The Fourth Conference on Information Theory and Complex Systems
TINKOS 2016

BOOK OF ABSTRACTS

Editors: Velimir Ilić and Miomir Stanković

Belgrade, Serbia, October 27-28, 2016
Mathematical Institute of the Serbian Academy of Sciences and Arts

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Република Србија
МИНИСТАРСТВО ПРОСВЕТЕ
НАУКЕ И ТЕХНОЛОШКОГ
РАЗВОЈА

The conference is organized by
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under auspices of
the Ministry of Education, Science and Technology Development
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THEMATIC FIELDS

- Information theory
- Information transmission
- Complex networks
- Decision making in complex systems
- Stochastic processes
- Intelligent systems
- Bioinformatics
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CONFERENCE PROGRAM

OCTOBER 27, 2016

OPENING: 10:00-10:10: Velimir Ilić

INFORMATION TRANSMISSION

10:10-10:40: Elza Dupraz - **Distributed K-means over Compressed Binary Data** (invited)

10:40-11:10: Predrag Ivanis, Bane Vasic - **Reliable Storage of Information Using the Effect of Error-Correcting Errors** (invited)

11:10-11:40: Miodrag Mihaljevic - **Two Approaches for Security Enhancement of Lightweight Encryption and Elements of the Security Evaluation** (invited)

11:40-12:00: Venceslav Kafedziski - **Compressed Sensing Channel Estimation**

PAUSE: 12:00-13:00

DECISION MAKING IN COMPLEX SYSTEMS

13:00-13:20: Aleksandar Janjić, Lazar Velimirović, Miomir Stanković - **Multi-attribute optimization of electric vehicle fleet charging scheduling**

13:20-13:40: Janaćković Goran, Malenović-Nikolić Jelena, Vasović Dejan - **Multi-criteria Selection of Maintenance Strategy for criteria Construction Winches**

13:40-14:00: Ana Luković, Srđan Glišović - **Development of an Eco-Industrial Network - Based Model for Managing Industrial Waste Flow**

14:40-14:20: Nataša Glišović, Miodrag Rašković - **The System for the Decision Support for Classifying the Patients using the measures for missing data**

14:20-14:40: Ivana Marković, Jelena Z. Stanković , Miloš Stojanović - **An AHP approach for modeling financial time series**

14:40-15:00: Popovic Predrag, Ristic Miroslav, Nastic Aleksandar - **Analysis of prediction errors generated by BINAR(1) models**

OCTOBER 28, 2016

COMPLEX SYSTEMS AND INFORMATION THEORY

10:00-10:30: Branko Dragovich, Natasa Z. Misic - **Ultrametrics in Bioinformation** (invited)

10:30-11:00: Miroslav Ciric, Jelena Ignjatovic - **Fuzzy relations and their use in the study of complex fuzzy systems** (invited)

11:00-11:30: Miroljub Dugic, Jasmina Jeknic-Dugic - **Quantum Information - Fundamentals and Prospects** (invited)

11:30-11:50: Momir Arsenijevic - **Limitations of Nakajima-Zwanzig method**

11:50-12:10: Velimir Ilić, Miomir Stanković - **Generalized entropies: review and open questions**

PAUSE: 12:10-13:20

COMPLEX NETWORKS

13:20:13:40: Jelena Smiljanic, Marija Mitrovic Dankulov - **Associative nature of conference participation dynamics - an empirical analysis and modeling**

13:40:14:00: Marija Mitrovic Dankulov, Bosiljka Tadic - **The structure of communities in networks co-evolving with online social interactions**

COMPLEXITY THEORY

14:00:14:20 Bojan M. Tomić, Milica M. Tomić - **The Width of Complexity Potential as an Integral Factor of Science**

14:20-14:40 - Miloš Milovanović, Gordana Medić-Simić - **Complexity Based Aesthetics and Gnoseology**

14:40-15:00 - Milica Bogicevic, Milan Merkle - **ABCDepth - Computation of High-dimensional Tukey Median**

PAUSE: 15:00-16:00

INTELLIGENT SYSTEMS

16:00-16:20 Marko Stevanović, Branimir Todorović - **Improving Text Classification Accuracy Using a Novel Corpora Cleansing Technique**

16:20-16:40 Branimir Todorovic, Jelena Milovanovic - **Semantic similarity detection in continuous vector space of words and phrases**

16:40-17:00: Dejan Mancev and Branimir Todorovic - **Structured classification with the averaged sum loss**

17:00-17:20: Aleksandar Trokicic, Branimir Todorovic - **Nystrom views via the randomized SVD for semi supervised learning**

17:20-17:40: Branimir Todorović - **Kalman filter training of Echo State Networks**

17:40-18:00: Predrag S. Stanimirovic, Ivan S. Zivkovic, Dimitrios Gerontitis - **Higher-order ZNN models for computing the matrix inverse**

CONTENTS

Distributed K-means over Compressed Binary Data

Elsa Dupraz[1]

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Keywords

Distributed source coding, K-means algorithm, Learning over compressed data, Sensor networks, LDPC codes

Summary

Networks of sensors have long been employed in various domains such as environmental monitoring, electrical energy management, and medicine [1]. In particular, inexpensive binary-valued sensors are successfully used in a wide range of applications, such as activity recognition on home environments [2]. In this paper, we consider a network of J binary-valued sensors that transmit their data to a fusion center. We assume that the fusion center has to perform K-means clustering on the binary data transmitted by the sensors.

In this context, the J sensors should send their measurements to the fusion center in a compressed form in order to greatly reduce the amount of data transmitted within the network. Low Density Parity Check (LDPC) codes have been shown to be very efficient for distributed compression in a network of sensors [3]. However, the standard distributed compression framework considers that the fusion center has to reconstruct all the measurements from all the sensors. Here, in order to avoid potentially complex decoding operations, we would like to perform K-means directly over the compressed data. For this problem, [4] considered real-valued measurement vectors compressed from Compressed Sensing (CS) techniques, and showed that applying the K-means algorithm in the compressed domain enables to recover the clusters of the original domain. However, K-means over compressed binary data was not considered in [4], nor in references therein.

In this work, we consider binary measurement vectors and we assume that the compression is realized from LDPC codes. We propose a formulation of the K-means algorithm that applies over binary data in the compressed domain. As for the original K-means, our clustering algorithm is divided into two steps, namely the cluster assignment step and the centroid estimation step.

We then carry a theoretical analysis of the performance of the proposed K-means algorithm in the compressed domain. We in particular derive analytical approximated error probabilities of each of the two steps of the K-means algorithm. In order to verify the accuracy of the analysis, we compare the obtained analytical expressions to the error probabilities measured from Monte Carlo simulations, see Figure 1. We observe that although the analytical expressions are only approximations, they predict accurately the error probabilities of the two steps of the algorithm. The theoretical analysis hence permits to verify that applying K-means in the compressed domain enables to recover the clusters of the original domain. It also serves to design the parameters of the LDPC codes that are used in the system.

At the end, we show from Monte Carlo simulations that the effective rate needed to perform K-means over compressed data is lower than the theoretical rate (the joint entropy of all the sensors measurements) that would be needed to reconstruct all the sensors measurements.

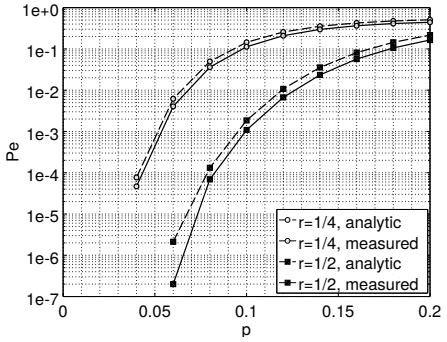

Figure 1: Approximated error probability of the centroid estimation step and error probability measured from Monte Carlo simulations, with respect to the binary symmetric source parameter p. The value r is the coding rate.

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Reliable Storage of Information Using the Effect of Error-Correcting Errors

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Keywords

LDPC codes, iterative decoding, memory architecture, noisy decoders, unreliable logic gates.

Summary

Many natural and man-made systems involving computing, control and communications are made of unreliable parts or parts exhibiting stochastic behavior. Examples of such systems range from quantum computers, nano-scale devices and radiation tolerant spacecraft electronics to gene regulatory networks and neural circuitry. No system using less reliable components is known to operate better than a system using perfect components. Here we present such a system.

We give an architecture of a storage system consisting of a storage medium made of unreliable memory elements and an error correction circuit made of noisy logic gates that is capable of retaining the stored information longer and with lower probability of error than a storage system with a correction circuit made of perfect logic gates.

Our correction circuit is based on iterative decoding of low-density parity check codes, and uses the positive effect of errors in logic gates to correct the errors in memory elements. In contrary to fault-tolerant Taylor-Kuznetsov architecture [1-2], the randomness introduced in the decoder of the proposed storage system provides not only robustness to logic-gate errors, but also superiority to other perfect iterative decoders.

We provide an experimental demonstration and a theoretical explanation of this phenomenon, and we show that the randomness in message updates helps the decoder to escape from local minima.

It is known that adding noise in messages of the belief propagation decoder can improve its performance in the error floor regime [3]. The same effect can be observed in hard decision decoders with reduced complexity [4-6]. Recently, we have shown that the performance of Gallager-B decoder and gradient descent bit flipping decoder can be highly improved if the deliberate flips of the massages are combined with reinitialization and restarts [7, 8].

In this paper, we use the observed effects to design a low complexity memory architecture that provides reliable storage of information and reduced energy consumption.

The same effect can be used for various applications where the performance improvement of the iterative decoder is critical parameter (as an example, to improve security of the code based cryptosystems).

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Compressed Sensing Channel Estimation

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Keywords

Compressed sensing; channel estimation; sparsity; massive MIMO; 5G

Summary

Compressed sensing (CS) is a recent technique used to reduce the number of samples used to sample sparse signals below the Nyquist rate [1,2]. Different optimization methods are used in CS to recover the original signal. Channel estimation is one of the most important applications of CS in wireless communications. This is due to channel sparsity in delay, Doppler and spatial (angle) domain [3]. Exploiting the sparsity, the number of pilots used for channel estimation can be reduced, and the signal transmission rate can be increased. We apply CS to several channel estimation problems, including time dispersive systems, time dispersive Single Input Multiple Output (SIMO) systems and massive Multiple Input Multiple Output (MIMO) systems. Massive MIMO is one of the most promising technologies in 5G mobile cellular systems [4]. The cellular base station (BS) uses a very large number of antennas, which increases channel capacity, averages out the effects of small scale fading and enables simple downlink signal processing architectures. CS is used to reduce the extreme number of pilots required for channel estimation.

In both [5] and [6] we consider an OFDM system with pilot aided channel estimation over sparse time dispersive channels. In [5] we model the channel as a Bernoulli-Gaussian channel and we use Lasso CS for channel estimation. We evaluate the mean square error using the replica method results, known from literature, and then evaluate a capacity lower bound for the OFDM system. We maximize this bound with respect to the number and power of pilot subcarriers.

Lasso is usually implemented on a grid of equidistant values of the quantity to estimate. Recently, atomic norm has been used in CS for estimation of quantities that can assume continuous values. In [6] we use the atomic norm minimization combined with a super resolution method for gridless estimation of arbitrary path delays in sparse time dispersive channels. In [6] the delays are chosen from a uniform distribution and the gains are complex Gaussian. Following the delays estimation, the channel gains are estimated using the LS method.

In [7] we extend the approach from [6] to time dispersive SIMO channels, using a single transmit and multiple receive antennas in an OFDM system. A joint estimation of the delays at different antennas corresponding to the same scatterers is obtained using the combination of the atomic norm minimization for the Multiple Measurement Vector (MMV) model and the MUSIC method, followed by the estimation of gains using the LS or the MMSE method.

Finally, we describe CS based downlink channel estimation in Frequency Division Duplex (FDD) multiuser massive MIMO systems. In massive MIMO besides the sparsity in the angle, delay and Doppler domain, the antenna correlation at the transmitter side (the BS) can be exploited for channel estimation. Here we use the sparsity in the angle domain and the transmit antenna correlation. We assume that the channels of a group of users that are geographically close (i.e. have close angles) can be jointly estimated at BS, using feedback and the MMV approach with mixed norm minimization for recovery.

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Multi-attribute Optimization of Electric Vehicle Fleet Charging Scheduling

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Keywords

multi-attribute optimization; frequency regulation; scheduling;

Summary

Electric vehicles become an important resource to achieve more reliable and sustainable power system [1,2]. However, for the optimal integration of electric cars in power network, several objectives have to be fulfilled simultaneously: the minimization of the driver discomfort, maximization of the revenues coming from possible services to the grid and the maximization of the vehicle fleet charging station efficiency. This problem is solved using the multi attribute utility theory that allows different decision maker's attitude toward risk [3,4,5]. The final output is the decision algorithm for a day-ahead schedule of electric cars usage offering only secondary frequency regulation, from the fleet owner perspective [6].

There are generally two approaches for the generation of solution sets for the multi objective optimization: scalarization and nonscalarization methods. Scalarization methods explicitly use a scalarization function to convert the problem into a single objective program. In our approach, we used multiplicative aggregation as one of the well-known scalarization technique.

The optimization problem is set as a MINLP problem. The optimization function is nonlinear, with linear constraints [7]:

$$\min_{t_{on},t_{plug}} U(X)$$

$$t_{on,i} + t_{plug,i} = T - 1, \forall i$$

$$T_{(\min,on),i} \le t_{on,i} \le T_{(\max,on)i}, \forall i$$

$$T_{(\min,plug),i} \le t_{plug,i} \le T_{(\max,plug)i}, \forall i$$

$$P_i \le P_{i,\max}, \forall i$$

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Multi-criteria Selection of Maintenance Strategy for Construction Winches

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Keywords

Maintenance; construction winch; fuzzy analytic hierarchy process (fuzzy AHP); goal programming (GP); group decision-making

Summary

Safety system is a complex, open system, which exists in conjunction with the environment. Its important elements are technics/technology, people and organization, described by a set of indicators and performance [1]. Optimizing the value of indicators increases system efficiency and organizational productivity. Technical system is significant element of this system. It is described by the following performance: costs, flexibility, functionality, and maintainability [1].

Maintenance is one of the most important organizational activities in manufacturing systems, allowing the technical system to remain in operation for a long time, significantly reducing overall costs. Maintenance allows proper equipment functioning within the permitted parameters' limits [2]. Selection of optimal way of maintaining is a complex process taking into consideration a large number of characteristics.

At construction sites, there is a number of machines for lifting and transfer of construction material. These are different types of cranes, winches and lifts. They raise the burden of weight from a few hundred to a few thousand kilos, so it is very important to properly work, and not to put their operators in situations which could lead to an injury or death. Therefore, the maintenance of these machines and equipment is very important. There are corrective, preventive and proactive maintenance. Maintenance based on risk, popular in recent years, is based on the last two maintenance strategies.

Various methods for maintenance based on multiple criteria analysis are applied: multi-attribute utility theory, multi-criteria analysis using the analytic hierarchy process (AHP), and combining AHP method with goal programming or lexicographical goal programming [3-5]. The proposed hybrid model for construction winches maintenance selection is based on the identification of technical system' subsystems, identification of elements for maintaining, the development of a hierarchical structure for the selection of optimal maintenance method, the key criteria selection, defining the objective function and maintenance constraints, and the selection of optimal maintenance strategy. Criteria for selection of optimal maintenance strategy are reliability and availability, offered safety level, and expected maintenance costs [2]. The high level of reliability, availability and protection requires additional organizational activities and investments. The strategy is selected on the basis of a compromise of these conflicting criteria.

The selection is carried out in two phases: (1) the determination of crisp values of global and local priority vectors of criteria and indicators based on the group fuzzy AHP method; (2) selection of optimum maintenance strategy based on defined objectives and constraints using a goal programming. To avoid erroneous reasoning, the analysis of the consistency of each expert' grade and the conformity assessment of various experts are obtained.

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Development of an Eco-Industrial Network - Based Model for Managing Industrial Waste Flow

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Keywords

Industrial waste; facility location; eco-industrial network; p-median model; AHP; decision making

Summary

One of the biggest problems of environmental protection in Serbia is inappropriate waste treatment, as well as non-utilization of industrial waste (limited capacities for waste recycling, non-utilization of industrial waste for reuse, and low utilization in energetics). The consequences of such behavior are negative environmental impact and exploitation of natural resources. According to the national document - Report on the State of the Environment in the Republic of Serbia for 2014 from Serbian Environmental Protection Agency, following results show: from the total quantity of generated industrial wastes, 76.81 % of non-hazardous waste are left on locations where the waste is generated without any treatment options. Also, the same non-treatment referes to the 80.43 % of hazardous waste [1].

The society deals with the problem of finding the way for waste reuse or by-product treatment which are dismissed by users or waste generators whit the aim of waste reduction and natural resourses conservation.

The main goal of the paper is creation of a model for solving the location problem of waste (secondary materials) treatment facilities, taking in consideration the territorial distribution of raw materials, the type and the quantities of raw materials and the distance between the industries, but simultaneously considering regional social, economic and environmental issues. The specific goal of the research is to design an appropriate model and software tool capable of analyzing all relevant industrial plants within an observed region according to the type of required secondary material and the amount of waste they generate, but in context of regional sustainability.

Methods of global optimization, i.e. heuristic algorithms will be applied to determine the initial location of by-product treatment facility. The limited capacity model of *p-median* and other similar models were used for initial network optimization [2]. For the final placement of the waste facility, after the initial priority optimization by p-median model, the analytic hierarchy process (AHP) is used as a multi-criteria decision support method of choice for the regional management of industrial waste. Previously, the economic, social and environmental protection criteria were defined as a necessary prerequisite for decision-making during integrated resource planning and preventive mitigation of the impacts that arise in an industrial area and its immediate surroundings.

The developed model for industrial by-product flow management, based on eco-industrial network operation principles, constitute a foundation for design of a decision support system which might contribute improvement of the current by-product management practices in the region. It would also assist the efforts to reduce consumption of primary materials and to save resources, while taking into consideration financial aspects and indicators of sustainable development.

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The System for the Decision Support for Classifying the Patients using the measures for missing data

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Keywords

Systemic diseases, missing data, distance, decision support, systemic lupus erythematosus, Sy Sjogren, systemic sclerosis

Summary

The aim of this paper is to show the system for making a decision in the diagnostics of the patients with autoimmune diseases. In this research we proposed two distances. One for missing value and other for the calculation of the distance of the patient from the diseases. The support system in the diagnostics uses these proposed distances implemented in the program language c#. It is often required to establish how the data are connected, how certain data differ or do not go together with each other and what the measure of their comparison is. An important part in detecting the similarities and grouping the data into clusters has the choice of metrics and the accuracy of the cluster algorithm operation. For clustering, we use the machine learning. The machine learning can be observed as determining the dependence on the available data [2]. The Metric learning has become a popular issue in many learning tasks and can be applied in a wide variety of settings, since many learning problems involve a definite notion of distance or similarity [1]. A metric or distance function is a function which defines a distance between the elements of a set [6]. In our paper we used the database of the patients with one of the mentioned three systemic autoimmune diseases: systemic lupus erythematosus (SLE), Sy Sjogren and systemic sclerosis (SScl).

Every patient was diagnosed on the basis of appropriate criteria. The selection of variables is established by the expert committee but is also under the strict influence of the statistical analyses. The classification criteria for SLE were established by the American College of Rheumatology from 1982. Later, in 1997 the criteria were revised [4, 5]. Systemic Lupus International Collaborating Clinics (SLICC) set up the new classification criteria in 2012. The diagnostic criteria for Sy Sjogren and the systic sclerosis [3], are given in a similar way. On the basis of the proposed distance given in

$$D(\varphi,\psi)=\frac{\max\limits_{A\in\varphi}\min\limits_{B\in\psi}d(A,B)+\max\limits_{B\in\psi}\min\limits_{A\in\varphi}d(A,B)}{2} \quad (1)$$

(where φ and ψ be two sets of the stated formulas to which the formulas which represent the literal conjunction belong, $d(A,B)$ is Hamming's distance), first, the base is filled in with the missing data, then, on the basis

$$D_1(\varphi,\psi)=\frac{D(p_1^l,\psi)+D(p_2^l,\psi)+\ldots+D(p_n^l,\psi)}{n}+\frac{D(\varphi,p_1^s)+D(\varphi,p_2^s)+\ldots+D(\varphi,p_m^s)}{m}$$

(2) (Where D is from (1), φ and ψ represent the conjunctive formula of the disease (in general sense), while p_i^l, $1\le i\le n$, I $l\in\psi$ (the patients of that disease), p_j^s, $1\le j\le m$, $s\in\varphi$.), the distance from the new patient to the disease is found. The system was tested its success showed 97.78%, only with one patient there was a mistake in the diagnosis. The aim of the research was to make a better system for giving a diagnosis of the patient as much as possible. The integrated information systems in medicine and the standardized database about the patients give the possibilities for the development of a new system generation for the support in clinical decision-making which were available to the users of such integrated systems. The proposed system showed better results than the existing methods.

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An AHP approach for modeling financial time series

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Keywords

Technical indicators; AHP; predictive modeling; financial time series; stock market

Summary

The dynamic filed of time series modeling has received a lot of interest by the research community over the last few years. Time series provide an overview of how a random process of discrete time intervals develops. The empirical data used to analyses financial markets contain a finite time increment, which usually represents a 24-hour interval. The amount of data for analysis is rapidly increasing, and the need for developing proper mathematical tools for the practical purposes of classification and understanding of financial market system is growing. If financial market trends could be predicted more accurately, this would provide the necessary conditions for achieving maximum return on investment. Currently, the two most widely debated approaches in understanding processes on the stock market are the paradigm of random walks with the related efficient market hypothesis and the existence of trends based on the assumptions of technical analysis [1]. According to [2] the more widely adopted of above mention methods of trend prediction, as applied to world stock markets, is technical analysis. Technical analysis is based on analyzing evolution of a financial instrument price, relying only on its price history. Past history of transaction practices and volumes is used to compute technical indicators. They in turn function as signals of future price changes.

It is well-known that by obtaining new information, the behavior of market participants constantly fluctuates, and that making decisions on activities are closely related to the experience and intuition of investors, influenced by dynamic market conditions and potential trading risk.

In this paper we propose a methodology which incorporates domain-specific knowledge by using a multi-criteria decision-making approach that is an analytical hierarchy process of the evaluation of relevance of technical indicators. In order to address this problem we propose the evaluation of technical trading strategies as potential measure of success of the technical indicator relied on. To clarify, a technical trading strategy is composed of a set of trading rules which are generated based on the values of the technical indicators and are used to generate trading signals.

AHP is used on stock market data in this paper due to its successful application in various empirical data analyses. Furthermore, AHP was introduced in several studies for feature ranking and weighting in combination with machine learning algorithms [3-5]. The method has been proven to be successful due to its ability to evaluate a group of factors based on their relevance, even in mutually opposed criteria, without any previous knowledge on the structure of their mutual relations.

In order to make an evaluation of the obtained set of technical indicators we select and describe three AHP evaluation criteria. The first and second criterion measures the economic relevance of the technical indicators. The cumulative gross return is used as a measure of stock market profitability. The second parameter is systematic risk as a measure of market volatility. The third criterion represents a comparison of the trading signals generated with a trading strategy and signals generated based on actual stock market index values. They are put into relation trough their achieved prediction accuracy. The weights obtained by AHP are then used for technical indicator ranking.

The model was tested on the Serbian stock exchange market using stock index Belex15. The test results indicate that the present AHP-based methodology could be used as a preprocessing method in order to assess the relevance of features from time series data.

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Analysis of prediction errors generated by BINAR(1) models

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Keywords

integer valued autoregressive models, time series of counts, binomial thinning, negative binomial thinning

Summary

Modeling integer valued time series is a point of interest for many researchers since this type of series can be found in many scientific fields. One of the first ideas devoted to modeling this type of time series can be found in [3] and [1]. It might happen that two series of counts are dependent, thus the definition of some bivariate models are necessary. This extension from the univariate to the multivariate case can be found in [2]. The goal is to define a model which well fits data and makes prediction errors as small as possible. There are different measures that researchers use to describe adequacy of some model for particular data set. Among mostly exploited methods are Akkaike information criteria and Root mean square error. These methods allows us to compare some models with each others, but not to analyze them and understand how the prediction errors are generated. The aim of our research is to define the approach that can help us better understand the one-step-ahead prediction error made by bivariate integer valued autoregressive models.
The bivariate models that we are investigating are autoregressive of order one. They are composed of two components: survival part and innovation part. The survival part is defined through the thinning operator, where we use the binomial or the negative binomial thinning operator. The distribution of the innovation part is determined under the stationarity condition. These type of models can be found in [6], [4] and [5]. Since the processes defined with these models are Markov processes of order one, we use conditional expectation for the one step ahead prediction, where the expectation is derived with respect to the previous state of the process. We introduce the approach that distinguishes the prediction error made by the survival and the innovation component separately. These two components are not observable, thus we need to derive their conditional expectations where we know the current and the previous states of the modeled process. In this manner, we can estimate the amount of information that we get from the survival and the innovation component separately. This approach let us better understand shortfalls of the observed models and thus it can be used for some further improvements.

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Ultrametrics in Bioinformation

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Keywords

ultrametrics; bioinformation; information theory; p-adic distance; genetic code

Summary

The choice of theoretical methods in the investigation of physical systems depends on their space and time scale as well as of their complexity. Sometimes standard methods are not sufficient and one has to invent a new advanced method. Biological systems belong to the most complex systems in the nature. In particular, biosystems which contain information are very complex and they cannot be reduced to the standard physical systems – they are something more than ordinary physical systems and need some new theoretical approaches to their description and understanding.

One of interesting tasks in information theory is how to describe similarity (or dissimilarity) between two information, especially between two bioinformation (similar structure – similar function). In an investigation of geometrical structure of physical system, we use ordinary (Euclidean and Riemannian) distance. However, when we are interested in the information content of a system, then some other distances between its elements emerge to be more adequate than the ordinary one. For example, the Hamming distance between two strings of equal length measures their similarity (dissimilarity): smaller Hamming distance - more similarity. However, Hamming distance is not appropriate when information has an ultrametric structure, i.e. when the elements at the beginning of sequence are more important than those at the end. In such case, an ultrametric distance is just what is necessary to measure similarity and then information system is an ultrametric space.

An ultrametric space is a metric space in which distance satisfies strong triangle inequality instead of the ordinary triangle equality, i.e. $d(x,y) \leq \max\{d(x,z), d(z,y)\}$. As a consequence of this ultrametric inequality, the ultrametric spaces have some rather unusual properties, e.g. all triangles are isosceles with one side length which cannot be larger than the other two.

There are many examples of ultrametric spaces which can be presented in the form of a tree, dendrogram or a fractal. The Baire metric and p-adic distance are typical examples of ultrametric distances. Ultrametrics has natural application in bioinformation, e.g. related to the taxonomy, phylogenesis and genetic code.

In this contribution we will demonstrate how a p-adic distance describes similarity between the codons in the case of vertebrate mitochondrial code [1, 2]. Then we will show how application of the p-adic distances can be extended to the amino acids, modified Hamming distance, similarity between strings of nucleotides, amino acids [3, 4].

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Fuzzy relations and their use in the study of complex fuzzy systems

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Keywords

Fuzzy relation equation; fuzzy automaton; fuzzy social network; fuzzy formal context; fuzzy control system

Summary

It is commonly known that throughout the history of fuzzy scientific research, fuzzy relations were early considered to be an efficient formal means for modeling a variety of complex phenomena (reasoning, decision, control, systems analysis and design, knowledge extraction, etc.) in the presence of uncertainty. Over the decades, fuzzy relations have gained a wide range of applications, and we review some of the latest, emerging from our research.

We start from applications in the theory of fuzzy automata. The key point in our research is that a fuzzy automaton $\mathcal{A}$ can be regarded as a fuzzy relational system – it can be specified by a family $\{\delta_x\}_{x\in X}$ of fuzzy transition relations on its set of states A, indexed by its input alphabet X, and fuzzy subsets σ and τ of A, the fuzzy subsets of initial and terminal states. If the composite fuzzy transition relations $\{\delta_u\}_{u\in X^*}$ are defined by putting that δ_ε is the crisp equality, and $\delta_{ux} = \delta_u \circ \delta_x$, for $u \in X^*$, $x \in X$, the fuzzy language recognized by $\mathcal{A}$ is defined as a fuzzy subset $[\![\mathcal{A}]\!]$ of X^* given by $[\![\mathcal{A}]\!](u) = \sigma \circ \delta_u \circ \tau$, for $u \in X^*$.[1] This way of viewing fuzzy automata, which was previously exploited only by few authors, enables to study fuzzy automata using fuzzy relational calculus, and to express many problems through fuzzy relation equations and inequalities.

The subject of our research were several fundamental problems of the theory of fuzzy automata. The first one is the *determinization*. Determinization of fuzzy automata is a procedure of their conversion into equivalent crisp-deterministic fuzzy automata, which can be viewed as being deterministic with possibly infinitely many states, but with fuzzy sets of terminal states. The standard determinization method, known as the subset construction, converts a nondeterministic automaton with n states to an equivalent deterministic automaton with up to 2^n states. The fuzzy version of this construction may even give an infinite crisp-deterministic fuzzy automaton. That is why an extremely important task is to find methods that will mitigate the potential enormous growth of the number of states during the determinization. Using an approach based on the fuzzy relational calculus, in a series of papers we have developed several such methods (cf. [3, 17, 25–28]), including two methods that always provide the minimal crisp-deterministic fuzzy automaton equivalent to the original fuzzy automaton (cf. [25, 28]).

Another fundamental problem of the theory of fuzzy automata we dealt with is the *state reduction*. In many real applications we are working with automata having a very large number of states, and an important practical problem is to reduce the number of states (or to minimize it, if possible), while preserving the basic function of the automaton. Unlike deterministic automata, the state minimization of fuzzy automata is computationally hard. For fuzzy automata a more practical problem is the state reduction, where a fuzzy automaton is replaced by an equivalent automaton with as small as possible number of states, which need not be minimal but must be effectively computable. In [11, 31] we reduced this problem to the problem of solving some specific systems of fuzzy relation equations and inequalities, where to get better reductions we search for greater solutions, preferably for the greatest one, if any.

The third problem we have considered in our research is whether two automata simulate each other, which is closely related to the problem whether two given automata are equivalent. The problem of the existence of simulation and bisimulation relations between two fuzzy automata we have also reduced to the problem of solvability of some specific systems of fuzzy relation equations and inequalities, and computing their greatest solutions, if they are solvable (cf. [5, 8, 9, 12, 24]).

The inequalities and equations which we have used in research in the theory of fuzzy automata can be writ-

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[1] Here X^* denotes the monoid of all words over X, $\varepsilon \in X^*$ is the empty word, and $\circ$ denotes the compositions of two fuzzy relations, of a fuzzy set and a fuzzy relation and two fuzzy sets (when the underlying set is finite these are the matrix product, vector-matrix products and scalar product of vectors), defined in the usual way over a residuated lattice or lattice-ordered monoid.

ten in matrix form as $AX \leqslant XB$, $XB \leqslant AX$ and $AX = XB$, where A and B are given fuzzy relations (matrices) and X is an unknown fuzzy relation (matrix). We called such inequalities and equations *weakly linear*. In our further research, the systems consisting of weakly linear inequalities and equations have been studied from a general point of view (cf. [16, 18, 20]), what has also initiated research in an even more general context, of equations and inequalities on partially ordered sets defined by means of residuated and residual functions.

We have found that equations of the form $AX = XA$ play also a very important role in the *social network analysis*, a branch of sociology and mathematics which provides formal models and methods for the systematic study of social structures. Since social networks share many common properties with other types of networks, methods of social network analysis are applied to the analysis of networks in general, including many kinds of networks that arise in computer science, physics, biology, etc., such as the hyperlink structure on the Web, the electric grid, computer networks, information networks or various large-scale networks appearing in nature. In order to overcome the vagueness, which is unavoidable when discussing the relationships between individuals, it is quite natural to study social networks from the aspect of fuzzy set theory, what is being done in our research. Positional analysis is a discipline of social network analysis whose main aim is to identify the position or role of actors in the network on the basis of relationships between them. A key role in the positional analysis play regular equivalences, which are actually solutions to the aforementioned equation $AX = XA$, where A is a fuzzy relation that defines the considered fuzzy social network. This fact has initiated a wide application of systems of weakly linear equations and inequalities in the positional analysis of social networks, the study of multi-relational networks, as well as the study of simulations and bisimulations between fuzzy social networks (cf. [16, 18, 20, 22, 34]).

Social network analysis also deals with two-mode (bipartite) social networks. We have shown that positions in a two-mode fuzzy network can be identified by means of solutions to equations of the form $XA = AY$, where A is a fuzzy relation that defines the considered two-mode network, and X and Y are unknown fuzzy relations on each of two modes (cf. [32–34]). Moreover, we have also solved the corresponding problems for multi-relational two-mode fuzzy networks, as well as for multi-relational multi-mode fuzzy networks with an arbitrary number of components (cf. [10]). The obtained results can also be applied in the analysis of any kind of data represented by tables (object-attribute dependencies, formal contexts) for simultaneous reduction of objects, attibutes and relations between them.

The fourth field of applications of the equations and inequalities studied in our papers is *fuzzy control*. Fuzzy control theory deals with a system S composed of an input universe of discourse A and an output universe of discourse B. The input universe usually consists of measured values of input variables, and the output universe consists of values of output variables, which are called control actions for the system S. The basic task of the fuzzy control theory is to determine a fuzzy control function relating input variables to output variables. Due to an intrinsic indistinguishability of measured values of state variables, input/output values are represented by suitable fuzzy subsets f_i of A and g_i of B, $i \in I$, and the dynamics of the system S are usually characterized by a system of IF-THEN rules IF x is f_i THEN y is g_i, $i \in I$. Each rule expresses a relation between elements from A and B, and the system of IF-THEN rules is modeled by a fuzzy relation R between A and B constructed from fuzzy sets f_i and g_i, $i \in I$. More precisely, a fuzzy relation R is assumed to be a solution to a system of fuzzy relation equations $f_i \circ R = g_i$, $i \in I$. We have provided a method for checking the solvability of this system in the case when $\{f_i\}_{i\in I}$ is a fuzzy partition and $\{g_i\}_{i\in I}$ is a fuzzy partition or a fuzzy semi-partition (cf. [7]). When the system is solvable, by the same method we construct a solution and solve the corresponding defuzzification problem.

It is worth noting that we can also consider equations of the form $f \circ R = g$, where R is given, but f and g are unknown, whose special cases are equations of the form $f \circ R = f$, known as an eigen fuzzy set equations. These equations play an important role in the stability analysis of fuzzy control systems, but also in other areas such as image reconstruction and medical diagnosis. We have provided methods for computing the greatest solutions to systems of eigen fuzzy set equations and the corresponding inequalities, and both for systems of equations and inequalities we characterize sets of their solutions (cf. [23]). The same systems have been also applied in the study of subsystems of fuzzy transition systems (cf. [21]).

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Quantum Information: Fundamentals and Prospects

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Keywords

quantum information; quantum computation; quantum foundations

Summary

Intuitively, "information" is a "surprise"–an "unexpected" outcome of a physical process of observation (measurement). Hence the usefulness of the quantum systems that are irreducibly random. More precisely, the process of quantum measurement is *par excellance* "information source".

Every single act of quantum measurement disturbs the (quantum) object of measurement and makes the outcome unpredictable, nevertheless describable by certain probability distribution (or probability density).

In order to have some control on the object of measurement, of interest is special kind of quantum measurement–the so-called predictable measurement, which allows for uniquely known the final state of the system (i.e. of the statistical ensemble of systems) [1, 2]. This kind of measurement is paradigmatic as pointing the influence of the measurement apparatus that is mathematically described by the so-called completely-positive trace preserving (CPTP) maps. Furthermore, most of the physically investigated external influences on a quantum system are described by those CPTP maps [3]. Fragility of the quantum systems under external influence implies that the quantum information resources (QIR) are rather fragile themselves. Hence one of the central task of the quantum information processing (and computation) is preservation of QIR.

Quantification of information as well as of the external influence on the quantum system goes with a proper definition of "entropy" and the derived quantities, such as "mutual quantum information" or "relative entropy". The most used and best investigated quantum entropy is the so-called "von Neumann entropy". The CPTP maps increase the von Neumann entropy, i.e. decrease the information about the system [1].

Quantum bit (qubit) is any two-dimensional unitary vector space. The choice of an orthonormalized basis (so-called "computational basis") is analogous to the classical "bit". However, linearity of quantum mechanics and of quantum dynamics introduce new kinds of information resources: (a) quantum parallelism, (b) uncertainty relations, and (c) quantum correlations (entanglement and discord) [1, 2, 4]. Those classically unknown characteristics of quantum systems ultimately base certain quantum protocols and algorithms, such as quantum cryptography [5], large numbers factoring [6], quantum simulations [1] and open the route to the information processing on large molecules [7]–the emerging field of quantum technology.

Practical quantum technology requires non-trivial operational control and experimental skills, notably scalability of the quantum hardware and its isolation from the environment thus making quantum technology the true technology of the 21st century with the indispensable role of the quantum foundations.

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Limitations of Nakajima-Zwanzig method

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Keywords

quantum correlations relativity; quantum structure; Nakajima-Zwanzig projection method

Summary

Quantum correlations (including quantum entanglement) are now widely recognized as a fundamental ingredient in tasks related to quantum information and quantum computation [1, 2, 3]. Recently established rules about entanglement relativity and quantum correlations relativity [4, 5, 6] emphasize the role of "quantum structure": non-classical correlations are the matter of the system's structure (i.e. of the system's partition into subsystems). By "structure" here is meant a set of the degrees of freedom, while structures are mutually related by linear canonical transformation (LCT), which can target local or global degrees of freedom. Some of the LCT examples are: composite system's center of mass and the "relative (internal)" degrees of freedom, fine and coarse graining, permutation of degrees of freedom, exchange of particles etc [7].

Nakajima-Zwanzig projection method is one of the most used techniques for obtaining open system's dynamical equation, that carries all the possible information regarding the open system and its dynamics–so called quantum master equation [8, 9]. Open quantum system is a part of a whole composed of open system plus the environment. Having in mind that particles exchange between open system and environment is one example of LCT, and structure dependence of non-classical correlations, it is natural to ask how the projection method fits in this "LCT induced relativity".

It turns out, in contrast to classical intuition, that similar systems (e.g. where difference is due to adding/removing one or more particles) do not have similar dynamics. Projection method is of no use for deducing dynamics of the "new" structure on the ground of known master equation. In other words: the analysis of the new degrees of freedom should be started from the scratch.

This conclusion refers to finite- and infinite-dimensional quantum systems and to arbitrary kinds of system-environment splitting.

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Generalized entropies: review and open questions

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Keywords

generalized entropy; Shannon-Khinchin axioms; non-extensive thermostatistics; maximum entropy; thermodynamical stability

Summary

Due to their thermostatistic properties, generalized entropies are very useful for systems which exhibit power-law statistics and form a basis for non-extensive thermostatistics. They are used in a number of different fields, such as complex systems, economics, social sciences and physics [3]. Different axiomatic systems have been proposed in order to characterize mathematical structure of the generalized entropies, which is helpful for understanding their fundamental properties. In [4], we introduced Shannon-Khinchin axioms for the case of quasi-linear mean nonadditive entropies. Thus, we characterized a wide class of entropies which contains Tsallis, Rényi, Sharma-Mittal and Gaussian entropies, as special cases.

Previous research has shown that the power law distributions are connected to generalized entropies via the maximum entropy principles, and that fact spawned an extensive body of work on non-extensive thermostatistics. This includes establishment of maximum entropy distribution, Legendre structure of thermodynamics, thermodynamic stability and Lesche stability conditions for different generalizations of Shannon entropy [8], [9], [6], [10], [2] and [7].

Here, we show that the maximum entropy distribution, which correspond to the generalized entropy [4], asymptotically approaches the power law, we derive a corresponding Legendre structure and thermodynamic stability condition. Therefore, we unified and generalized many of the previous results for Shannon entropy [5], [1], Rényi and Tsallis entropies [8], [9], [6], [10], Sharma-Mittal entropy [2] and Gaussian entropy [7]. The results further justify the usage of the entropy for complex systems with power law behavior.

Some directions for future research in the fields of characterization of generalized entropies and generalized thermostatistics are also presented.

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Associative nature of conference participation dynamics: an empirical analysis and modeling

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Keywords

science of science; truncated power law; Pólya process; positive feedback; community inclusiveness

Summary

The search for regularities in scientific activities has attracted a large research interest in recent years [3]. The methods of statistical physics have been widely used to analyze patterns of scientific publications, collaborations and citations in scientific journals [2, 4, 1]. Despite the important role participation in scientific conferences has both for the individual careers of scientists, as well as for the development of science itself, little work has been done on understanding mechanisms that underlie conference participation dynamics. In this work we present results from the empirical analysis of conference participation patterns at six conferences of different sizes and from different fields of science for the period of three decades [5]. We focus on the distribution of the total number of participations, number of successive participations and the time lag between two consecutive conference participations for each author and find that all these properties exhibit truncated power-law behavior, regardless of the conference size and degree of specialization. The observed statistical evidence indicates that scientists don't attend conference randomly with some constant probability. In order to investigate the mechanism behind conference participation patterns, we propose a microscopic stochastic model that can fit observed data. The model is based on two key ingredients, 2-bin generalized Pólya process and random termination time of a conference career. The model parameters, obtained using Monte Carlo simulations, indicate that conference participation dynamics is governed by positive feedback mechanism. Accordingly, the probability for a scientist to re-attend a conference grows superlineary with the number of participations, while the frequent pauses have the opposite effect. This finding suggests that the social component has important role in conference choice. An active participation in a conference series strengthens the scientists association with that particular conference community and thus increases the probability of future participations. The fact that the model predicts participation patterns for all six observed conferences regardless of their sizes or research fields indicates its universal character. We expect to see similar participation dynamics in other types of social groups.

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The structure of communities in networks co-evolving with online social interactions

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Keywords

bipartite networks; online interactions; collective behaviour; community structure;

Summary

The appearance of communities, recognisable by formal graph theory in the underlying bipartite networks, is an essential feature of online collaborative behaviour. Using the empirical data and theoretical modelling, we demonstrate how the emergence of community structure relates to the self-organized dynamics and (cognitive, emotional) contents of the involved artefacts.

The prevalence of information communication technologies in everyday activities of a significant portion of the world population resulted in the vast amount of data. On the Web, people exchange information and emotions, engage in solving problems, provide support, influence each others opinion, or search for a soulmate. The availability of large-scale data has enabled researchers from different fields to search for trends and *laws* in social systems analogous to ones observed in natural science [1]. In this context, the use of methods of Statistical Physics is crucial to describe the emergence of collective phenomena appropriately in these social systems [2].
Combining the methods of Statistical Physics with Graph Theory and Machine Learning methods of text analysis, recently we developed a systematic approach to analyse the collective social behaviour from the empirical data and provide theoretical modelling [3, 4]. Specifically, this approaches revealed the underlying mechanisms leading to the emergence of common emotions via exchange of emotional messages on Blogs [3] and the creation of collective knowledge in Questions& Answers systems [4]. In these online systems, the interactions among actual participants in the process occur trough creations of artefacts (questions and answers, post and comments), which suitably map onto *co-evolving bipartite networks*, with the users as one partition, and the artefacts, as the other. The analysis of the topology of these networks uncovers their partitioning into mesoscopic communities—the users grouped around certain artefacts, where the main social activities concentrate. These groups appear topologically well separated as well as conceptually relatively independent from each other. Therefore, the research of the collective social behaviour in a large dataset reduces to the identification of communities in these bipartite networks (and monopartite projections) and understanding their evolution mechanisms concerning the contents of the involved artefacts.
Here, we apply this methodology to study the collaborative problem solving in Question and Answer (Q& A) sites [4]. We demonstrate how the user cooperation leads to the emergence of knowledge as a collective value in an extensive network of actors and artefacts. We also show that the occurrence of communities is self-organized and closely relates to the long-range correlations in time series. Furthermore, using the agent-based modelling, we examine the structure of connections and formation of communities concerning the level of expertise of the actors, which we can vary within the model. Our results show that the dynamics of collective knowledge building is strongly influenced by the distribution of expertise and the activity patterns of the principal actors.

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The Width of Complexity Potential as an Integral Factor of Science

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Keywords

complexity; fractality; new methods; cultural heritage; Orthodox icon

Summary

Complex systems theory represents an umbrella term for various types of research that include dynamical systems, discrete dynamical systems and cellular automata, game theory, information theory, networks, computational complexity, numerical methods, agent-based modeling and more [1]. Organizational clusters of complex systems reveal dozens of thematic frameworks, because each of these is covering several. For the chaos theory the turning point is considered to be in 1970-s [2], while the end of the second and the beginning of the third millennium is considered a milestone for complexity [3].

The frequent appearances of topics that are not classical example of complex systems and those that are not studied within mainstream scientific disciplines are of particular interest. Even the mere titles of papers in the field of fractality, which is a very illustrative field, draw the scientists' attention. Some of these topics are: structural scaling of Johann Sebastian Bach's Cello Suite No. 3 [4], fractal behaviors in a soccer game [5], measuring the temperature of texts [6], fractal analysis of different musical instruments [7], complexity perturbations in tanpura signals [8].

It is very interesting to look at the most cited papers in the field of complexity, as well as at the most approached works. They illustrate the impact of complexity as well as its permanent appearance in new areas. Among these are: Risk evaluation of diabetes mellitus by relation of chaotic globals to HRV [9], Cosmological natural selection and the purpose of the universe [10] etc.

Looking at the originating and linking of the fields over the period of the last 60-70 years (taking, for example, cybernetics as the starting point [11]) it is clear what kind of theoretical diversification we are talking about – the one that corresponds to the observed phenomena in natural as well as in social sciences. In the context of the diversity of topics we give an example from the practice of local authors. It is about a research that is completely unknown and new in this field. It is a specific, integral approach to an Orthodox icon that includes fractality, self-organization, examination specific geometry, lighting and the role of observer [12]. This was preceded by the following steps: the research of quantification of self-organization and complexity by which a door to a new methodological framework for dealing with data is opened [13,14]; simultaneously, the work on the application of new methods in working with cultural heritage [15], primarily Orthodox iconography, was being created [16]. Consideration of the role of the observer in this model was based on relying on phenomena of quantum optics [17].

The presented example is a typical indicator of the potential which complexity has, as well as its power of integration.

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Complexity Based Aesthetics and Gnoseology

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Keywords

complexity; aesthetics; gnoseology; self-organized systems; wavelet domain hidden Markov model

Summary

The prior results concerning the originality of artworks in terms of the complex systems physics [1] have been elaborated in order to elucidate their ontological context. It has been demonstrated that the originality issue, such conceived leads to a criterion of applied aesthetics that is not restricted to the fine arts domain covering also physics, biology, cosmology and other fields construed in complex systems terms.
The aforementioned conception, however, transcends the viewpoint of modern humanities supporting the individualistic concept of originality. It reveals aesthetics figured through inspiration whereat the originality is established through self-organization, implying a process that is not of individual character. By such a paradigmatic art the authors consider medieval ecclesial art referring exactly to the Orthodox iconography of Byzantine style [2]. On the other hand, since corresponded to self-organization such aesthetics is not only the philosophy of art but also the philosophy of science. A paradigmatic science in that regard is considered to be just the complex systems physics.
The computational neuroscience related to the complex systems [3] conjugates the access with neuroaesthetics [4] indicating an opportunity of its foundation in an accurate manner. The computation concerned should correspond to the neural substrates of aesthetics relating sensation and neural activity that is the crucial aim of psychophysics in Fechner`s view [5] referred to as inner psychophysics.
The basic assumption of the model is the signal space $L^2(\Re)$ consisting of square integrable function defined on the real line. The discretization of the signal space due to a base choice corresponds to an individual perception relating stimulation and sensation that is referred to by Fechner as outer psychophysics [5]. The inner psychophysics, however, is related to self-organization in a hierarchical base having implied statistical model of the wavelet coefficients [6]. Estimation of the model parameters using the Baum-Welch algorithm [7] includes an iterative upward-downward procedure that fits well to the predictive coding model of perception [8]. The exponential decay of the coefficients across scale [9] has reproduced Fechner`s law stating that the sensation scale is proportional to the logarithm of the stimulus.
The model concerns an ontology substantiating both art and science upon the originality issue. Moreover, it corresponds to the truth criterion of a substantial gnoseology actually implied by Gethmann-Siefert theory of art [10].

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ABCDepth: Computation of High-dimensional Tukey Median

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Keywords

Data centrality, Multivariate medians, Tukey median, Tukey depth, Complexity computation

Summary

The Tukey depth of a point $\boldsymbol{x} \in \mathbb{R}^d$ relative to a multivariate data set is defined as the minimal number of observations in any closed halfspace that contains $\boldsymbol{x}$. With respect to this definition, Tukey median is a point $\boldsymbol{x}$ with maximal Tukey depth. We present an approximate algorithm for Tukey (halfspace) median, i.e. for finding deepest location in higher dimensions. Given d-dimensional data set for any $d \geq 2$, the algorithm is based on representation of level sets as intersections of balls in $\mathbb{R}^d$. The algorithm complexity is $O(dn^2 + n^2 \log n)$ where n is the data set size. It's very efficient and it can accept thousands of multidimensional observations, while other algorithms are tested with two-dimensional data or with a couple of hundreds multidimensional observations. The algorithm can be easily adapted to work not only with balls, but with other convex sets, so the appropriate name is Algorithm based on Balls or other Convex sets to evaluate Deepest points, or ABCDepth.

A basic statistical tasks is to simplify a large amount of data using some values derived from the dataset as representative points. Among many ways to choose representative points, a natural idea is to choose those that are located in the center of data set. One way to define a center is to define what is meant by deepness, and then to define the center as the set of deepest points. In [9] John W. Tukey proposed the halfspace depth as a new approach to visualize bivariate data sets by ordering data according to their depth, i.e. centrality in the data cloud. In $\mathbb{R}^d$ with $d > 1$, there are several different concepts of depth and medians (see for example [6], [7], [8]).

The theoretical background of ABCDepth algorithm relies on depth functions based on families of convex sets. Let us denote $\mathcal{V}$ as the family of all open halfspaces and their complements as closed half-spaces. Then, the usual definition of Tukey depth can be defined as

$$D(x; \mu) = \inf\{\mu(H) \mid x \in H \in \mathcal{H}\}, \qquad (1)$$

where $\mathcal{H}$ is the family of all closed halfspaces and μ is the corresponding distribution, i.e., a probability measure on $(\mathbb{R}, \mathcal{B})$.

A depth function can be defined based on different families $\mathcal{V}$. We say that families $\mathcal{V}_1$ and $\mathcal{V}_2$ are depth-equivalent if $D_{\mathcal{V}_1}(x; \mu) = D_{\mathcal{V}_2}(x; \mu)$ for all $x \in \mathbb{R}^d$ and all probability measures μ. Sufficient conditions for depth-equivalence are given in [1, Theorem 2.1], and it was shown there that in the case of half-space depth the following families are depth-equivalent: a) family of all open halfspaces; b) all closed halfspaces; c) all convex sets; d) all compact convex sets; e) all balls. For determining level sets, among all other types of convex sets, we choose balls in such way that the level set is defined as:

$$S_\alpha(\mu, \mathcal{V}) = \bigcap_{B \in \mathcal{V}, \#\{x_i:\, x_i \in B\} \geq \lfloor n(1-\alpha)+1 \rfloor} B, \qquad (2)$$

where $\alpha \in (0, 1]$, n is a set of data points $\{x_1, \ldots, x_n\}$ and B is a ball that contains at least $\lfloor n(1-\alpha)+1 \rfloor$ data points.

Detailed theorems and proofs are given in [1], [2] and [3].

Algorithm implementation takes three steps. At the step one, we calculate Euclidian inter-distances of points and it runs in $O(dn^2)$ time. The second step constructs the data structure that contains sorted distances for each data point. This step has complexity of $O(n^2 \log n)$. Finally, the third step determines level sets and, as a consequence, a median since $\alpha_1 < \alpha_2$,$S_{\alpha_1} \supseteq S_{\alpha_2}$ and $S_\alpha = \emptyset$ for $\alpha > \alpha_m$, where α_m is the maximal depth. Third step runs in $O(n^2)$. Altogether, the ABCDepth complexity is

$$O(dn^2) + O(n^2 \log n) + O(n^2) \sim O(dn^2 + n^2 \log n). \quad (3)$$

Precise implementation and pseudocode are given in [3].

Many examples with real and synthetic data are shown in [3]. Synthetic data are produced by distribution generators implemented and presented in [4] and [5].

Finding Tukey median is a computationally challenging. During the last several decades, a few algorithms for halfspace median have been constructed. An exact algorithm (HALFMED) for finding Tukey median in bivariate data set is proposed in [10] with complexity $O(n^2 + log^2 n)$. First approximate algorithm (DEEPLOC) for finding Tukey median in higher dimensions is proposed in [11] and it runs in $O(kmn \log n + kdn + md^3 + mdn)$, where k is the number of steps taken by the

program and m is a number of directions, i.e. vectors constructed by the program. Although not implemented yet, there is a randomized algorithm for maximum Tukey depth proposed in [12]. It runs in $O(n^{d-1})$. In our novel approach we show that ABCDepth complexity grows linearly with number of dimensions and quadratically with number of data points. Hence, for any fixed d the complexity of ABCDepth algorithm is $O(n^2 \log n)$.

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Improving Text Classification Accuracy Using a Novel Corpora Cleansing Technique

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Keywords

classification; text categorization; noise detection; corpora cleansing; corpora relabeling

Summary

Text categorization is one of the most common machine-learning problem nowadays. In the past two decades many techniques have been developed to address this problem. The effectiveness of these techniques strongly relies on the train corpora quality. In many real-life situations train corpus is often polluted with significant number of misclassified examples, which may lead to a less accurate classifier. In this paper we propose a novel approach that deals with this problem.

There are several approaches that handle learning on noisy labels. Starting from the work in [1], many noise-tolerant versions of the perceptron algorithm have been developed. This versions includes confidence weighted learning [2], the AROW [3] and the NHERD algorithm [4]. Most recent algorithm, described in [5], is based on loss function modification, whose usage in optimization process produces noise tolerant SVM and logistic regression classifiers.

Our approach differs from the above mentioned approaches in sense that it does not modifies existing training algorithms. The proposed *corpora cleansing* algorithm has two parts. First part, called *noise detection*, is focused on detecting wrongly classified examples in the train corpus. To detect wrongly classified instances we trained an over-regularized classifier on noisy corpus, and then used it to classify all train instances. All train errors in that case are considered as noise which needs to be relabeled. We used L1-regularized logistic regression training algorithm from LIBLINEAR library [6]. Second part of the algorithm is called *noise relabeling* and has a task to assign a possibly correct class to wrongly classified examples detected in the first step. In order to relabel train example we find its k-nearest-neighbors examples and assign it the most frequent class among that neighbors. In kNN analysis distance is measured as cosine similarity.

Testing setup includes two standard corpora: Reuters and 20 Newsgroups. Adequate corpora preprocessing steps are taken such as stop words removal, lowercasing and bigrams generation. For vector representation of documents tf-idf weighting scheme is used. For each corpus we introduced synthetically generated noise. Namely, from each class we deliberately reclassified p-percent of examples into wrong categories. Value p goes from 10 to 50% with step of 5%, giving us 9 noisy variants of each corpora (see column N[%] in Table 1). 5-fold cross-validation is conducted both on noised and cleansed versions of corpora and corresponding F1-measures are compared. In each cross-validation fold test part is noise-free, while train part is noised as mentioned before. Table 1 shows experimental results. Column N_c[%] shows noise percentage after the cleansing, and F_n and F_c show F1-measure obtained by classifiers which are trained on noised and cleansed versions of corpora, respectively.

N[%]	Reuters			20 Newsgroups		
	N_c[%]	F_n	F_c	N_c[%]	F_n	F_c
10	**4**	0.89	**0.91**	**5**	0.84	**0.86**
15	**5**	0.87	**0.91**	**7**	0.82	**0.86**
20	**6**	0.85	**0.90**	**9**	0.79	**0.86**
25	**7**	0.83	**0.90**	**10**	0.76	**0.85**
30	**9**	0.80	**0.90**	**12**	0.74	**0.84**
35	**12**	0.77	**0.89**	**15**	0.70	**0.83**
40	**15**	0.72	**0.87**	**18**	0.67	**0.82**
45	**19**	0.66	**0.84**	**21**	0.62	**0.80**
50	**23**	0.60	**0.81**	**26**	0.58	**0.78**

Table 1. Corpora cleansing results

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Semantic similarity detection in continuous vector space of words and phrases

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Keywords

word embedding; semantic similarity; natural language processing; clustering; knowledge extraction

Summary

Similar words detection can help users extract new entities and refresh data bases with up to date information appeared in varius types of documents. In this paper we propose a method for semantic similarity detection based on distributional vector space embedding of words and phrases. Embedding assumes that words and phrases are represented as dense real-valued vectors. It is designed to satisfy the distributional hypothesis: words and phrases that occur in similar contexts tend to have similar meanings, and therefore they should have vectors which are close to each other in a vector space.
We have extracted phrases using Pointwise Mutual Information and then learned word and phrase vectors, using as a training corpora set of business articles, job vacancies and employee resumes. We have produced the embeddings of words and phrases in a vector space, where distance measures difference between them. In a next step of information extraction procedure, we have applied hierarchical agglomerative clustering of vectors in order to detect clusters of similar entities. Using known entities from business domain as seeds, we were able to extract clusters which contain them. Inside such clusters of entities (words and phrases), we have found examples, which were semantically similar to the given seeds, but were not given as a component of the original query. In this way we were able to extract new entities. Example: using a ‘’c++’’ and ‘’java’’ as seeds we have got ‘’perl’’, ‘’cobol’’, ’’assembler’’, ‘’pascal’’, ‘’visual basic’’ as extracted entities.

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Structured classification with the averaged sum loss

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Keywords

structured classification; loss function; primal sub-gradient method; sequence labeling;

Summary

In this talk we discuss structured classifiers defined with the average sum loss and their influence to the results of sequence labelling problems. Instead of a standard hinge loss [1], which deals with a single structure from each example (the one with the highest score), the average sum loss [2] is defined over the set of structures inside each example.

Let us consider the problem of minimizing the regularized empirical risk over the set $\mathscr{D} = ((\boldsymbol{x}^n, \boldsymbol{y}^n))_{n=1}^N$

$$\min_{\mathbf{w}} \frac{\lambda}{2} \|\mathbf{w}\|^2 + \frac{1}{N} \sum_{n=1}^{N} \ell_n(\mathbf{w}), \tag{1}$$

where $\ell_n(\mathbf{w})$ represents a loss function on the nth example with parameters $\mathbf{w}$, and $\boldsymbol{y}^n \in \mathscr{Y}(\boldsymbol{x}^n)$ are the structures associated with the training example $\boldsymbol{x}^n$. We consider the hinge loss for structure $\boldsymbol{y}$ defined as

$$\ell(\mathbf{w}; (\boldsymbol{x}^n, \boldsymbol{y})) = \max\left(0, L(\boldsymbol{y}^n, \boldsymbol{y}) - \mathbf{w}^\mathsf{T} \Delta\mathbf{F}_n(\boldsymbol{y})\right),$$

where $L(\boldsymbol{y}^n, \boldsymbol{y})$ represents the cost of assigning structure $\boldsymbol{y}$ to example $\boldsymbol{x}^n$ instead of $\boldsymbol{y}^n$, and $\Delta\mathbf{F}_n(\boldsymbol{y}) = \mathbf{F}(\boldsymbol{x}^n, \boldsymbol{y}^n) - \mathbf{F}(\boldsymbol{x}^n, \boldsymbol{y})$, where $\mathbf{F}(\boldsymbol{x}, \boldsymbol{y})$ represents a global feature vector measuring the compatibility of $\boldsymbol{x}$ and $\boldsymbol{y}$. The average sum loss is defined as

$$\ell_n(\mathbf{w}) = \frac{1}{|\mathscr{Y}_{-n}|} \sum_{\boldsymbol{y} \in \mathscr{Y}_{-n}} \ell(\mathbf{w}; (\boldsymbol{x}^n, \boldsymbol{y})),$$

and it represents the expected hinge loss for structures inside the nth example, where $\mathscr{Y}_{-n} = \mathscr{Y}(\boldsymbol{x}^n) \setminus \boldsymbol{y}^n$.

With the efficient optimization in primal space [3, 2], the problem (1) can be optimized iteratively by traversing through examples and by choosing in each iteration a set of structures which will be included in the optimization inside each example.

The average sum loss allows us to include more information from each example and obtain better recognition results when we don't have enough training data. This approach is also useful when the existing model should be corrected online as a new example is presented.

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Nystrom views via the randomized SVD for semi supervised learning

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Keywords

Nystrom method; randomized SVD; multi-view regression; matrix approximation; kernel method

Summary

In this paper we investigated the semi-supervised kernel regression problem and proposed an algorithm based on an application of multi-view regression to the Nystrom views via the randomized SVD.

We assume that the input set contains n feature vectors and that only a small fraction of them are labeled. Authors in [2] proposed a learning algorithm that is composed of two main steps. In the first step from each feature vector two random feature vectors, called random views, are constructed based on a Nystrom method resulting in a two view data set. Two view data set means that for each item in a data set we have two vectors representing it. Complexity of view construction is $O(np^2 + p^3)$ where p is the number of randomly chosen feature vectors needed for Nystrom method and number p is arbitrarily chosen.

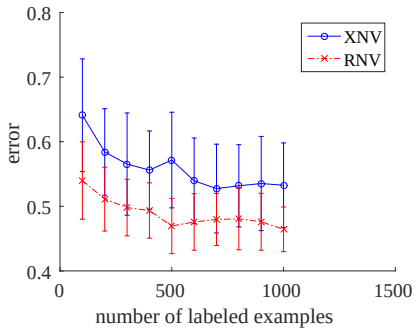
In the second step multi view regression via canonical correlation analysis is applied on the two view data set. CCA aims to find vectors such that projection of observed data onto those vectors results in the largest correlation between two sets. Finally linear regression penalized with a canonical norm is applied.

Nystrom method requires complete eigenvalue decomposition of a $p \times p$ submatrix with time complexity of $O(p^3)$. On one hand, larger p results in better approximation and on the other hand larger p results in slower algorithm. Therefore authors in [3] proposed the use of randomized SVD method for approximate decomposition of $p \times p$ submatrix.

We propose to change step 1 of algorithm from [2] using Nystrom method via the randomized SVD for construction of two random views. In short our algorithm goes as follows:

1. Select p randomly chosen feature vectors. Construct a new view from each vector based on a Nystrom method, where eigenvalue decomposition of a $p \times p$ submatrix is performed using a randomized SVD algorithm. Perform this part twice.
2. We perform a CCA on this two view data set.
3. Finally we apply linear regression penalized by a canonical norm.

We evaluated the performance of our algorithm (*RNV*) compared to the algorithm (labeled *XNV*) from [2] on real world data sets. Because of the limited space here we show results only on *sarcos* data sets. Our algorithm gave better results on this data set than *XNV* algorithm. For error we chose the mean squared error (MSE) normalized by the variance of the test output. We set the dimension of random feature vectors to be 10.



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Kalman filter training of Echo State Networks

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Keywords

Reservoir computing, Kalman filter, Echo state

Summary

Artificial Recurrent Neural Networks (RNN) are computational model of dynamic systems, in which connections between processing units can form cycles. These cycles endow RNN to develop a self-sustained temporal activation dynamics, even in the absence of the input signal.

Reservoir Computing (RC) networks represents relatively new approach to RNN design and training. The most common approach to Reservoir Computing are Echo State Networks (ESN), proposed by Herbert Jaeger [1, 2] and asynchronous Liquid State Machines (LSM) introduced by Wolfgang Maass [3]. ESN has been applied to various engineering problems, often outperforming other RNN architectures in dynamic system modelling tasks, while LSM (composed of biologically realistic spiking neurons) is popular as computational model in neuroscience.

The main characteristic of RC approach is that Recurrent Neural Network contains two distinct parts: a reservoir of processing units (often sparse and randomly connected) with fixed synaptic weights, and readout linear or nonlinear part, which combines the output of reservoir units to produce the output of the network.

Current input signal and previous output of the network are fed into a fixed reservoir. The dynamics of the reservoir maps these signals to a new space. Due to the fixed reservoir, the training is performed only on readout part of the network, which combines the output of the reservoir processing units to the desired output.

We have derived on line training algorithm for ESN with feedback connections from the output of the network to the reservoir (RESN), based on approximate recursive Bayesian estimator, extended Kalman filter. Along with the synaptic weights, algorithm estimates outputs of the reservoirs neurons. In this way algorithm, we named “Teacher Leading”, generalizes the technique known as “Teacher Forcing”, where instead of previous processing units outputs, true values of signal, if known, are used. On the contrary to the “Teacher Forcing”, which cannot be applied to hidden neurons, nor to training on noisy data (when the true value of a signal is not known) “Teacher Leading” uses the estimates obtained from Extended Kalman filter.

We give here comparison of results on Mackey Glass (MG) chaotic time series prediction, using ESN, without feedback connection from the output, trained by regularized Least Squares and Kalman filter and RESN, network with feedback connections, trained by “Teacher Leading” algorithm based on Extended Kalman Filter.

All networks were trained on 3000 samples, for 30 independent runs on different reservoirs. After the training, each network produced long term iterated prediction, by feeding back its output to the reservoir for next 1000 and 300 samples in the first and second example respectively. Normalized Root Mean Square Error is used to measure the difference between prediction and the original time series.

Teacher Leading algorithm has superior accuracy compared to other two algorithms, however, due its complexity of $O(n3)$, n being number of trainable parameters and reservoir units training time is much longer.

Table 1: nRMSE of long term prediction of MG17 ($\tau = 17$)

Algorithm	Mean (nRMSE)	Var (nRMSE)	Best (nRMSE)	Time[s]
ESN + LS	5.43e-1	9.04e-2	4.36e-2	2.62e-1
ESN + KF	3.64e-1	3.28e-2	3.14e-2	10.78
RESN + EKF	8.26e-2	9.1e-3	2.06e-3	154.15

Table 2. nRMSE of long term prediction of MG30 ($\tau = 30$)

Algorithm	Mean (nRMSE)	Var (nRMSE)	Best (nRMSE)	Time[s]
ESN + LS	4.55e-1	5.98e-2	1.4e-1	2.76e-1
ESN + KF	4.16e-1	3.06e-2	8.27e-2	10.47
RESN + EKF	1.99e-1	7.87e-3	6.33e-2	139.94

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Higher-order ZNN models for computing the matrix inverse

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Keywords

Zhang neural network; matrix inverse; convergence; time-varying complex matrix; iterative methods

Summary

An analogy between the scaled hyperpower family (SHPI family) of iterative methods for computing the matrix inverse and the discretized Zhang Neural Network (ZNN) models is presented. On the basis of the new-found analogy, the ZNN models corresponding to the hyperpower family of the convergence order p are denoted as the ZNN models of the order p. The implementation of the introduced ZNN models of the orders 2 and 3 in the Matlab Simulink is developed. For this purpose, we define a class of ZNN dynamic systems which represent continuous-time analogy of the scaled hyperpower iterative family for computing generalized inverses. The graphical editor, customizable block libraries and solvers available in the Matlab Simulink are used in the implementation of the proposed dynamic systems. Convergence properties as well as numerical behavior of the proposed ZNN models are investigated.

Our motivation arises from the discretization of the Zhang Neural Network (ZNN) model which was defined in [7]. It was assumed that the matrix A is a constant $n \times n$ matrix. Classic approach assumes usage of the matrix-valued Zhang function (ZF) of the form

$$E(X(t), t) := AX(t) - I \tag{1}$$

in the ZNN dynamic of the general form

$$\frac{\mathrm{d}E(X(t),t)}{\mathrm{d}t} = -\Gamma \mathcal{H}\left(E(X(t),t)\right), \tag{2}$$

where $\Gamma \in \mathbb{R}^{n\times n}$ is a positive-definite matrix used to scale the convergence rate and $\mathcal{H}(\cdot) : \mathbb{R}^{n\times n} \to \mathbb{R}^{n\times n}$ denotes an appropriate matrix-valued activation-function mapping. Since A is time-invariant, an application of the general pattern (2) on the Zhang error-monitoring function (1) after the choice $\Gamma = \gamma I$, $\gamma > 0$ and $\mathcal{H} = I$ leads to the following implicit ZNN dynamic equation:

$$A\dot{X}(t) = -\gamma\left(AX(t) - I\right). \tag{3}$$

The discretization of the continuous-time model (3) was performed by the Euler forward-difference rule

$$\dot{X}(t) \approx (X_{k+1} - X_k)/\tau,$$

where τ denotes the sampling time and $X_k = X(t = k\tau)$, $k = 1, 2, \ldots$. Then the discrete-time model of (3) is defined by

$$AX_{k+1} = AX_k - \beta\left(AX_k - I\right),$$

where $\beta = \tau\,\gamma > 0$ is the step size that should appropriately be selected. After the approximation of A^{-1} by X_k, the implicit discrete-time ZNN model can be rewritten as the scaled Newton iteration for computing outer inverses with prescribed range and null space, introduced in [2]:

$$\begin{aligned} X_{k+1} &= X_k - \beta X_k\left(AX_k - I\right) \\ &= (1+\beta)X_k - \beta X_k A X_k. \end{aligned} \tag{4}$$

Our continuous-time ZNN model is based on the error-monitoring function defined by

$$\begin{aligned} E(X(t),t) &:= I - AX(t) + \left(I - AX(t)\right)^2 \\ &= 2I - 3AX(t) + \left(AX(t)\right)^2. \end{aligned} \tag{5}$$

In view of (2), the Zhang error-monitoring function (5) leads to the following implicit dynamic equation

$$\begin{aligned} \dot{E}(X(t),t) &= -3A\dot{X}(t) + A\dot{X}(t)AX(t) + AX(t)A\dot{X}(t) \\ &= -\Gamma\mathcal{H}\left(2I - AX(t)\left(3I - AX(t)\right)\right). \end{aligned} \tag{6}$$

The expected convergence of $X(t)$ to A^{-1} approves the substitution $AX(t) = I$ in the left hand side of (6), which in the case $\Gamma = \gamma I$ leads to

$$\begin{aligned} A\dot{X}(t) &= \gamma\mathcal{H}\left(2I - AX(t)\left(3I - AX(t)\right)\right) \\ &= -\gamma\mathcal{H}\left(-\left(AX(t)\right)^2 + 3AX(t) - 2I\right), \end{aligned} \tag{7}$$

where $X(0)$ is appropriately defined initial point.

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In the linear case $\mathcal{H} = I$ the discretization based on the Euler forward-difference rule of the model (7) is defined by

$$AX_{k+1} = AX_k + \beta\left(2I - AX_k\left(3I - AX_k\right)\right),$$

where $\beta = \tau\,\gamma > 0$ is the step size. Since A is nonsingular, after the replacement of A^{-1} by X_k, the implicit discrete-time ZNN model for the usual matrix inversion can be stated as

$$X_{k+1} = X_k\left(I + \beta\left(2I - 3AX_k + (AX_k)^2\right)\right), \qquad (8)$$

i.e. in the form of the scaled hyperpower iterative method of the order 3. This method was proposed by Srivastava and Gupta in [3] for estimating the Moore-Penrose inverse.

Activation functions introduced in [1] will be exploited. It is assumed that two real matrices $A \in \mathbb{R}^{n\times m}$ and $B \in \mathbb{R}^{n\times m}$ are given. Additionally, let $\mathcal{F}(C)$ be an odd and monotonically increasing function element-wise applicable to elements of $C = (c_{kj}) \in \mathbb{R}^{n\times m}$ according to the rule $\mathcal{F}(C) = (f(c_{kj}))$, where $f(\cdot)$ is an odd and monotonically increasing function. For given matrices $A, B \in \mathbb{C}^{n\times n}$, $A \circ B$ denotes the Hadamard product of matrices $A = (a_{kj})$ and $B = (b_{kj})$, i.e., $A \circ B = (a_{kj}b_{kj})$.
The type I activation function is defined by

$$\mathcal{H}_1(A + \iota B) = \mathcal{F}(A) + \iota\mathcal{F}(B). \qquad (9)$$

The type II activation function is defined as

$$\mathcal{H}_2(A + \iota B) = \mathcal{F}(\Gamma) \circ \exp(\iota\Theta), \qquad (10)$$

where $\iota = \sqrt{-1}$ denotes the imaginary unit, $\Gamma = |A + \iota B| \in \mathbb{R}^{n\times n}$ and $\Theta = \Theta(A + \iota B) \in (-\pi, \pi]^{n\times n}$ denote element-wise modulus and the element-wise arguments, respectively, of $A + \iota B$.

Theorem 1. *Let the invertible complex matrix $A \in \mathbb{C}^{n\times n}$ be given. Then the state matrix $X(t) \in \mathbb{C}^{n\times m}$ of the complex neural network model* (7) *based on the activation functions $\mathcal{H}_1$ converges to the matrix inverse A^{-1}, and the solution is stable in the sense of Lyapunov.*

Theorem 2. *Let the invertible complex matrix $A \in \mathbb{C}^{n\times n}$ be given. Then the state matrix $X(t) \in \mathbb{C}^{n\times m}$ of the complex neural network model* (7) *based on the activation function $\mathcal{H}_2$ converges to the matrix inverse A^{-1}, and the solution is stable in the sense of the Lyapunov.*

Also, a hybrid method based on the combination of the ZNNNM and ZNNCM method is defined. The hybrid method starts using the ZNNCM method and then continues on the basis of the ZNNNM method. The starting point x_0 of the ZNNNM method is just the output of the ZNNCM method and the finishing time of the ZNNCM method is just the initial time of the ZNNNM method.
Numerical results and comparison of the ZNNCM, ZNNNM and the ZNNHM models among themselves and with the GNN model are presented.
For now, it is very difficult to determine or estimate the optimal value of the decisive time moment t_0. These investigations should be interesting topic for further research. In the current research, we recommend only heuristics and verification.

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