systems, expert systems, hybrid systems – followed by an highlighting of the expert systems. From the discussion about intelligent systems and using them at a larger scale in the economic environment we reach the concept of Business Intelligence and we present some of its applications. The entrance of the Machine Learning concept proves there's a continuous effort in developing computer-based systems which improve their performances based on achieved experience, their so-called "learning" activity provided by a learning agent being similar to the learning process of the human subject. The Machine Learning showcase insists on decision trees, the Reinforcement Learning technology, example-based learning, deductive an inductive learning, supervised and unsupervised learning, thus providing a correct understanding of the concept.

Some systems based on Machine Learning technologies tend to eliminate the need of human intuition for data analysis, while others adopt a collaborative approach between man and machine. Human intuition cannot be completely eradicated since the system developer must specify the means of data representation and the mechanism used to search data. Machine Learning resembles a tentative of automation of scientific method parts.

Machine Learning refers to modifications in systems that perform different artificial intelligence-related tasks, which imply recognition, diagnose, planning, robot control, forecasting, which can only be completely defined through examples, specifying the input data and expected results. It is desirable for the result to be deducted based on the hypothesis that there are a series of input data, but lacking a well-defined input-output function and only approximating the implicit relations. However, in many situations correlations and links are "hidden" behind large amounts of data, but these can be successfully extracted using Machine Learning technologies.

Systems that don't function efficiently in their environment are often being designed because some characteristics of the working procedure were not able to be explicitly defined at the time they were built. Machine Learning methods come to the rescue in these situations. Information is being diversified and generates new knowledge flows which would require a new implementation of artificial intelligence systems, but given this is not a convenient resolution it is forecasted that Machine Learning technologies would handle these situations well.

Machine Learning areas of interest seek to answer the question of "how we can develop computer-based systems that are able to improve performances through gained experience and what are the fundamental laws that govern all the learning processes?" In order to clear a path leading to the answer, we have displayed an analogy between human learning and the one of a learning agent and have described a few usual technologies in this domain.

One of the high-importance Machine Learning technologies is represented by decision trees. Decision trees are a technique that can be applied both to classification and prediction, shaping the result into a tree structure displaying a hierarchy of logical rules automatically established by exploring an example base. Examples are data records composed of multiple attributes. Rules are obtained as an effect of dividing the example base in more and more detail, with respect to the value of attributes.

Decision trees prove to be excellent instruments for making financial or any kind of number-related decisions whenever a large amount of complex information must be taken into account. These provide an efficient structure for evaluating alternative decisions and their implications and help outline a correct, well-balanced vision upon the risks and benefits resulting from making a certain decision.

Most decision tree algorithms that can be successfully used for learning problems are actually versions of the same algorithm that performs a top-down search within all the possible decision trees. An example is the ID3 algorithm designed in 1986 by Australian professor J.R. Quinlan and another is its successor, the C4.5 algorithm.

Reinforcement Learning refers to a certain type of Machine Learning algorithms. The idea behind it is simple: an agent explores some environment and in the end it receives a reward or a penalty. Hence, the agent discovers if the path taken was correct or not, without understanding the reasons.

Reinforcement Learning does not provide any clues on the expected results; it only classifies the result as wrong or right, similar to a non-talkative critic. However, it

often happens that the reward is delayed. These kinds of delayed-reward learning techniques are currently being tested in game development, like chess or backgammons.

Reinforcement Learning applies upon classes of problems that involve an agent exploring an environment and recording certain actions. It is the environment that responds to actions through rewards and penalties.

The Reinforcement Learning algorithms aim to find the best way to maximize the reward. The learning subject must not be told which way to go, as in most Machine Learning techniques, but it needs to unveil the path that brings to most efficient reward by itself, by trial and error.

In the most complex situations the taken actions will not only affect the immediate rewards, but future ones as well. Thus, the Reinforcement Learning technique delimits itself through two particularities: the trial-and-error one and the delayed reward one. It will not be defined through describing the characteristics of learning methods, but through describing the learning problem. The primary conclusion is that aspects of the real problem must be understood using a learning agent which is capable of comprehending the environment and of taking the appropriate measures.

CHAPTER III. DECISION SUPPORT SYSTEM DESIGN ELEMENTS

Throughout Chapter III decision support systems' involvements in management were being discussed. Therefore, initially some details on decision support systems, classifications, components and future steps in development were presented, followed by data storage solutions, emphasizing on data warehouses, OLAP technologies and the Data Mining concept respectively. Given this approach a structure of a computer-based decision support system within a strongly-computerized organization were outlined. In this same chapter, the stages of development of decision support systems were described with respect to the software engineering development standards, decision support system architectures were depicted and group decision support systems were discussed.

Management activity within organizations has suffered significant modifications in the context of information society development and the new computer technologies have beneficially influenced the most important domain of this activity, decision making. Decision tasks become harder and harder to achieve without the support of computer-based instruments known as decision support systems (DSS).

Equally difficult to finding an adequate definition for decision support systems is finding one for their components, for authors involved in this area of research. Therefore, corresponding to Sprague and Carlson the components of a decision support system are:

- the data management component;
- the model management component;
- the user interface management component;
- the decision support system architecture.

Our approach considers the components of a decision support system to be similar to the ones identified by Sprague in 1982 (Figure 2.):

- the user interface;
- the knowledge-based subsystems;
- the data management module;
- the model management module.

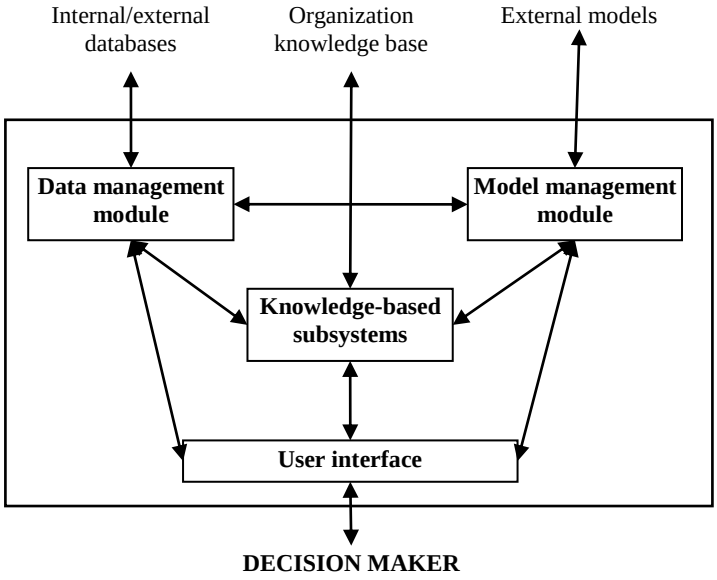

Figure 2 *The components of a decision support system*

(adaptation after: Lungu, 2003)

At the organization level there's dealing with large quantities of data, both internal and external. Internal sources are mostly represented by the production system while external sources consist of partners, clients, the environment, the market etc. The amount of data from internal sources is larger than the one coming from external sources, but the latter one is evolving in growth due to development of advanced data collection techniques.

The important data volume from within the company must be stored and maintained safely in order to be consumed later, the main storage environments for these kinds of data consisting of data warehouses and data marts.

The available technologies for storing data and information must help understand the past better and forecasting the future through improving the efficiency of the decisions made. The Data Mining technologies come into play for this purpose.

Data Warehousing technologies can prove to be highly useful to various categories of decision makers and the main means of benefiting from Data Warehouses storage facility are Online Analytical Processing (OLAP) and Data Mining techniques. The OLAP technology refers to being able to aggregate data in a Data Warehouse aiming to separate information useful to the decision process within an organization from the large amount of data. According to specialists, a more representative alternative term for the OLAP concept would be FASMI (Fast Analysis of Shared Multidimensional Information). The essence of any OLAP system is the OLAP cube,

also known as the multidimensional cube, consisting of numerical facts named measures, grouped by dimensions. These measures are derived from records in a fact table in a relational database. The results of user requests can be obtained by a dynamic parsing of the data cube's dimensions at different levels of synthesis or detail.

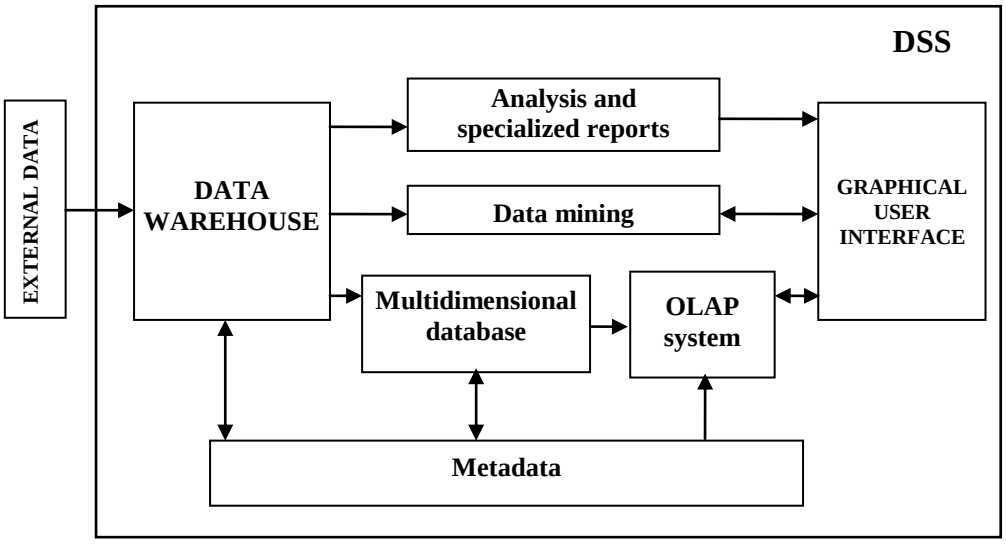

Figure 3. *The components of a decision support system in a strongly-computerized organization*

Data Mining technologies integrated into decision support systems determine a decision support tool still founded on the man-machine interaction, and these two entities as a whole create a spectrum of analytic computer technologies that stands as foundation for an optimal combination of data-oriented analysis, but driven by man [Ganguly05].

Data Warehousing is an important component of a data-oriented decision support system and its relationship with other components is illustrated by Figure 3.

CHAPTER IV. THE DESIGN AND IMPLEMENTATION STRATEGY OF A DECISION SUPPORT SYSTEM

Chapter IV opens with several approaches on the effective development of decision support systems and also on programming languages used to implement them. It highlights the advantages of the object-oriented approach in the design of such decision systems, revealing the choice of C# as a programming language and Microsoft Visual Studio as an Integrated Development Environment (IDE) for the implementation of the system that makes the object of this thesis. Choosing to represent data in XML format is reasoned through comparing it with other file-storage formats used in similar integrated systems. However, other major advantages that prove the superiority of this solution are also enhanced. The designed XML structure is based on an XML schema (XSD), which is essential for validating the inputs as well as for file data verification, thus emerging a simple means of representation having an increased safety level regarding input data.

The proposed system aims to be a framework for a decision support system that will allow implementing all sorts of algorithms with the purpose of helping the decision makers in solving complex decision problems. With this in mind, the system is designed with the greatest respect to the Design Patterns [Gamma 95], with increased levels of reusability.

The integrated system is developed using the Microsoft Visual Studio IDE, it is a Windows-forms application based on the .NET Framework 2.0 architecture and the code is written in the C# programming language.

The Visual Studio solution is divided into two projects, one being the main executable application that contains the graphical user interface (GUI); the other project consists of a class library that embeds the mechanisms of managing relations, attributes and instances. It also defines a number of sample decision algorithms based on this framework. This structural definition of the solution explains itself through the general recommendation of separating the core, logic compound from the user interface, design rule that should be obeyed in the process of development computer applications.

The class library project defined for the integrated system aggregates a series of class assemblies, each one having its corresponding namespace definition (Figure 4.). The basic assembly will be named *ML.Core*; the classes that manage relations and their

subparts will be grouped under the *ML.Core.Relations* assembly and all the algorithm classes will be stored in *ML.Core.Algorithms*.

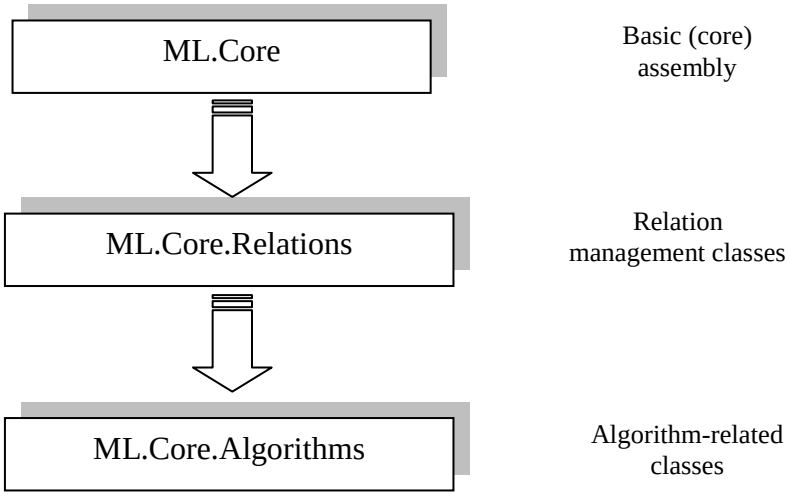

Figure 4. *Class library assemblies*

The compound that is formed from data models represented in XML format together with corresponding XSD schemas and computer applications implemented in the programming languages that offer a set of functions for processing these data models (.NET Framework, Java packages, Qt) stands for a solution that is powerful and efficient, but mostly elegant from an object-oriented standpoint.

The idea of using XML files to store data emerged from the numerous benefits this format brings along:

- ease of data structuring process
- the files are "human readable" (similar to text files, in this case)
- platform independency, open standard with no license required

Storing data for a DSS in XML format may be structured in many ways and the solution proposed in this thesis was inspired by the WEKA project, developed for research purposes by a team from the Waikato University in New Zealand. WEKA represents data using the ARFF (Attribute-Relation File Format) which is essentially a text file that describes a list of instances based on an attributes collection. Following the same pattern, the XML file will first define the list of attributes identified by name and data type, followed by the training data, the so-called instances, every one of each representing an enumeration of values for the previously defined attributes. Some

attributes may be missing from the instance definition, this case being handled separately by the relation management system and the algorithms.

If we were to emphasize the improvement brought by using the XML format upon other formats, like the simple plain-text file, this could be summed up by the fact that the XML file can be validated upon loading, using a XML validation schema and the class library functions to parse the XML document performing the validation. Also, a validation upon saving can be implemented to verify the document was built correctly and will pass any subsequent load validations.

The XML document handled by the integrated system represents a so-called relation, the *Relation* element being the root node of the XML tree (Figure 5). This element aggregates two major sub-elements: the attribute definition list (*Attributes*) and the instance list (*Instances*). Each relation will have a name in order to ease identification; this name can be displayed in the title bar of the GUI application.

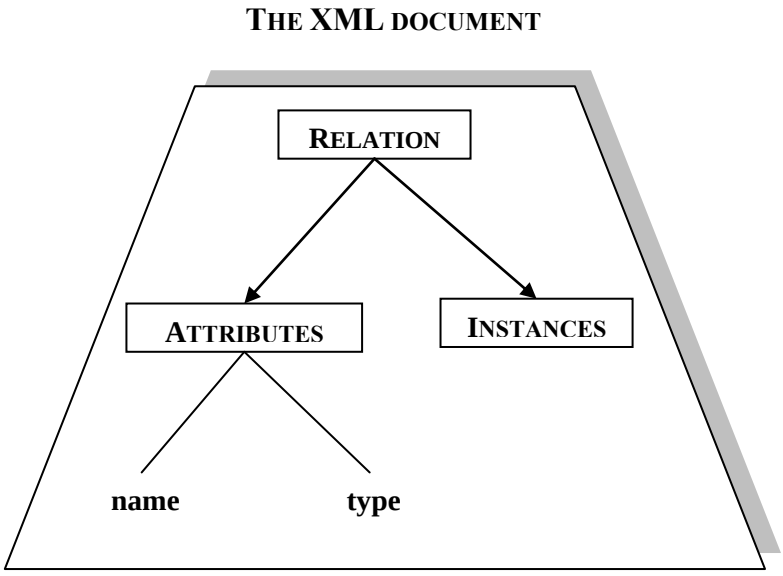

Figure 5. *The XML document structure*

CHAPTER V. SOLUTIONS FOR DESIGNING, IMPLEMENTING AND INTEGRATING DECISION ALGORITHMS INTO DECISION SUPPORT SYSTEMS

The beginning of Chapter V describes XML files handling methods with respect to the optimization of the load/save operations. The solution for implementing the system is presented in detail, depicting the XML entities and the top-down model implemented within the class library of the framework which makes sure of its expandable and reusable character. The base abstract classes for algorithms is described, and to prove the correctness of their functionality a decision tree algorithm (ID3) and training instance-based learning algorithm (k-Nearest Neighbor) are implemented. The end of this chapter proposes a variant for a graphical interface as an example, to prove the system's functionality.

Following the ideology of developing strongly object-oriented software and of the design patterns we considered appropriate to create a separate class for almost all of the XML element types that make up the input relation document. The alternative would have consisted of processing all of the XML elements solely at the *RelationDocument* class level and probably using .NET XML DOM classes (*XmlElement*, *XmlAttribute*, *XmlNode* etc.) all throughout the code in the class library. This approach would have been primarily hard to use from outside the class library, supplying a weak characteristic of reusability to the entire framework, and secondly, the *Load* and *Save* methods would have become long and incomprehensible.

In the proposed structure for the XML document, the *Relation* element is the root element of any document representing a decision relation, hence the definition of the class with same name within the library, which will implement the *IXmlEntity* interface.

Figure 6. depicts a detailed class diagram for the main entities in the class library.

Implementing the algorithms represents a large step in this software development process. The goal of the algorithm class library is to offer a solid technical foundation for developing almost any decision algorithm, as well as presenting the developers with the possibility of using the base classes define here as a starting point

for implementing new algorithms which are using a dataset that can be represented in the XML format described in the previous chapters (Figure 7.).

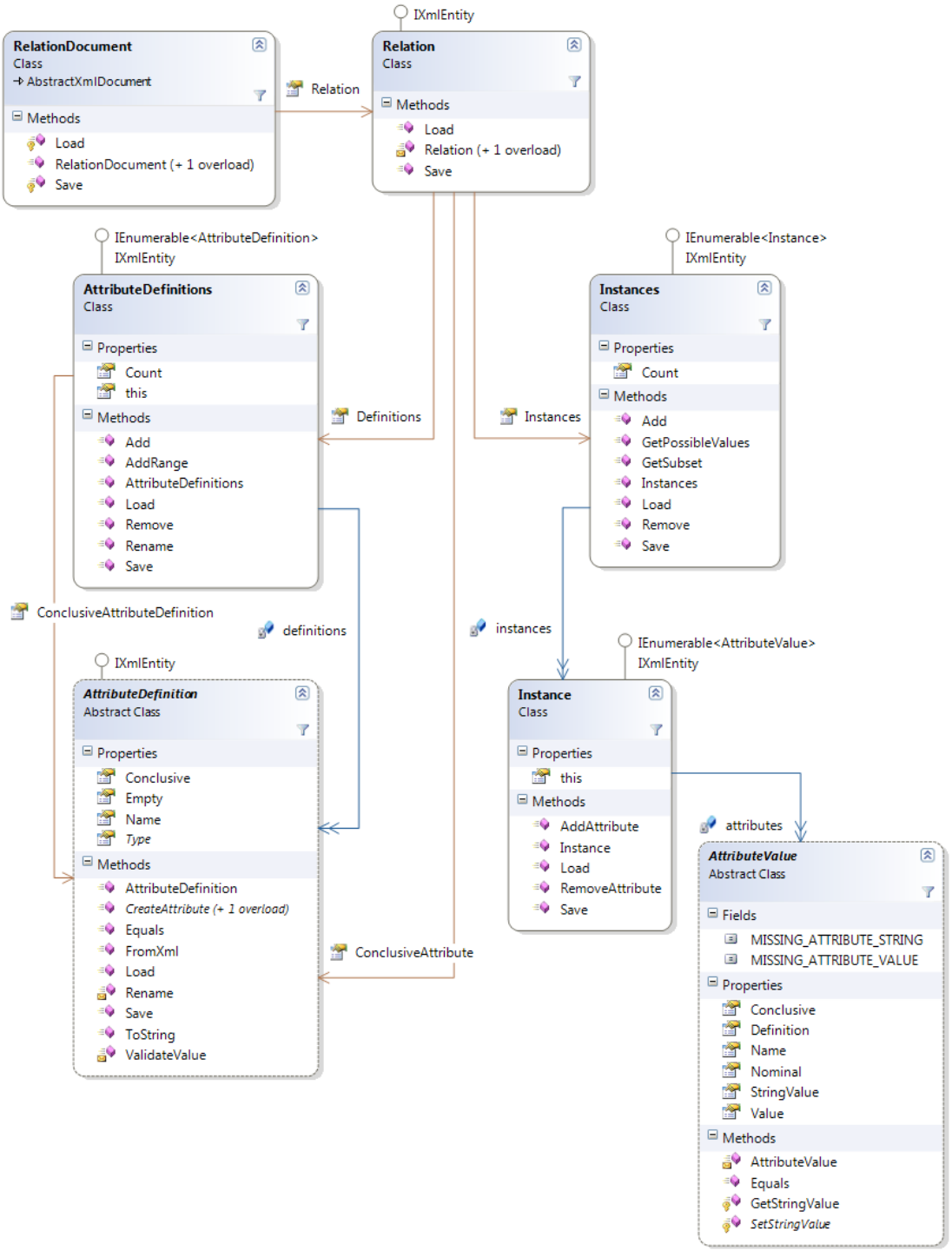

Figure 6. *Class diagram for the main classes in the library*

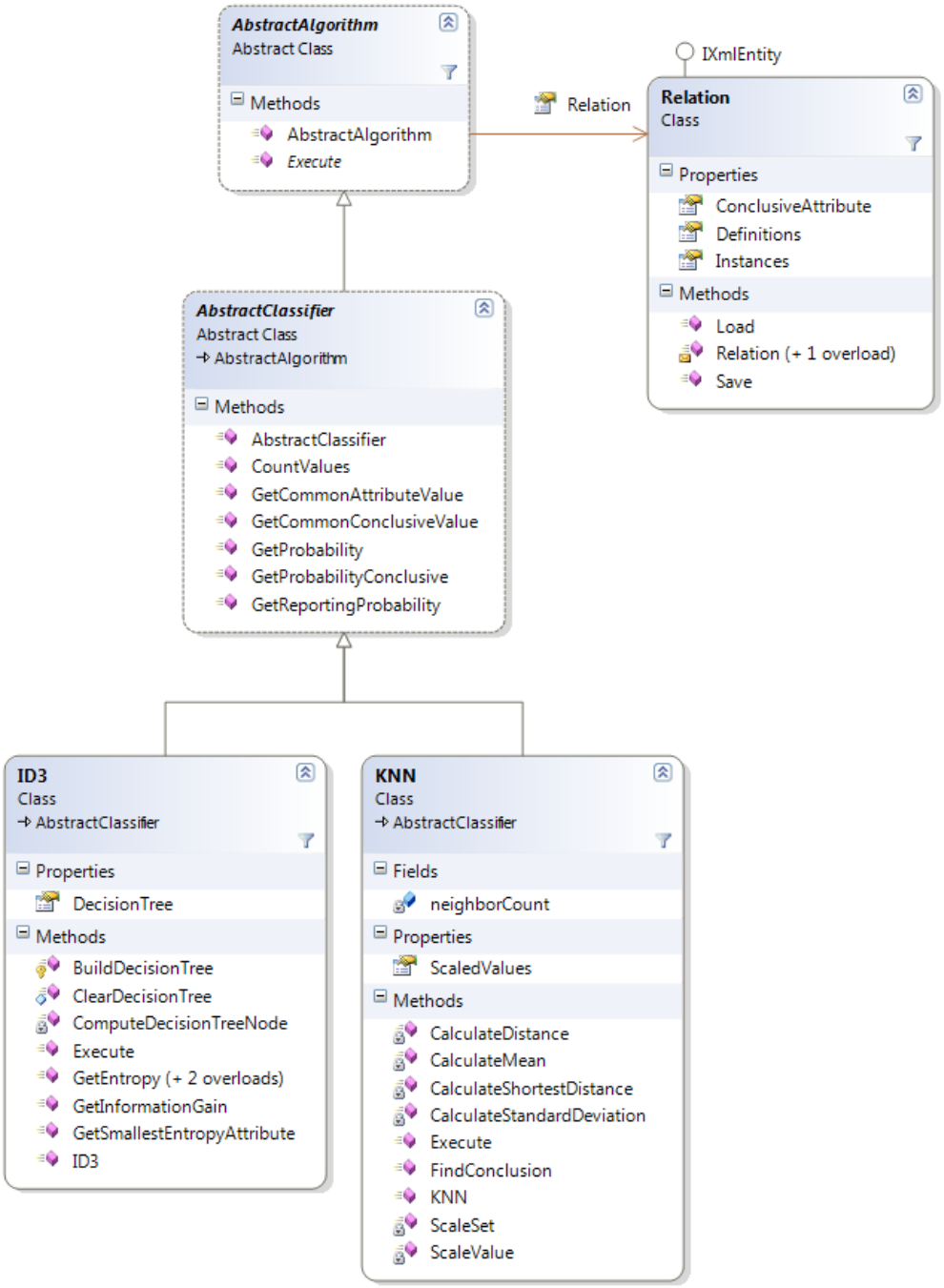

Figure 7. *Hierarchy of algorithm classes*

In order to exemplify the learning algorithms we illustrated the implementation of the ID3 algorithm and the KNN algorithm. The algorithm class library was build in such a manner as the addition of new algorithms will not impose any problems, given that we succeeded in putting together a very intuitive framework within which method overloading is omnipresent to aid simplify the usage process.

CHAPTER VI. VERIFICATION, VALIDATION AND TESTING THE DECISION SUPPORT SYSTEM

Considering that in the process of developing any software system verification, validation and testing it represent a very important and step which should not be overlooked, the last chapter, chapter VI comes to prove the system works as expected, using the NUnit testing application for .NET Framework, so we proceeded to describing in detail the means to test the application. A generic and expandable class library for testing was implemented, displaying highly polymorphic features, just like the class library being tested.

Verification and validation play an important role in ensuring the system matches its projected goal. In any case performing these tasks will not guarantee the system is perfect, completely error-free, they will only presume the resulted system is good enough for the tasks it was developed to achieve.

Regardless of the testing means of choice, this will prove its efficiency only in under the conditions in which as many errors as possible are highlighted and their probable propagations, which can severely damage the quality of the system. With the help of the testing metrics we can monitor the software's progress as the testing and error correction advance.

Testing an application or a .NET class library is performed using the NUnit testing application which in turn offers a whole library of classes and functions specific for testing and validating. Testing is achieved internally, automated, through an exception throwing and catching mechanism that occurs in invalid cases.

The most appropriate and recommended practice for developing the testing mechanism is to define a test class for each target-class to be tested, and defining a test method for each public property or method from the target-class respectively. In our case there is the *TestID3* class testing the *ID3* algorithm class and within this test class, among others, there is the *TestCountValues* method that tests the *CountValues* method from the *ID3* class.

The NUnit class library works by preceding test classes and methods with a specific .NET attribute in order to identify the tasks these entities will be performing at the time of test suite execution.

CONCLUSIONS AND PROPOSALS

The present thesis emphasizes the complexity of the decision process in the contemporary society and stands proof for the utility of the computer-based decision support systems in an ever-evolving decision environment. Moreover, we've shown that even the classical computer systems no longer successfully respond to the decision makers' requests, so we envisioned a solution based on modern technologies, more precisely, Machine Learning technologies.

Information represents the foundation of any quality managerial decision. The possibility of running a worthy decision process is directly proportional with the amount of information at disposal and its quality. A significant role in this direction is played by the informational assets as they allow information storage and management, and at the same time facilitate broadcasting and applying decisions on time.

The decision process must be received as a complex one, which ideally would be executed in multiple stages and phases. Thus, the decision process starts with preparing the decision, then choosing the optimal solution and taking the effective decision, followed by implementing the decision and controlling the means of its realization. The final stage, often overlooked, consists of evaluating the decision results aiming to try to improve the efficiency of future decisions. The stages of the decision process are rarely respected in this form in practice; in reality these are not so clearly defined and delimited. Modeling the decision process is achieved with respect to each stage in the structure of the process, meaning we can build a model for each decision activity, or even more than one model, if necessary.

The idea of intelligent systems being able to achieve tasks that were considered until recently to be exclusively reserved to human resources has increased the interest of researchers in all domains, the applications in the area of artificial intelligence becoming more and more numerous and converging to new technologies. One of these technologies generated by artificial intelligence development and by the interest in systems capable of "learning" like the human individual is represented by Machine Learning.

The systems that derive from Machine Learning do not necessarily eradicate the human intuition, but usually a more collaborative approach between man and machine

is preferred, hence the tendency of using these also for building decision support systems.

The primary Machine Learning technologies we insisted on throughout the theoretical study are decision trees and Reinforcement Learning, but we mapped out others as well, such as instance-based learning, deductive and inductive learning, supervised and unsupervised learning.

Computer-based decision support systems are those helping the human decision maker in solving complex decision problems, semi-structured and unstructured. An important aspect to emphasize is that man is still in control of the decision process, and these systems only supply alternatives for decision, built upon tools of modeling and data analysis.

Given that organizations usually deal with large amounts of data that need storage, then management and processing, efficient solutions for optimizing these processes were researched. One of them is the data warehouse, a complex system that stores operational and historical data from within the organization, both from internal and external sources. As for processing the huge quantities of data, the Data Mining technology successfully takes up the challenge. These technologies are fit for establishing pattern within datasets, even raw, unprocessed data, supplying results that can be used with computer-based decision support systems.

The primary objective of this thesis was to create a foundation for a class library that would allow implementation of complex decision algorithms. In this context an expandable and reusable environment was developed that facilitates the implementation of modern algorithms that aim to help decision makers in solving complex problems. Also, we pursued the realization of a well-founded study regarding the decision environment, the computer-based decision support systems and the Machine Learning technologies, the ways in which these technologies are able to assist in making the decision process more efficient and modern respectively.

As a whole, the presented solution is a powerful, efficient and "elegant" from an object-oriented programming standpoint, given it was built using XML-represented data models, with corresponding XSD schemas and C#.NET source code implementations, which offers libraries of functions for processing these data models.

The application was inspired by the WEKA project, which is used for Machine Learning applications and offers a graphical interface with the user as well as a number

of different algorithms, including the rule induction ones, example-based learning, regression algorithms, relational rules algorithms etc. WEKA is very well fit for solving Data Mining problems. The file format, even though the proposed solution is using the XML format, contains the same data mostly in the same order as the .arff format defined by WEKA.

Choosing the XML format to store data was influenced by the many advantages this format brings to the table. The XML format facilitates the process of data structuring, it presents a characteristic of comprehensibility at first sight. Also, XML files are highly recommended for representing tree structured hierarchic data structures and, very important, data validation can be achieved easily by using XML schemas. Hence a remarkable improvement compared to other data formats.

Considering using XML for developing a framework for an integrated decision support system was an accurate choice because it can handle tree structures easily, it is painless to use and flexible when alterations are needed – but it has one disadvantage: it does not excel with very large amounts of data because it cannot be natively indexed.

Adding the algorithm implementations to the framework naturally played an important role in the development process. The algorithms definition section in the class library was developed keeping in mind the basic characteristics of algorithms and types of algorithms, and also wanting to offer the possibility of extending these classes to any abstraction of an algorithm implementation.

Obviously further studies having as starting point the ideology behind this thesis are in order. We are planning on continuing our research on computer-based decision support systems based on Machine Learning technologies. Even from the very beginning we had in mind the future evolution of this application, allowing the implementation of many more decision algorithms and the possibility of using new technologies.

We're already envisioning as future development the possibility of the application to communicate with various database systems, MySQL databases as a first step and any other connections after that, in order to be able to handle very large amounts of data. This enhancement will not be difficult to implement given that all the classes for storing data are already in place, they just need to be adapted and connected to database entities. Also, as future plans, a rather modern enhancement would be implementing Web Services by creating ASP.NET web methods which would allow initialization of the data set and offer the capability of running algorithms upon it.

The primary conclusion that is highlighted is that the thesis presents a new approach upon the development of decision support systems, emphasizing new means of implementing the decision algorithms though an expandable system that respects advanced principles of software engineering.

Regarding the dissemination of the results obtained from research process performed for this thesis, these are materialized in published scientific articles that debate on the subject.

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