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Generalized Nets as a Tool for the Modelling of Data Mining Processes. A Survey

Dafina Zoteva[1], **Maciej Krawczak**[2]

[1] Institute of Biophysics and Biomedical Engineering
Bulgarian Academy of Sciences
105 Acad. G. Bonchev Str., Sofia 1113, Bulgaria
e-mail: dafy.zoteva@gmail.com
[2] Systems Research Institute
Polish Academy of Sciences
ul. Newelska 6, OL-447 Warsaw, Poland
and
Wyzsza Szkola Informatyki Stosowanej i Zarzadzania,
Warsaw, Poland
e-mail: krawczak@ibspan.waw.pl

Abstract: Planned as an extension and continuation of the first review of the applications of generalized nets (GNs) in data mining (DM), the present paper discusses the results in the field of modelling and optimization of DM processes using GNs. It has been made an attempt to classify them with respect to the DM techniques (neural networks, genetic algorithms, etc.) and the tools used, as well as on the basis of the different areas of DM application (education, medicine, genetics, etc).
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1 Introduction

Huge amounts of data are generated daily everywhere around us. Today, collecting and storing this data is obviously not a problem, but generating meaning in this sea of information is.

Data mining (DM) or Knowledge Discovery in Databases (KDD) is a research area focused on discovering potentially useful patterns in large amounts of data or the relevant to us part of the information. DM can be considered as an intersection of artificial intelligence, statistics and database systems [93]. DM has two main objectives: prediction and description.

- Descriptive DM tasks define the general properties of the data in a database. The main goal here is to gain an understanding of the analysed data by uncovering patterns and relationships. Association and clustering tasks, as well as the secularization or generalization of the data fall here.

- Predictive DM tasks make predictions based on conclusions on the current data [128]. The main goal here is to create a model based on the available data that helps to predict unknown and future values of another dataset of interest. Classification and prediction tasks, time-series analysis fall here.

The main data mining techniques are the following:

- **Statistics.** Classical techniques which are driven by data, used to discover patterns and to build predictive models or in the process of initial data processing, such as estimation of noise, smoothing data, filling in the missing data, and then in evaluating the results of the data process. For example, the **regression**, as a statistical method, is used to predict the value of a continuous and numerical target based on the values of other objects in the dataset, assuming some kind of linear or non-linear dependency between them. It starts with an initial dataset and is based on training.

- **Classification analysis.** The initial data in this case is pre-classified or labelled. Classification is the process of defining and describing models of the classes in order to predict the target class that a particular unlabelled object has to be assigned to. It is an important part of the decision making process. The methods used to classify the data are decision tree induction, rule-based expert systems, neural networks, support vector machines, genetic algorithms, fuzzy logic techniques, etc.

- **Cluster analysis.** This is the process of identifying objects from the initial dataset that are similar to each other. There is no labelled data in this case. The similarities are conducted based on the characteristics of the objects. The objects of the same group (cluster) have similar in a sense characteristics, unlike the objects in different clusters whose characteristics differ significantly in the same sense. The main categories of clustering methods (or algorithms) are hierarchical, partitioning, grid based, density based and model based algorithms.

- **Association analysis.** The main goal in this analysis is to find a set of strong association rules, hidden in large datasets in the form of implications $A \implies B$, that show associations that occur frequently and also can be used to extract additional knowledge. The rules have to meet certain user-defined constraints, like support (how often is the rule applied) and confidence (how often the rule is correct). If the support and confidence measures are not sufficient to filter some association rules, a correlation measure can be used.

- **Mining sequential patterns.** Used for analysing long-term sequential data, the sequential patterns are applicable for identifying frequently occurrences of similar events or relevant sub-sequences in a set of sequences in terms of specific criteria.

- **Spatial data mining, text mining**

  A **spatial database** stores a large amount of space-related data, such as maps, preprocessed remote sensing or medical imaging data. Spatial data mining refers to the extraction of knowledge or other interesting patterns not explicitly stored in spatial databases.
  Text databases consist of large collections of documents from various sources, such as news articles, research papers, books, digital libraries, Web pages and others. The stored data is semi-structured. The main approaches to text mining are keyword-based, tagging and information extraction approach.

- **Change and deviation detection.** It is focused on discovering the most significant changes in the data compared to previously measured values or norms.

Generalized Nets (GNs, [21]) are an appropriate tool for describing and analysing these DM tasks, techniques and methods.

GNs are an extension of Petri Nets (PN, [201]) with this major difference that the tokens are a source of information. GNs can store all the history of their initial characteristics as well as the ones received during the GN functioning. Another significant difference with PN is the use of index matrices (IM, [10]) with predicates that define the rules of the tokens' transfer inside the GN model.

GNs have been proven to be an easy and comprehensible way to describe the logic of each modelled process [17, 27, 80, 100, 133, 230, 277]. The present paper is focused on the results of exactly this kind of research papers where GNs are used as a relatively universal mathematical tool for describing and modelling the above mentioned DM techniques, methods and their applications.

The use of one and the same means for describing these different DM techniques and methods, namely GNs, makes it possible to explore them in terms of speed, resources, correctness of the results. This approach will facilitate the transfer of ideas from one area to another. Constructing models for different methods of one and the same DM technique contributes to their analysis and the choice of the optimal method depending on the data being used. Last but not least, the structured and systematic way of presenting these methods, using GN models, enables new ways of improving them.

The present paper is an attempt to classify the results of the studies of GN applications in DM. The next section includes notes on the directions of the reviewed studies and their outcomes.

2 Generalized Nets and Data Mining up to Now

Machine Learning (ML) can be interpreted as retrieval of structural descriptions from examples which can be used for prediction, explanation and understanding. The GN models concerning ML of different real or abstract processes, as well as ML techniques are presented in [4, 27, 153]. [27] summarises studies on GNs for neural networks learning [1], genetic algorithms learning [3], intellectual games learning [28, 85], learning of a GN [2, 26], machine learning for abstract systems [5, 202] and abstract processes [18]. The models allow monitoring of the work of the training procedures and analysing their efficiency at different stages of the learning process.

ML provides some of the tools and techniques in the practical DM for finding and describing structural patterns in data [322]. Having that in mind, all the studies conducted for the possibilities of applying the means of GNs in modelling ML processes can be transferred to DM.

The first steps in exploring the GNs as an instrument of modelling DM processes, DM techniques and methods are collected and analysed in [25]. Several GN models are analysed in details in this paper. The first model concerns the process of determining which is the appropriate DM tool, from a set of DM tools, that should be applied to a particular problem. The selection criteria for choosing this appropriate tool are described as an initial and constant characteristic in a token. Another model describes the possibility for running more than one DM tools on a particular set of data and comparing the results of their work. An interpretation of the work of a flexible manufacturing system or a living organism is also explored in details and even extended. The possibility of machine learning of the GN model is studied. Some of the older developments in the field of flexible manufacturing systems are presented in [38,82,298,299].

The present paper will follow the structure of [25]. For the sake of completeness, the studies included in the first review will be mentioned in less details than others that are included only here. The classification of the research papers is done with respect to the theoretical aspect of DM, i.e. modelling and analysing DM techniques and methods. Another point of view that is considered is the practical one, i.e. modelling of processes in which DM techniques are applied.

2.1 GN Models of a DM Process

The life cycle of a DM process consists of 6 phases [86]: business understanding, data understanding, data preparation, modelling, evaluation and deployment. These phases are presented in a compact form with the GN model described in [293].

Each of the phases can be analysed in more details by a GN model designed specifically for it. Such a model is created for the modelling phase of the cycle in [165]. The constructed GN is a model of the applying DM tools that provide the discovered patterns. The GN model allows more than one DM tool to be applied to the data.

The GN models that are directly connected to the phases data understanding and data preparation of the life cycle of a DM process are reviewed in the next section.

2.1.1 GNs for OLAP, Data Warehouses and Big Data

Data Warehouses combine data in multidimensional space. The construction of data warehouses involves data cleaning, data integration and data transformation which are part of the preprocessing step for data mining [128]. Data Warehouses provide on-line analytical processing (OLAP) tools for interactive analysis of multidimensional data, which ease the effective data mining.

The theory of Intuitionistic Fuzzy Logic (IFL, [23]) is applied to the OLAP model in order to handle uncertain or imprecise values in the multidimensional data model. The cubic operators union, intersection, difference and join are extended and enhanced with IFL. A GN model is constructed to describe a general approach to these operations on IF OLAP cubes [81]. A GN model of the selection operation over IF OLAP cube is presented in [84] and later extended in [79] so that more than one cube can be processed by the same operation.

The theory of the IM and particularly the multidimensional ones [10, 24, 76, 316] can be used for describing the OLAP-structures. Therefore, the future research in this direction will include presenting the operations, relations and operators on IM with the means of GNs.

The GN models defined so far for different types of databases [133] can be transferred with some necessary modifications for the cases of Data Warehouses and Big Data. Some of the studies, for example, refer to IF GN analysis of concurrency control with periodic [131] or continuous [132] deadlock detection in database systems.

GN models presenting data warehouse operations, such as unary and binary read-only or read-write operations, are proposed in [83].

The above mentioned studies, related to modelling IF OLAP cubes, data warehouse operations, and more are collected in [80]. In addition to the above, a GN model of an IF mediator [133], for querying probabilistic and null values in multiple sources containing uncertain data, is included to the same book.

In terms of multi-source database systems, the focus in [134] is on determining the source that can satisfy a particular query, while the response time is kept to a minimum. The different databases, presented as tokens in the model, are combined with expert system (ES) and system administrator to establish a partial order for the sources with respect to the query. The model can be extend to a relational intuitionistic environment for representing uncertainty and contradiction or conflict in a multiple-source database.

Referring Big Data, the workflow of the MapReduce, a programming model for parallel processing of large volumes of data in distributed environment, is constructed using GNs in [70]. As a result the MapReduce framework can be observed in details.

The applications of GNs in the modelling phase of a DM process are listed in the next sections in regards to the modelling techniques and methods that are used. The list of the reviewed papers in each section will include studies in the relevant areas. The main focus, however, will be on the latest ones.

2.1.2 GNs for Clustering, Data Classification, Association Rules

Three different methods for mining frequent patterns are modelled using GNs so far. These are the Apriori algorithm [66], FP-Growth method [67] and Eclat algorithm [71]. The GN models of these three methods can be used for comparing and analysing them.

In terms of the clustering procedures, a GN model of selecting a method for clustering is proposed in [73]. It is a subnet of the GN model "Hierarchical generalized net model of the process of clustering" shown in [72]. The use of the model is in analysing, managing and optimizing the process of clustering. A clustering procedure based on self-organizing map is modelled in [295].

Some basic grid-based methods for clustering are also modelled in terms of GNs in [75]. The future studies will be focused on modelling clustering algorithms for high-dimensional data.

In terms of classification analysis, a GN model of the process of constructing a support vector machine classifier is presented in [69]. The classifier is applied to weather data. An example of GN model used for monitoring the sequence pattern mining process, depending on meteorological parameters from weather databases, is shown in [74]

The method of decision tree induction is another classification method. A GN model of the process of the decision tree construction using top-down tree construction algorithm is described in [68].

An intuitionistic fuzzy version of another classification method, the Nearest Prototype (NP) method, is proposed and modelled in terms of GNs in [118]. The degrees of membership, non-membership and uncertainty of a pattern with unknown classification to a given class are evaluated taking into account the distance to the prototype (mean) vector of that class.

The K-Nearest neighbour rule pattern recognition algorithm combined with the advantages of IFS is modelled with GN in [321]. The described model allows parallel estimation of the degrees of membership, non-membership and uncertainty of a pattern to particular classes.

A GN model of an aggregation algorithm for IF estimates of two or more classification procedures is proposed in [311] aiming to decrease the areas of uncertainty.

The future plans in this field are directed to exploring other types of clustering algorithms in terms of GNs. Since the input parameters settings are essential for the work of the algorithms, the possibilities of designing self-learning GN models for searching appropriate values for these input parameters might be explored.

2.1.3 GN Models Related to Expert Systems

Expert System (ES) are designed to model the knowledge of experts and to apply this knowledge into assessing and defining solutions to well-structured problems. A widely used representation of the knowledge is in the form of if-then rules.

A GN representation of the basic properties of a knowledge base is shown in [90].

Ten models of ESs are described with the means of GNs. Models of ordinary ESs [29–32], ESs with priorities of their Database (DB) facts and Knowledge Base (KB) rules [15, 41], ESs with metafacts [39], Intuitionistic Fuzzy ES [40] and ES with temporal facts and answering to temporal questions [12], as well as a new type of ESs [33], are collected in [17]. Later, ESs are extended into ESs with temporal components, the process of their functioning and the results of their works are described in [35]. This tenth model of ESs is included also in [133].

GNs are used as an instrument for describing the process of ES construction in [172]. A methodology for modelling open, hybrid and closed systems by using GNs is presented in [290]. The validity testing process of an ES is modelled in [52].

A GN model of an ES, in which new facts and rules with IF degree of validity and non-validity can be introduced during its functioning, is proposed in [36]. A GN model of ESs with Frame-Type Data Bases is introduced in [60]. The model is enhanced with IF estimations of the frames in [50]. An extension of the last model with truth-values of the hypotheses is the model described in [53]. Three different estimation types are discusses there as possibilities for evaluation of the truth-values of the hypotheses: optimistic, average and pessimistic. A GN model based on IFS theory, that gives the possibility to evaluate the time of the occurrence or completion of the events, is shown in [78]. The model can answer questions such as: ”Is the fact valid?”, ”How many facts does it contradict?”, ”How many facts does it confirm?”.

The above mentioned GN models of ESs can be regarded as a proof that ESs can be expanded and each of their extensions can be described in terms of GNs.

Advisory systems can be classified as a type of ESs. They provide support through the decision making process, they do not make decisions, instead the final decision is taken by the human alone.

The means of GNs and IFS are applied to modelling advisory systems for on-line control of cultivation processes [173, 174, 176]. The searched effect is significant decrease of the measurement error and noise influence. The presented GN models describe ESs that are able to advise the user which new functional state can be reached and what kind of control actions have to be taken.

2.1.4 GN Descriptions of Neural Networks

Neural Networks (NNs) or Artificial Neural Networks (ANNs) are a mathematical model inspired by biological NNs. An ANN is a collection of a large number of connected units called neurons. The information is processed by the receiving neurons and then passed down to the neurons connected to them. The neurons are organized in layers.

The main advantage of NNs are precisely these layers of neurons. The NNs can learn to work around uninformative or even erroneous examples in the data set because of the weighted connections between the neurons [154].

NNs are one of the most popular method for clustering, classification, pattern recognition and prediction. With regards to their application in DM tasks, the NNs can be divided into the following three types. In the areas of prediction and pattern recognition feed-forward networks are mainly used. Feedback networks are used for associative memory and optimization calculation. As for cluster analysis, self-organization networks are used.

As mentioned in [25], the first results related to the GN-interpretation of neural networks date back to 1990 [124–126]. A GN model of intuitionistic fuzzy NNs is first shown in [127]. NNs learning algorithms are presented with GN models in [1, 4]. A representation of a single neuron with a GN model is proposed in [9], modelling of neural signals is shown in [157].

The process of functioning and the results of the work of different types of NNs are later described by GNs in a series of papers, listed here in chronological order.

A GN interpretation of the adjoint NNs, in which signals flow in opposite direction, is presented in [141]. Exploring NNs from graph theory point of view shows some new properties of their learning process. Series of studies are conducted for multilayer NNs [142–145, 148]. Along with others, they are later collected and summarized in [146] and extended in [150]. An example of multilayer NNs, that will be discussed later, is the multilayer perceptron (MLP). MLP is a class of feed-forward NNs which consists of at least three layers of neurons. MLP is usually used in supervised learning problems, where the learning is carried out through backpropagation algorithm.

The work of a self-organizing NN is modelled in terms of GNs in [280]. Optimization of a self-organizing map with time limits is explored with the means of GNs in [55]. GN models of Grossberg [279,287] and ART (Adaptive Resonance Theory) NNs [273, 281, 282] are created. Later, the feed-forward NNs have become an object of interest by various authors. Combining the ideas of feed-forward NNs and IFL results in an Intuitionistic Fuzzy Feet Forward Neural Network which model is shown in [57]. Implementation of GN models of feed-forward NNs are presented in [116]. A special type of NNs, called Distributed Time Delay Neural Networks, is modelled in [274]. GN models are also constructed for a layered digital dynamic network [283] and a brain-state-in-a-box NN [286]. A GN representation of Hierarchical NNs is proposed in [58]. Later studies on modelling the functioning of a certain type of NNs concern designing of GN models of ART1 [195] and ART2 [194] NNs. The simulations of the models allow better understanding of the test process of a learned NN. The latest research is on a self-organizing network, referred to as a Neocognitron, with the ability to recognize patterns based on the difference of their form [190].

A few GN models focused on various learning algorithms in NNs are discussed next.

The backpropagation algorithm, as the basic algorithm for supervised NNs learning, have been an object of research in many papers concerning modelling NNs with GNs. The first model on backpropagation NNs is proposed in [161]. A GN model of the pure backpropagation algorithm is shown in [148]. The way of working of a NN with straight propagation and its learning with the backpropagation algorithm is modelled in [270] and later extended in [271], as the calculation of the new weight coefficients and NN's bias are illustrated in details with a sub-GN model. An accelerating backpropagation algorithm is an object of research in [272]. The backpropagation algorithm for Elman NN is modelled in [276]. GN representations of fast [193] and slow [192] learning algorithms of an ART2 NN are proposed. The models show the changes in the input vector values during the training. Another algorithm used in the training process of a NN, namely the Levenberg–Marquardt algorithm, is modelled in [305].

Finally, some models used for analysing different methods for parallel optimizations of various types of NNs are discussed.

The means of GNs are used for analysing the possibilities of parallel optimization of feed-forward NN [56]. The proposed GN model is extended over a pair of NNs with different structures, trained with variable learning rate backpropagation algorithm [48]. The difference between the two NNs lies in the number of neurons in the hidden layer which reflects on all other NNs properties. A time limit is added to the model in [278]. A generalized model for parallel optimization of multilayer NN with time limit is shown [151]. The proposed GN models allow simulation and optimization of the architecture of NNs. As a continuation of the research on parallel optimization of other types of NNs, such a study is also conducted for the MLP [285]. The optimization process is explored in terms of a different technique to adapt the learning rate, namely conjugate gradient [284].

The GN model of the verification process of MLP is shown in [302]. A GN model of the regularization process in MLP is proposed in [304]. The latest research in the field addresses the problem of overfitting in a MLP or when a learning algorithm adapts too well to a training set [152]. Overfitting of the MLP can vary significantly in different regions of the model. The proposed GN gives a possibility for parallel optimization of MLP, where the early stopping algorithm is used for reducing the overfitting.

The models in [56], [48], [278], [284] and others are a good example that the graphical structure of a GN can be used for different models with a slight change only in transition condition predicates and characteristic functions.

Part of the listed so far GN models of NNs are collected, summarized and analysed in [277]. Another proof that "the generalized net theory can be successfully used as a new description of multilayer neural networks" is [147]. Descriptions of NN functioning processes, namely the simulation process of networks, a system of NNs and learning algorithms are explored in the books.

Different possibilities of applying NNs in various areas of human life are described using GNs. GNs as a means of controlling and optimizing real processes through NNs and IF estimations are explored in [149]. A GN model of the students' knowledge assessments with IF estimations using MLP is shown in [91]. The process of prognosis biomass accumulation with a NN is represented with GN models in [92, 117]. Another GN model is designed for the process of forest fire detection with an ART2 NN [200]. A GN model of the process of obtaining credit risk assessment is proposed in [159]. The process of encrypting a message in a sound using a ANN [199] and in an image with a self-organizing map NN [191] are also explored in terms of GNs.

The plans for future work in the field of modelling NNs are connected to the hybrid learning algorithms where NNs are combined with genetic algorithms, ant colony optimisations and others. Another direction for the future is to create universal GN models for all types of NNs.

2.1.5 GN Models of Image, Speech, Face, Iris and Other Types of Recognitions

The majority of the applications of NNs concern problems in pattern recognition.

The initial studies regarding GNs as a means of describing pattern recognition processes, such as face [110], signature, handwriting [108, 237] and speaker [119–121, 238] recognition, are summarized in [45]. Some of these studies are enhanced with IFL in order to take into account the fact that the information may be imprecise and there is inherent uncertainty [111, 123, 239, 240]. The next book that summarizes the studies in this field up to that point is [42].

Later studies concern computer scene analysis [109, 113] in which both objects and the scene background are taken into consideration.

The use of IF contrast intensification operators in enhancing images is shown in [167]. The preprocessing phase of the digital image recognition process is modelled in terms of GNs in [203]. The focus is mainly on describing the major step in image preprocessing concerning the image smoothing and contrast enhancement. A GN model of IF image preprocessing is presented in [168].

As a complement to the GN models for writer verification and identification [46], a GN model describing the process of on-line/off-line signature verification is proposed in [112]. The model explores the parallel processing of two signature models: digital image and tablet signal. Another model of signature verification is investigated in [171]. A GN model for a combined method for on-line signature verification is later proposed in [65].

The process of handwritten Arabic word recognition is modelled in [114].

Different models concerning face recognition with various types of NNs applied in the process are proposed in [196, 198, 303]. A model of the colour recognition process is given in [197].

In general, all the above models can be included as a sub-GN in a larger scheme for biometric authentication. Verification and identification of a person based on biometrics, including iris recognition, are modelled with GNs in [34, 43, 44, 115, 241, 275]. The latest studies concerning modelling verification and identification based on biometrics refer to fingerprint recognition [77]. The process integrates IFS in the evaluation of the equivalence of the respective assessment units.

The common feature shared by these models is that they describe the general phases of the process, namely the stages of processing, feature extraction and classification. The models can be used not only for graphical representation of the processes, but also for their subsequent analysis.

A GN model for simultaneous calculation of estimates for pattern recognition problems in medicine is shown in [308].

2.1.6 GN models of Problems Related to Intelligent Control and Decision Making

GNs as a tool for modelling intelligent systems are shown in [22]. A GN with decision making component is described in [160].

Control systems could be considered as decision systems. They facilitate deciding which process conditions have to be changed and in what way in order to maintain some process variables at desired levels.

GNs are proved to be an appropriate tool for describing the logic of processes in biotechnology [103, 184], for modelling different operational modes of biotechnological processes as cultivations of *E. coli* [227] and *Br. flavul* [222], as well as for the wastewater treatment processes [102, 104, 187]. Some of these studies are collected in [258]. Another direction in the research of these processes, along with modelling the processes themselves, is to design different monitoring and control systems for them, thus analysing the possibilities for optimal processes carrying out.

The proposed in [212] GN provides the possibility of optimal variation of the feeding solution concentration. The calculus of variations is applied to determine an optimal feed rate profile. The apparatus of GN is applied in [231] for modelling of proportional-integral-derivative (PID) control algorithm. GN model describes three integrated control terms of PID controller and allows easy implementation of various controller types. In [234] a GN for tuning the PID controller for control of fed-batch cultivation processes is proposed. The controller itself is used to control feed rate and to maintain glucose concentration at the desired set-point. The GN allows tuning the PID controller to achieve good closed-loop system performance using different optimization methods like genetic algorithms.

The control of some physics-chemical parameters of biotechnological processes is an object of interest in another series of papers. For example, in [224] the apparatus of GN is applied for modelling the temperature control outline. As a result some factors that effect the temperature control system can be taken into consideration. The GN model presents the calculations for the temperature of the water that should be added into the double jacket of the bioreactor. Paper [214] is focused on modelling the foam monitoring control system during a cultivation process. The designed GN model observes the foam levels and allows an automatic foam control by monitoring the foam level and the dosage of an appropriate antifoam agent. In [223] a GN is proposed for modelling the pH control outline in biotechnological processes. The GN model takes into account the value of pH in the bioreactor and determines what kind of solution (base or acid) has to be added in order for the pH value to be kept within a desired range. A GN model of oxygen control system in fermentation processes is proposed in [213]. The GN model describes the process of control of the dissolved oxygen by variation of rotation speed of stirrer or variation of the aeration gas concentration added to the bioreactor in dependence on user decision. IFL is applied in this GN model, resulting in decrease of the measurement error influence. The GN model described in [213] is extended with a loop for monitoring the carbon dioxide, rendering also respiratory quotient variation [232]. Better monitoring and control of exhaust gases is ensured and higher process efficiency is achieved due to the presented GN model. A GN model for *E.coli* glycolysis control is shown in [137].

Another implementation of IFL in the GN model is proposed in [228]. The authors use IFL in order to reflect the degree of uncertainty which is typical for measurements of variables, such as temperature. As a result a significant decrease of the measurement error influence is attained when the temperature is controlled. Therefore, some of the designed GN models of control systems are enhanced using fuzzification.

IFL can be used in other types of decision making processes. As a result of combining IFL and IM, a novel method for decision making called InterCriteria analysis (ICrA) is introduced in [49]. The integration of ICrA or statistical analysis in GN models can improve a decision making process.

One example of the joint use of GN models and IFL is the GN model of a decision making process of a group of experts published in [306]. The experts evaluate some objects, situations or events based on criteria that each of them has chosen on their own. Therefore, each expert uses a different set of criteria. The GN model allows to evaluate the selected by each expert criteria as well as the accuracy of the expert's assessment made based on the chosen criteria.

Other GN models of a multi-expert multi-criteria decision making process are described in [59,169,170]. The GN model in [59] is extended with an ICrA of the criteria used by experts so that at the end of a certain procedure the set of criteria can be modified in order for a new procedure to be run with improved criteria.

An example of combined use of GNs and statistical analysis (step linear discriminate analysis and logistics regression) on data provided by medical investigations is proposed in [307]. The model aims to classify the patients suffering from acute respiratory insufficiency who needed continuous mechanical ventilation into two classes, those who are ready for getting mechanical ventilation off and those who are not. A fuzzy surface-based version of Voronoi diagram area-stealing is used for the classification of the patients.

The problem of the travelling salesman is explored in some older studies [11–13]. GN interpretations of the transportation problem are shown in [135]

2.1.7 GN models of Problems Related to Optimizations Based on Metaheuristics

Metaheuristics are mathematical optimization algorithms that have been successfully applied in various real-life problems. These problems are usually defined with many complicated constraints and optimization criteria. Metaheuristics are designed to find or generate an heuristic that may lead to a suboptimal sufficiently good solution to the problem.

There is a wide variety of metaheuristic algorithms that can be classified based on different criteria like local or global search, single solution or population-based search, nature inspired metaheuristics, etc. Many of them are explored in terms of GNs.

Genetic Algorithms (GA) are parallel, global search technique used in complex optimization problems applying genetic operators as mutation, crossover and selection. The search is performed through a population of individuals.

A large part of the research on the applicability of the GNs as a modelling tool focuses on GA, as one of the most popular methods in optimizations and DM. The main studies regarding modelling GA functions, operators and results of standard GAs with the means of GNs are summarized in [230]. Some of the studies collected in [230] are [175,177–181,188,215–217,225,226,233]. The GN models are analysed and modified in order to present some modifications of the standard GA regarding the order of the basic GA operators. An estimation of the calculation time of the modifications is also performed and analysed.

The basic operators of GA, namely selection, crossover and mutation, as well as different functions for selection (roulette wheel selection method [177] and stochastic universal sampling [178]), different crossover techniques [188] (one-point crossover, two-point crossover and "cut and splice" technique) and a mutation operator (mutation operator of the Breeder genetic algorithm [233]) are described with GN models. These models can be considered as separate modules, but they can also be accumulated into a single GN model to describe a whole GA. Some of the latest results on modelling GA with GNs are found in [189].

Ant colony optimization (ACO) is another metaheuristic method inspired by the foraging behaviour of the ants. ACO is most suitable for solving NP optimization problems with strict constraints. It is popular mostly because of its flexibility and good results.

A GN model of the functioning of a standard ACO algorithm is first described in [94]. It is used to identify the weak points in the algorithm as well as some possibilities for improvements. IF estimations are added to the model in [95]. The GN model from [94] is extended in [99]. The aim is to use the experience of the ants from previous iterations to choose a better starting node. The estimations are based on IFL. The model shows that the use of start strategies can lead to better results than the random start.

There have been many attempts to enhance the performance of metaheuristics with local search procedures or some exact methods. As a result new algorithms called hybrids are created. They are more efficient and flexible when dealing with large scale problems. An example of such a hybrid ACO algorithm combined with local search procedures is modelled with GN in [96].

In addition to the above mentioned studies, others like [61, 62, 97, 101], concerning the research of the GNs models and ACO are summarized in [100].

The idea of modifying and improving the standard metaheuristic algorithms is further developed in [63] where a GN model of a new hybrid metaheuristic is shown. The new hybrid method combines the advantages of two composite metaheuristics, ACO and GA. ACO generates initial solutions which are used as an initial population of GA. If, after a certain number of iterations, the population stops improving, GA solutions are returned to ACO to update the pheromone and thus to generate new population for GA. Any of the ACO and GA algorithms can be applied as long as they are appropriate for solving the particular problem. Describing this new hybrid algorithm with a GN provides better understanding of its behaviour and identify some possibilities for its improvement.

Other metaheuristic algorithms explored with the means of GNs are Cuckoo Search algorithm, Firefly algorithm, Artificial Bee Colony optimization and Bat algorithm.

The logic of the metaheuristic population-based algorithm Cuckoo Search is described using a GN model in [218]. This model is enhanced and expanded to a Universal GN model for metaheuristic algorithms and it is used for the Firefly algorithm and Artificial Bee Colony optimization [220]. Describing the Bat algorithm in terms of this Universal GN by only varying the characteristic functions of the tokens is another proof for the correctness of the proposed model [219].

One of the main challenges regarding the metaheuristic algorithms is to choose appropriate parameter values for the algorithm run. GNs are used as a tool to describe the process of parameters' control while trying to improve the algorithm performance. In order to tune dynamically the parameters of a metaheuristic algorithm a GN model of IFL controller is shown in [221].

The algorithm of neuro-dynamic programming (NDP) is studied in [130].

The presented GN models confirm again that the apparatus of GN is a very appropriate tool for the modelling and description of complex algorithms and processes.

An example of modelling a real-life problem in which some optimization algorithms are applied is explored in [88, 89]. The proposed GN model is used for comparing different mathematical models of an *E. coli* fed-batch cultivation process, obtained by a GA, a Tabu search algorithm and a Firefly algorithm, and then chooses the best process model, based on a predefined criteria. A simulation of the GN model is performed.

2.2 Areas of Data Mining Applications

Other classification of the research papers can be made with respect to the different areas of human life where DM techniques and methods are applied as a means for controlling or optimizing the described process.

2.2.1 GN Models in Education

The administrative and academic functions of electronic information processing and exchanges within a university have been studied in series of research.

The initial studies in GN modelling of the basic processes in a university (flow of information [264], finance, organization of timetable schedules [245], administrative services and electronic archives), models of e-learning systems (electronic learning, evaluation, intelligent training systems), university Intranet [246] and Internet flow models are included in a book [235].

An extended model of the information flow in an abstract university is presented in [244]. The models of processes of producing a timetable [251, 253], updating [248] and evaluating existing ones [252] are extensions of previous models. The GN model of the process of administrative servicing in a digital university [87] is enhanced with IF estimations [259]. The GN models of a training system are explored in [247, 255], the precise order of the university subjects which is directly related to the training process is modelled in [261]. The models for electronic archives are enhanced with IF estimations of the searched information in [267]. A GN model of an electronic system for the student-teacher interaction is shown in [250].

There are GN models created to describe a learning management system [166], the process of selection and usage of an intelligent e-learning system [163, 254], as well as the process of personalization of the e-learning environment [164].

The evaluations of lecturers, students, subjects or universities are a topic of increased interest. An attempt to introduce relatively objective methods for evaluating each of the objects have been made in the following studies.

There are GN models designed for describing the processes of evaluating lecturers based on different criteria, like results of student exams, evaluation of students' inquiries and lecturer's scientific work or other factors [129, 236, 288].

The evaluation of the students is made on the basis of assessments of students problem solving and lecturers' evaluation of student work [156, 243, 249, 260, 263]. Different methods, like MLP [91] and self-organizing map [289, 296], are used for the evaluation process which is described with GNs and uses IF estimations. The standardization and reliability of the assessments of the students problem solving is modelled in [262]. A GN model of the analysis of the evaluations by DM techniques is presented in [292].

A GN model of a student's course evaluation is shown in [266]. University subject ratings are modelled and explored in [265]. Both of the models are combined with IF estimations.

A GN model for object evaluation based on a set of criteria is shown in [291]. The evaluated objects can be lecturers, students, Ph.D. candidates, problems solved by students, courses, etc. The ICrA method is used to calculate the estimates, some possible correlations between pairs of criteria can be detected. A model for evaluating the quality assurance in universities and scientific organizations is proposed in [294].

Another group of articles is connected to processes of progressing through the hierarchy in universities and scientific institutions. A GN model with IF estimations is designed for the process of obtaining scientific titles and degrees [242]. The administrative information processes are modelled in [122]. A GN model of the process of PhD preparation is shown in [256]. A new perspective of the last two process is shown in [257].

The presented GN models can be used to optimize the functioning of a particular university, for monitoring and management of the quality of university education.

2.2.2 GN Models in Medicine and Medical Diagnosing

GNs have been used for modelling physiological processes, diagnoses of different deceases and pathological conditions, organisational and administrative processes in hospitals.

A large part of the initial studies of the applications of GNs in medicine in general are collected in [268]. This research is later extended with models of diagnoses of neurological deceases [37]. The GN applications in general and internal medicine are collected in [269]

A review of the GN models in medicine with focus on telehealth is shown in [297].

The latest studies are related to modelling the processes of diagnosing different deceases and pathological conditions, like shoulder pain [206], osteoarthritis [204], muscle pain [207], adhesive capsulitis [210] and proximal humeral fractures [211]. The process of diagnosing of asymptomatic osteoporosis is modelled with an ordinary GN model in [208]. A different approach to the modelling of the process [8] is tried after the introduction of a new extension of GNs, GNs with characteristic of places [6]. As a result the graphical representation of the model is simplified.

A novel approach for early detection of adolescent idiopathic scoliosis (AIS) and its categorization using a GN model is proposed in [205]. The combined means of GNs and IFS are used for classification and evaluation of the curve progression probability in patients with confirmed AIS in [209]. GN models for diagnosis of multiple sclerosis [309], assessment [312] and monitoring the degree of disability in patients with multiple sclerosis [310] are constructed.

A GN model for evaluating the objective condition of ventilated patients in order to determine if they are ready for weaning the off mechanical ventilation support is given in [313]. A GN model for describing the diagnostic method before implantation of cerebrospinal fluid draining shunt in infants is proposed in [314].

The models in medicine can be used for simulation of real processes with educational purpose. They can guide specialists in studying the logic of the processes related to diagnoses and help in acquiring knowledge and diagnostic skills [37].

2.2.3 GN Models in Ecology

A GN model of the process of wildfire extinguishing by a fire service is presented in [7]. Clearing as a prevention measure is modelled in [64]. A GN model of forest fire detection is modelled in [200]. The models can be used for control of the available resources and can help in the decision making process in different simulated situations.

A GN model of the work of a typical wastewater treatment plant and its simulation is shown in [106]. Other models concerning the wastewater treatment process, like mechanical water pre-treatment [105], physics-chemical purification [107], purification in "Biological Reservoir - Sedimentor" [183] are designed. A comparison of wastewater treatment modelling with partial differential equations and GNs is shown in [182]. Part of the mentioned GN models are collected in [229].

The work of oil refinery is modelled in [301]. The GN model of the process of evaluation of the impact of refinery activity on the environment is shown in [162] and enhanced in terms of IFS in [186].

2.2.4 GN Models for Genetics

GN models of Iac operon are proposed in [138, 185]. A model of interval mapping QTL analysis is designed in [136]. Models for Cytokinin/Auxin Interactions are explored in [139, 140].

2.2.5 GN Models for Transport, Economy, Security, Industry

GNs can be used as a tool for modelling the complex systems of urban and railway transport [98, 319]. The proposed models describe the current state of the networks. They can be used to explore the possibilities for optimizing the networks and to identify a possible solution in case of a problem .

A GN model is used to describe the identified key components required for the development, testing, implementation and assessment of a novel compensation model in [51].

GNs are successfully applied to modelling processes concerning security issues. All the above mentioned GN models applied to verification and identification of a person based on biometrics [34,43,44,115,241,275] can be related to this field. Another example is the GN model constructed to describe processes for protection patients' personal e-data, transmitted between healthcare information systems over the Internet [320].

2.2.6 Other GN applications

GNs can be used for representing any abstract system (statical, dynamical, stochastic, etc.). Examples of such models are given in [54, 202]. An IF system capable of self-modifying is represented with a GN model in [5]. Some properties of the connections and the events of the abstract systems, interpreted in terms of GNs, are discussed in [16, 19, 20, 47].

Other applications of GNs can be found in describing the standard commands in robotic systems. A GN representation of production system interpreters is shown in [300]. The discrete part manufacturing process of CMOS integrated circuit wafers is described in [155]. The presented GN model includes all phases, all possible work cycles in the process. The model illustrates the capabilities of GNs for modelling and simulation of large-scale technological processes.

GNs as a tool for modelling multi-agent systems are presented in [317, 318]. One of the reasons GNs are chosen as a modelling tool for multi-agent systems is the possibilities they offer for modelling parallel processes. GN models of an industrial robot [315] and a modular robotic system [158] are designed. The different units of the robotic systems are regarded as elements (agents) that are part of an abstract multi-agent system.

3 Conclusion

GNs have been proven to be a very appropriate tool for the modelling and describing complex algorithms and processes. The visualization with the means of GNs allow not only an easy and comprehensible way of describing the logic of the modelled object/ process, but also retrieving additional information about the connections of its internal components.

The benefits of using GNs as a modelling tool can be found in several different directions: managing of the modelled object/ process, finding relations with other objects/ processes, generating hypotheses for the improvement of the process. Another GNs advantage is that the created models can be easily extended or generalized when necessary.

The GNs can be used without restrictions for modelling any DM process, DM technique or method. The designed models can be used for better understanding of the modelled objects and as a means for exploring the possibilities of improving them.

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