IPMU2020 LISBOA

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IPMU 2020
18th International Conference on Information Processing and Management of Uncertainty in Knowledge-Based Systems

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Program

Monday, June 15

15:40 – 16:00 **Opening session**

16:00 – 17:00 *Invited Talk: How Action Shapes Thought (Barbara Tversky)*

17:10 – 18:50 Parallel Section 1

SS2: Theoretical and Applied Aspects of Imprecise Probabilities, part I	Games & SS18: Discrete Models and Computational Intelligence	Real World Applications	Knowledge Processing and Creation
Page 11	*Page 14*	*Page 16*	*Page 18*

19:10 – 20:30 Parallel Section 2

SS2: Theoretical and Applied Aspects of Imprecise Probabilities, part II	XAI & SS13: Image Understanding and Explainable AI	SS10: Fuzzy Implication Functions	SS11: Soft Methods in Statistics and Data Analysis, part I
Page 23	*Page 25*	*Page 27*	*Page 29*

21:00 Welcome reception BYOD (bring your own drink)

Tuesday, June 16

14:30 – 15:30 Parallel Section 1

Image Processing	SS21: Formal Concept Analysis, Rough Sets, General Operators and Related Topics, part I	SS9: Computational Intelligence for Logistics and Transportation Problems	SS11: Soft Methods in Statistics and Data Analysis, part II
Page 33	*Page 35*	*Page 36*	*Page 38*

15:40 – 16:00 **Homage to Enrique Ruspini**

16:00 – 17:00 *Invited Talk: Average Jane, Where Art Thou? - Recent Avenues in Efficient Machine Learning under Subjectivity Uncertainty (Björn Schuller)*

17:10 – 18:50 Parallel Section 2

Decision making, preference & votes	SS5: Aggregation: Theory and Practice, part I	SS15: Mathematical Methods Towards Dealing with Uncertainty in Applied Sciences, part I	SS16: Statistical Image Processing and Analysis, with Applications in Neuroimaging
Page 41	*Page 43*	*Page 46*	*Page 48*

17:10 – 18:50 Parallel Section 1

SS2: Theoretical and Applied Aspects of Imprecise Probabilities, part III	SS5: Aggregation: Theory and Practice, part II	Temporal Data Processing	SS20: Mathematical Fuzzy Logic and Graded Reasoning Models, part I
Page 53	*Page 55*	*Page 57*	*Page 59*

Wednesday June 17

14:30 – 15:30 Parallel Section 1

SS19: Current Techniques to Model, Process and Describe Time Series	SS21: Formal Concept Analysis, Rough Sets, General Operators and Related Topics, part II	SS6: Aggregation: Pre-aggregation Functions and other Generalizations of Monotonicity	SS20: Mathematical Fuzzy Logic and Graded Reasoning Models, part II
Page 63	*Page 65*	*Page 66*	*Page 67*

16:00 – 17:00 *Invited Talk: From Eliza to Siri and beyond (Luísa Coheur)*

17:10 – 18:50 Parallel Section 2

SS7: Aggregation: Aggregation of Different Data Structures	SS15: Mathematical Methods Towards Dealing with Uncertainty in Applied Sciences, part II	Machine Learning, part I	Optimization and uncertainty
Page 69	*Page 71*	*Page 73*	*Page 76*

17:10 – 18:50 Parallel Section 1

SS5: Aggregation: Theory and Practice, part III	SS15: Mathematical Methods Towards Dealing with Uncertainty in Applied Sciences, part III	Text Analysis and Processing	SS17: Interval Uncertainty, part I
Page 81	*Page 82*	*Page 83*	*Page 86*

Thursday, June 18

14:30 – 15:30 Parallel Section 1

SS8: Fuzzy methods in Data Mining and Knowledge Discovery		SS9: Computational Intelligence for Logistics and Transportation Problems	SS17: Interval Uncertainty, part II
Page 89	*Page* **??**	*Page 91*	*Page 92*

15:40 – 16:00 **Best paper award**

16:00 – 17:00 *Invited Talk: Keynote Talk: Making Sense out of Activity Sensing in Eldercare (Jim Keller)*

17:10 – 18:50 Parallel Section 2

Foundations and Mathematics	SS3: Similarities in Artificial Intelligence	Machine Learning, part II	SS4: Belief Function Theory and its Applications, part I
Page 95	*Page 98*	*Page 100*	*Page 102*

17:10 – 18:50 Parallel Section 1

SS1: Fuzzy Interval Analysis	SS14: Fuzzy and Generalized Quantifier Theory	SS23: Computational Intelligence Methods in Information Modelling, Representation and Processing	SS4: Belief Function Theory and its Applications, part II
Page 107	*Page 109*	*Page 110*	*Page 112*

Invited Talks

Keynote Talk: How Action Shapes Thought

Barbara Tversky

Keynote Talk: Making Sense out of Activity Sensing in Eldercare

Jim Keller

From Eliza to Siri and beyond

Luísa Coheur

Since Eliza, the first chatbot ever, developed in the 60s, researchers try to make machines understand (or mimic the understanding) of Natural Language input. Some conversational agents target small talk, while others are more task-oriented. However, from the earliest rule-based systems to the recent data-driven approaches, although many paths were explored with more or less success, we are not there yet. Rule-based systems require much manual work; data-driven systems require a lot of data. Domain adaptation is (again) a current hot-topic. The possibility to add emotions to the conversational agents' responses, or to make their answers capture their "persona", are some popular research topics. This paper explains why the task of Natural Language Understanding is so complicated, detailing the linguistic phenomena that lead to the main challenges. Then, the long walk in this field is surveyed, from the earlier systems to the current trends.

Keywords: Natural Language Processing – Natural Language Understanding – Chatbots

Average Jane, Where Art Thou? - Recent Avenues in Efficient Machine Learning under Subjectivity Uncertainty

Björn Schuller

In machine learning tasks an actual 'ground truth' may not be available. Then, machines often have to rely on human labelling of data. This becomes challenging the more subjective the learning task is, as human agreement can be low. To cope with the resulting high uncertainty, one could train individual models reflecting a single human's opinion. However, this is not viable, if one aims at mirroring the general opinion of a hypothetical 'completely average person' – the 'average Jane'. Here, I summarise approaches to optimally learn efficiently in such a case. First, different strategies of reaching a single learning target from several labellers will be discussed. This includes varying labeller trustability and the case of time-continuous labels with potential dynamics. As human labelling is a labour-intensive endeavour, active and cooperative learning strategies can help reduce the number of labels needed. Next, sample informativeness can be exploited in teacher-based algorithms to additionally weigh data by certainty. In addition, multi-target learning of different labeller tracks in parallel and/or of the uncertainty can help improve the model robustness and provide an additional uncertainty measure. Cross-modal strategies to reduce uncertainty offer another view. From these and further recent strategies, I distil a number of future avenues to handle subjective uncertainty in machine learning. These comprise bigger, yet weakly labelled data processing basing amongst other on reinforcement learning, lifelong learning, and self-learning. Illustrative examples stem from the fields of Affective Computing and Digital Health – both notoriously marked by subjectivity uncertainty.

Keywords: Machine Learning – Uncertainty – Subjectivity – Active Learning – Cooperative Learning.

Monday, June 15 – Parallel Session 1

SS2: Theoretical and Applied Aspects of Imprecise Probabilities, part I

Imprecise Classification with Non-Parametric Predictive Inference

Serafín Moral-García, Carlos J. Mantas, Javier G. Castellano and Joaquin Abellán

In many situations, classifiers predict a set of states of a class variable because there is no information enough to point only one state. In the data mining area, this task is known as Imprecise Classification. Decision Trees that use imprecise probabilities, also known as Credal Decision Trees (CDTs), have been adapted to this field. The adaptation proposed so far uses the Imprecise Dirichlet Model (IDM), a mathematical model of imprecise probabilities that assumes prior knowledge about the data, depending strongly on a hyperparameter. This strong dependence is solved with the Non-Parametric Predictive Inference Model (NPI-M), also based on imprecise probabilities. This model does not make any prior assumption of the data and does not have parameters. In this work, we propose a new adaptation of CDTs to Imprecise Classification based on the NPI-M. An experimental study carried out in this research shows that the adaptation with NPI-M has an equivalent performance than the one obtained with the adaptation based on the IDM with the best choice of the hyperparameter. Consequently, since the NPI-M is a non-parametric approach, it is concluded that the NPI-M is more appropriated than the IDM to be applied to the adaptation of CDTs to Imprecise Classification.

Keywords: Imprecise Classification – Credal Decision Trees – IDM – NPI-M – imprece probabilities.

On the elicitation of an optimal outer approximation of a coherent lower probability

Enrique Miranda, Ignacio Montes and Paolo Vicig

The process of outer approximating a coherent lower probability by a more tractable model with additional properties, such as 2- or completely monotone capacities, may not have a unique solution. In this paper, we investigate whether a number of approaches may help in eliciting a unique outer approximation: minimising a number of distances with respect to the initial model, or maximising the specificity of the outer approximation. We apply these to 2- and completely monotone approximating lower probabilities, and also to possibility measures.

Keywords: Coherent lower probabilities – 2-monotonicity – Belief functions – Possibility measures – Specificity.

Binary Credal Classification under Sparsity Constraints

Tathagata Basu, Matthias Troffaes and Jochen Einbeck

Binary classification is a well known problem in statistics. Besides classical methods, several techniques such as the naive credal classifier (for categorical data) and imprecise logistic regression (for continuous data) have been proposed to handle sparse data. However, a convincing approach to the classification problem in high dimensional problems (i.e., when the number of attributes is larger than the number of observations) is yet to be explored in the context of imprecise probability. In this article, we propose a sensitivity analysis based on penalised logistic regression scheme that works as binary classifier for high dimensional cases. We use an approach based on a set of likelihood functions (i.e. an imprecise likelihood, if you like), that assigns a set of weights to the attributes, to ensure a robust selection of the important attributes, whilst training the model at the same time, all in one fell swoop. We do a sensitivity analysis on the weights of the penalty term resulting in a set of sparse constraints which helps to identify imprecision in the dataset.

Keywords: Classification – High dimensional data – Imprecise probability.

Cautious label-wise ranking with constraint satisfaction

Yonatan Carlos Carranza Alarcon, Soundouss Messoudi and Sébastien Destercke

Ranking problems are difficult to solve due to their combinatorial nature. One way to solve this issue is to adopt a decomposition scheme, splitting the initial difficult problem in many simpler problems. The predictions obtained from these simplified settings must then be combined into one single output, possibly resolving inconsistencies between the outputs. In this paper, we consider such an approach for the label ranking problem, where in addition we allow the predictive model to produce cautious inferences in the form of sets of rankings when it lacks information to produce reliable, precise predictions. More specifically, we propose to combine a rank-wise decomposition, in which every sub-problem becomes an ordinal classification one, with a constraint satisfaction problem (CSP) approach to verify the consistency of the predictions. Our experimental results indicate that our approach produces predictions with appropriately balanced reliability and precision, while remaining competitive with classical, precise approaches.

Keywords: Label ranking problem – Constraint satisfaction – Imprecise probabilities.

Approximating general kernels by extended fuzzy measures: application to filtering

Sébastien Destercke, Agnes Rico and Olivier Strauss

Convolution kernels are essential tools in signal processing: they are used to filter noisy signal, interpolate discrete signals, ... However, in a given application, it is often hard to select an optimal shape of the kernel. This is why, in practice, it may be useful to possess efficient tools to perform a robustness analysis, talking the form in our case of an imprecise convolution. When convolution kernels are positive, their formal equivalence with probability distributions allows one to use imprecise probability theory to achieve such an imprecise convolution. However, many kernels can have negative values, in which case the previous equivalence does not hold anymore. Yet, we show mathematically in this paper that, while the formal equivalence is lost, the computational tools used to describe sets of probabilities by intervals on the singletons still retain their key properties when used to approximate sets of (possibly) non-positive kernels. We then illustrate their use on a single application that consists of filtering a human electrocardiogram signal by using a low-pass filter whose order is imprecisely known. We show, in this experiment, that the proposed approach leads to tighter bounds than previously proposed approaches.

Keywords: Signal filtering – Probability intervals – Signed fuzzy measures – Interval-valued filtering

Games & SS18: Discrete Models and Computational Intelligence

From Truth Degree Comparison Games to Sequents-of-Relations Calculi for Gödel Logic

Christian Fermuller, Timo Lang and Alexandra Pavlova

We introduce a game for (extended) Gödel logic where the players' interaction stepwise reduces claims about the relative order of truth degrees of complex formulas to atomic truth comparison claims. Using the concept of disjunctive game states this semantic game is lifted to a provability game, where winning strategies correspond to proofs in a sequents-of-relations calculus.

OrdinalGraph-basedGames

Arij Azzabi, Nahla Ben Amor, Hélène Fargier and Régis Sabbadin

The graphical, hypergraphical and polymatrix games frameworks provide concise representations of non-cooperative normal-form games involving many agents. In these *graph-based* games, agents interact in simultaneous local subgames with the agents which are their neighbors in a graph. Recently, ordinal normal form games have been proposed as a framework for game theory where agents' utilities are ordinal. This paper presents the first definition of *Ordinal Graphical Games* (OGG), *Ordinal Hypergraphical Games* (OHG), and *Ordinal Polymatrix Games* (OPG). We show that, as for classical graph-based games, determining whether a pure NE exists is also NP-hard. We propose an original CSP model to decide their existence and compute them. Then, a polynomial-time algorithm to compute possibilistic mixed equilibria for graph-based games is proposed. Finally, the experimental study is dedicated to test our proposed solution concepts for ordinal graph-based games.
Keywords: Possibility theory, ordinal game theory, algorithms and complexity

Improvements on the Convergence and Stability of Fuzzy Grey Cognitive Maps

Istvan Harmati and Laszlo T. Koczy

Fuzzy grey cognitive maps (FGCMs) are extensions of fuzzy cognitive maps (FCMs), where the causal connections between the concepts are represented by so-called grey numbers. Just like in classical FCMs, the inference is determined by an iteration process, which may converge to an equilibrium point, but limit cycles or chaotic behaviour may also show up.

In this paper, based on network measures like in-degree, out-degree and connectivity, we provide new sufficient conditions for the existence and uniqueness of fixed points for FGCMs. Moreover, a tighter convergence condition is presented using the spectral radius of the modified weight matrix.

Keywords: Fuzzy cognitive map – Fuzzy grey cognitive map – Stability – Convergence – Equilibrium point

Group definition based on flow in community detection

María Barroso, Inmaculada Gutiérrez, Daniel Gómez, Javier Castro and Rosa Espínola

Community detection problems are one of the hottest disciplines in social network analysis. Nevertheless, most of the related algorithms are specific for non-directed networks, or are based on a density concept of group. In this paper, we deal with a new concept of community for directed networks that is based on the classical flow concept. A community is strong and cohesive if their members can communicate among them. With the aim of dealing with the identification of this new class of groups, in this work, we propose the use of fuzzy measures to represent the flow capacity of a group. We also provide a competitive community detection algorithm that focus on the identification of these new class of flow-based community.

Keywords: Directed Networks – Flow – Fuzzy Measures – Community Detection Problem – Louvain Algorithm.

Fuzzy Temporal Graphs and Sequence Modelling in Scheduling Problem

Margarita Knyazeva, Alexander Bozhenyuk and Uzay Kaymak

Processing sequential data and time-dependent data is a problem of constructing computational graph with a certain structure. A computational graph formalizes the structure of a set of computations including mapping temporal inputs and outputs. In this paper we apply graph theory and fuzzy interval representation of uncertain variables to indicate states of the temporal scheduling system. Descriptive model for temporal reasoning

on graph, sequence modelling and ordering of fuzzy inputs for scheduling problem is introduced.

Keywords: Fuzzy Sequence Modelling, Computational Graph, Fuzzy Graph, Fuzzy Temporal Intervals, Temporal Reasoning, State-Transition System

Real World Applications

On relevance of linguistic summaries - a case study from the agro-food domain

Anna Wilbik, Diego Barreto and Ge Backus

We present an application of linguistic summaries in the agro-food domain. We focus on the relevance aspect. Using the interviews we determine which linguistic summaries are useful and appropriate for target users (farmers). The user evaluation with a TAM survey indicates that linguistic summaries allow farmers to understand quickly the past performance of their pig barns.

Keywords: Linguistic summaries – Relevance – Case study – Computing with Words

Data-Driven Classifiers for Predicting Grass Growth in Northern Ireland: A Case Study

Orla McHugh, Jun Liu, Fiona Browne, Philip Jordan and Deborah McConnell

There are increasing pressures to combat climate change and improve sustainable land management. The agriculture industry is one of the most challenging areas for these changes, especially in Northern Ireland, as agriculture is one of the larger industries. Research has been carried out across the island of Ireland into methods of improving farm efficiency in multiple areas of farming, including livestock health, machinery improvements, and crop growth. Research has been carried out in this study into grass growth in the dairy farming sector, specifically within Northern Ireland. Grass growth prediction aims to inform farmers and policy makers in their decision-making process regarding sustainable land management in agriculture. The present work focuses on analysing and evaluating how data-driven classifiers can be used for grass growth prediction using the data related to soil content, weather, grass quality components etc. Four classifiers,

namely Decision Trees, Random Forest, Naïve Bayes, and Neural Networks, are chosen for this purpose. Classification results based on a real-world data set are analysed and compared to evaluate and illustrate the performance and robustness of the classifiers. The results indicate that it is difficult to declare a single classifier with the highest performance and robustness. Nevertheless, it indicates that tree classification methods are better suited to the data to be studied, as opposed to probabilistic methods and weighted methods, e.g., the naïve Bayes classifier obtained a predictive performance of 78

Keywords: Climate Change, Grass Growth Prediction, Data-driven Classifier

Forecasting Electricity Consumption in Residential Buildings for home Energy Management Systems

Karol Bot, Antonio Ruano and Maria Da Graça Ruano

Prediction of the energy consumption is a key aspect of home energy man-agement systems, whose aim is to increase the occupant's comfort while re-ducing the energy consumption. This work, employing three years measured data, uses radial basis function neural networks, designed using a multi-objective genetic algorithm (MOGA) framework, for the prediction of total electric power consumption, HVAC demand and other loads demand. The prediction horizon desired is 12 hours, using 15 minutes step ahead model, in a multi-step ahead fashion. To reduce the uncertainty, making use of the preferred set MOGA output, a model ensemble technique is proposed which achieves excellent forecast results, comparing additionally very fa-vorably with existing approaches.

Keywords: Home consumption forecasting, HVAC consumption forecasting, prediction methods, neural networks, multi-objective optimization, home energy management systems, ensemble modelling

Solving Dynamic Delivery Services using Ant Colony Optimization

Miguel Martins, Tiago Coito, Bernardo Firme, Joaquim Viegas, João Sousa, João Figueiredo and Susana Vieira

This article presents a model for courier services designed to guide a fleet of vehicles over a dynamic set of requests. Motivation for this problem comes from a real-world scenario in an ever-changing environment, where the time to solve such optimization problem is constrained instead of endlessly searching for the optimal solution. First, a hybrid method combining Ant Colony Optimization with Local Search is proposed,

which is used to solve a given static instance. Then, a framework to handle and adapt to dynamic changes over time is defined. A new method pairing nearest neighbourhood search with subtractive clustering is proposed to improve initial solutions and accelerate the convergence of the optimization algorithm. Overall, the proposed strategy presents good results for the dynamic environment and is suitable to be applied on real-world scenarios.

Keywords: Pickup delivery problem, ant colony optimization, local search, time windows, dynamic requests.

Acoustic feature selection with fuzzy clustering, self organizing maps and psychiatric assessments

Olga Kamińska, Katarzyna Kaczmarek-Majer and Olgierd Hryniewicz

Acoustic features about phone calls are promising markers for prediction of bipolar disorder episodes. Smartphones enable collection of voice signal on a daily basis, and thus, the amount of data available for analysis is quickly growing. At the same time, even though the collected data are crisp, there is a lot of imprecision related to the extraction of acoustic features, as well as to the assessment of patients' mental state. In this paper, we address this problem and perform an advanced approach to feature selection. We start from the recursive feature elimination, then two alternative approaches to clustering (fuzzy clustering and self organizing maps) are performed. Finally, taking advantage of the partially assumed labels about the state of a patient derived from psychiatric assessments, we calculate the degree of agreement between clusters and labels aiming at selection of most adequate subset of acoustic parameters. The proposed method is preliminary validated on the real-life data gathered from smartphones of bipolar disorder patients.

Keywords: Self organizing maps – Fuzzy C-Means – Recursive Feature Selection – Cluster Agreement – Bipolar Disorder Episode Prediction

Knowledge Processing and Creation

Concept Membership Modeling Using a Choquet Integral

Grégory Smits, Ronald R. Yager, Marie-Jeanne Lesot and Olivier Pivert

Imprecise and subjective concepts, as e.g. *promising students*, may be used within data mining tasks or database queries to faithfully describe data properties of interest. However, defining these concepts is a demanding task for the end-user. We thus provide a strategy, called CHOCOLATE, that only requires the user to give a tiny subset of data points that are representative of the concept he/she has in mind, and that infers a membership function from them. This function may then be used to retrieve, from the whole dataset, a ranked list of points that satisfy the concept of interest. CHOCOLATE relies on a Choquet integral to aggregate the relevance of individual attribute values among all the representative points as well as the representativity of sets of such attribute values. As a consequence, a valuable property of the proposed approach is that it is able to both capture properties shared by most of the user-selected representative data points as well as specific properties possessed by only one specific representative data point.

Keywords: Fuzzy concept, fuzzy measure, Choquet integral

Using Topic Information to Improve Non-Exact Keyword-Based Search for Mobile Applications

Eugénio Ribeiro, Ricardo Ribeiro, Fernando Batista and João Oliveira

Considering the wide offer of mobile applications available nowadays, effective search engines are imperative for an user to find applications that provide a specific desired functionality. Retrieval approaches that leverage topic similarity between queries and applications have shown promising results in previous studies. However, the search engines used by most app stores are based on keyword-matching and boosting. In this paper, we explore means to include topic information in such approaches, in order to improve their ability to retrieve relevant applications for non-exact queries, without impairing their computational performance. More specifically, we create topic models specialized on application descriptions and explore how the most relevant terms for each topic covered by an application can be used to complement the information provided by its description. Our experiments show that, although these topic keywords are not able to provide all the information of the topic model, they provide a sufficiently informative summary of the topics covered by the descriptions, leading to improved performance.

Keywords: Application search – Topic information – Non-exact queries.

A Graph Theory Approach to Fuzzy Rule Base Simplification

Caro Fuchs, Simone Spolaor, Marco S. Nobile and Uzay Kaymak

Fuzzy inference systems (FIS) gained popularity and found application in several fields of science over the last years, because they are more transparent and interpretable than other common (black-box) machine learning approaches. However, transparency is not automatically achieved when FIS are estimated from data, thus researchers are actively investigating methods to design interpretable FIS. Following this line of research, we propose a new approach for FIS simplification which leverages graph theory to identify and remove similar fuzzy sets from rule bases. We test our methodology on two data sets to show how this approach can be used to simplify the rule base without sacrificing accuracy.

Keywords: Fuzzy Logic – Takagi–Sugeno Fuzzy Model – Data-Driven Modeling– Open-Source Software – Python – Graph Theory.

MaTED: Metadata-assisted Twitter Event Detection System

Mourad Oussalah, Abhinay Pandya and Panos Kostakos

Due to its asynchronous message-sharing and real-time capabilities, Twitter offers a valuable opportunity to detect events in a timely manner. Existing approaches for event detection have mainly focused on building a temporal profile of named entities and detecting unusually large bursts in their usage to signify an event. We extend this line of research by incorporating external knowledge bases such as DBPedia, WordNet; and exploiting specific features of Twitter for efficient event detection. We show that our system utilizing temporal, social, and Twitter-specific features yields improvement in the precision, recall, and DERate on the benchmarked Events2012 corpus compared to the state-of-the-art approaches.

Keywords: Twitter – Event Detection – Dbpedia – Microblogging – Social Media

Image-based World-perceiving Knowledge Graph (WpKG) with Imprecision

Navid Rezaei, Marek Z. Reformat and Ronald R. Yager

Knowledge graphs are a data format that enables the representation of semantics. Most of the available graphs focus on the representation of facts, their features, and relations between them. However, from the point of view of possible applications of semantically rich data formats in intelligent, real-world scenarios, there is a need for knowledge graphs that describe contextual information regarding realistic and casual relations between items in the real world.

In this paper, we present a methodology of generating knowledge graphs addressing such a need. We call them *World-perceiving Knowledge Graphs – WpKG*. The process of their construction is based on analyzing images. We apply deep learning image processing methods to extract scene graphs. We combine these graphs, and process the obtained graph to determine importance of relations between items detected on the images. The generated WpKG is used as a basis for constructing possibility graphs. We illustrate the process and show some snippets of the generated knowledge and possibility graphs.

Keywords: Knowledge Graph – Deep Learning – Common Sense – Possibility Theory.

Monday, June 15 – Parallel Session 2

SS2: Theoretical and Applied Aspects of Imprecise Probabilities, part II

Metrical approach to measuring uncertainty

Andrey G. Bronevich and Igor N. Rozenberg

Many uncertainty measures can be generated by the corresponding divergences, like the Kullback-Leibler divergence generates the Shannon entropy. Divergences can evaluate the information gain obtained by knowing a posterior probability distribution w.r.t. a prior one, or the contradiction between them. Divergences can be also viewed as distances between probability distributions. In this paper, we consider divergences that satisfy a weak system of axioms. This system of axioms does not guaranty additivity of divergences and allows us to consider, for example, the L_α-metric on probability measures as a divergence. We show what kind of uncertainty measures can be generated by such divergences, and how these uncertainty measures can be extended to credal sets.

Keywords: uncertainty measures – divergences – credal sets.

Conditioning and Dilation with Coherent Nearly-Linear Models

Renato Pelessoni and Paolo Vicig

In previous work [**?**] we introduced Nearly-Linear (NL) models, a class of neighbourhood models obtaining upper/lower probabilities by means of a linear affine transformation (with barriers) of a given probability. NL models are partitioned into more subfamilies, some of which are coherent. One, that of the Vertical Barrier Models (VBM), includes known models, such as the Pari-Mutuel, the ε-contamination or the Total Variation model as special instances. In this paper we study conditioning of coherent NL models, obtaining formulae for their natural extension. We show that VBMs are stable after conditioning, i.e. return a conditional model that is still a VBM, and that this is true also for the special instances mentioned above but not in general for NL models. We then analyse dilation for coherent NL models, a phenomenon that makes our *ex-post* opinion on an event A, after conditioning it on any event in a partition of hypotheses, vaguer than our *ex-ante* opinion on A.

Keywords: Conditioning – Coherent imprecise probabilities – Nearly-Linear models – Dilation.

Learning Sets of Bayesian Networks

Andrés Cano, Manuel Gómez-Olmedo and Serafin Moral

This paper considers the problem of learning a generalized credal network (a set of Bayesian networks) from a dataset. It is based on using the BDEu score and computes all the networks with score above a predetermined factor of the optimal one. To avoid the problem of determining the equivalent sample size (ESS), the approach also considers the possibility of an undetermined ESS. Even if the final result is a set of Bayesian networks, the paper also studies the problem of selecting a single network with some alternative procedures. Finally, some preliminary experiments are carried out with three small networks.

Keywords: Generalized credal networks – Learning – Likelihood regions – Probabilistic graphical models.

A study of the set of probability measures compatible with comparative judgements

Alexander Erreygers and Enrique Miranda

We consider a set of comparative probability judgements over a finite possibility space and study the structure of the set of probability measures that are compatible with them. We relate the existence of some compatible probability measure to Walley's behavioural

theory of imprecise probabilities, and introduce a graphical representation that allows us to bound, and in some cases determine, the extreme points of the set of compatible measures. In doing this, we generalise some earlier work by Miranda and Destercke on elementary comparisons.

Keywords: Comparative probabilities – credal sets – lower previsions – sets of desirable gambles – extreme points.

XAI & SS13: Image Understanding and Explainable AI

Performance and Interpretability in Fuzzy Logic Systems – can we have both?

Direnc Pekaslan, Chao Chen, Christian Wagner and Jonathan M. Garibaldi

Fuzzy Logic Systems can provide a good level of interpretability and may provide a key building block as part of a growing interest in explainable AI. In practice, the level of interpretability of a given fuzzy logic system is dependent on how well its key components, namely, its rule base and its antecedent and consequent fuzzy sets are understood. The latter poses an interesting problem from an optimisation point of view – if we apply optimisation techniques to optimise the parameters of the fuzzy logic system, we may achieve better performance (e.g. prediction), however at the cost of poorer interpretability. In this paper, we build on recent work in non-singleton fuzzification which is designed to model noise and uncertainty 'where it arises', limiting any optimisation impact to the fuzzification stage. We explore the potential of such systems to deliver good performance in varying-noise environments by contrasting one example framework - ADONiS, with ANFIS, a traditional optimisation approach designed to tune all fuzzy sets. Within the context of time series prediction, we contrast the behaviour and performance of both approaches with a view to inform future research aimed at developing fuzzy logic systems designed to deliver both – high performance and high interpretability.

Keywords: Non-Singleton Fuzzy System – Interpretability – ADONiS – ANFIS – Parameter Tuning

Explaining the neural network: A case study to model the incidence of cervical cancer

Paulo Lisboa, Sandra Ortega and Ivan Olier

Neural networks are frequently applied to medical data. We describe how complex and imbalanced data can be modelled with simple but accurate neural networks that are transparent to the user. In the case of a data set on cervical cancer with 753 observations excluding, missing values, and 32 covariates, with a prevalence of 73 cases (9.69

The model achieves an AUROC of 0.621 CI [0.519,0.721] for predicting positive diagnosis with Schiller's test. This is comparable with the perfor-mance obtained by a deep learning network with an AUROC of 0.667 [1]. Instead of using all covariates, the Partial Response Network (PRN) in-volves just 2 variables, namely the number of years on Hormonal Contra-ceptives and the number of years using IUD, in a fully explained model. This is consistent with an additive non-linear statistical approach, the Sparse Additive Model [2] which estimates non-linear components in a lo-gistic regression classifier using the backfitting algorithm applied to an ANOVA functional expansion.

This paper shows how the PRN, applied to a challenging classification task, can provide insights into the influential variables, in this case corre-lated with incidence of cervical cancer, so reducing the number of unnecessary variables to be collected for screening. It does so by exploiting the effi-ciency of sparse statistical models to select features from an ANOVA de-composition of the MLP, in the process deriving a fully interpretable model

Keywords: Explainable Machine Learning, FATE, KDD, Medical Decision Support, Cervical Cancer

Transparency of classification systems for clinical decision support

Antoine Richard, Brice Mayag, François Talbot, Alexis Tsoukias and Yves Meinard

In collaboration with the Civil Hospitals of Lyon, we aim to develop a "transparent" classification system for medical purposes. To do so, we need clear definitions and operational criteria to determine what is a "transparent" classification system in our context. However, the term "transparency" is often left undefined in the literature, and there is a lack of operational criteria allowing to check whether a given algorithm deserves to be called "transparent" or not. Therefore, in this paper, we propose a definition of "transparency" for classification systems in medical contexts. We also propose several operational criteria to evaluate whether a classification system can be considered "transparent". We apply these operational criteria to evaluate the "transparency" of several well-known classification systems.

Information Fusion-2-Text: Explainable Aggregation via Linguistic Protoforms

Bryce Murray, Derek Anderson, Timothy Havens, Tim Wilkin and Anna Wilbik

Recent advancements and applications in artificial intelligence (AI) and machine learning (ML) have highlighted the need for explainable, interpretable, and actionable AI-ML. Most work is focused on explaining deep artificial neural networks, e.g., visual and image captioning. In recent work, we established a set of indices and processes for explainable AI (XAI) relative to information fusion. While informative, the result is information overload and domain expertise is required to understand the results. Herein, we explore the extraction of a reduced set of higher-level linguistic summaries to inform and improve communication with non-fusion experts. Our contribution is a proposed structure of a fusion summary and method to extract this information from a given set of indices. In order to demonstrate the usefulness of the proposed methodology, we provide a case study for using the fuzzy integral to combine a heterogeneous set of deep learners in remote sensing for object detection and land cover classification. This case study shows the potential of our approach to inform users about important trends and anomalies in the models, data and fusion results. This information is critical with respect to transparency, trustworthiness, and identifying limitations of fusion techniques, which may motivate future research and innovation.

Keywords: deep learning, machine learning, information fusion, information aggregation, fuzzy integral, explainable artificial intelligence, XAI, protoform, linguistic summary

SS10: Fuzzy Implication Functions

An Initial Study on Typical Hesitant (T,N)-Implication Functions

Mônica Lorea Matzenauer, Renata Reiser, Helida Santos, Jocivania Pinheiro and Benjamin Bedregal

In the theory of Hesitant Fuzzy Sets (HFS), the membership degree of an element is characterized by a membership function which always returns a fuzzy set. This approach enables one to express, for example, the hesitance of several experts in the process of de-

cision making based on multiple attributes and multiple criteria. In this work, we focus on the study of a class of implication functions for typical hesitant fuzzy sets (THFS). The novelty of our proposal lies on the fact that it is the first time that an admissible order is used to define operators on hesitant fuzzy setting. Thus, we introduce typical hesitant fuzzy negations, typical hesitant t-norms and typical hesitant implication functions considering an admissible order, which allows the comparison of typical hesitant fuzzy elements with different cardinalities.

Keywords: Hesitant Fuzzy Sets – Admissible Orders on THFS – Typical Hesitant Implication Functions – (T,N)-Implication Functions.

Is the invariance with respect to powers of a t-norm a restrictive property on fuzzy implication functions? The case of strict t-norms

Raquel Fernandez-Peralta, Sebastia Massanet and Arnau Mir

The invariance with respect to powers of a t-norm has emerged as an important property for fuzzy implication functions in approximate reasoning. Recently, those fuzzy implication functions satisfying this property where fully characterized leading to seemingly new families of these operators. In this paper, the additional properties of the family of fuzzy implication functions which are invariant with respect to powers of a strict t-norm are analyzed. In particular, properties such as the exchange principle, the law of importation with respect to a t-norm or the left neutrality principle, among others, can be fulfilled by some members of this family. This study allows to characterize the intersection of these operators with the most important families of fuzzy implication functions.

Keywords: Fuzzy implication function – Invariance – powers of t-norms – Exchange principle.

Some Remarks on Approximate Reasoning and Bandler-Kohout Subproduct

Katarzyna Miś and Michal Baczynski

In our contribution we give some remarks and conclusions regarding reasoning schemas used in approximate reasoning. Based on created computer tool for image customization we give some advices regarding FITA. Also, we show some facts regarding Bandler-Kohout subproduct and we present results for several inference schemas.

Keywords: Bandler-Kohout subproduct – Compositional Rule of Inference – Fuzzy implications – Fuzzy connectives.

Modus Ponens Tollens for RU-implications

Isabel Aguiló, Sebastià Massanet, Juan Vicente Riera and Daniel Ruiz-Aguilera

In fuzzy rules based systems, fuzzy implication functions are usually considered to model fuzzy conditionals and to perform forward and backward inferences. These processes are guaranteed by the fulfilment of the Modus Ponens and Modus Tollens properties by the fuzzy implication function with respect to the considered conjunction and fuzzy negation. In this paper, we investigate which residual implications derived from uninorms satisfy both Modus Ponens and Modus Tollens properties with respect to the same t-norm and a fuzzy negation simultaneously. The most usual classes of uninorms are considered and many solutions are obtained which allow to model the fuzzy conditionals in a fuzzy rules based systems (and perform backward and forward inferences) with a unique residual implication derived from a uninorm.

Keywords: Fuzzy implication Function – Modus Ponens – Modus Tollens – Uninorm.

SS11: Soft Methods in Statistics and Data Analysis, part I

Imprecise approaches to analysis of insurance portfolio with catastrophe bond

Maciej Romaniuk

In this paper, imprecise approaches to model the risk reserve process of an insurer's portfolio, which consists of a catastrophe bond and external help, and with a special penalty function in the case of a bankruptcy event, are presented. Apart from the general framework, two special cases, when parameters of the portfolio are described by L-R fuzzy numbers or shadowed sets, are discussed and compared. In a few examples based on the real-life data for these two types of impreciseness, some important characteristics of the portfolio, like the expected value and the probability of the ruin, are estimated, analysed and compared using the Monte Carlo simulations.

Keywords: Risk process – Fuzzy numbers – Shadowed sets – Insurance portfolio – Numerical simulations.

Random Steinhaus distances for robust syntax-based classification of partially inconsistent linguistic data

Laura Franzoi, Andrea Sgarro, Anca Dinu and Liviu P. Dinu

We use the Steinhaus transform of metric distances to deal with inconsistency in linguistic classification. We focus on data due to G. Longobardi's school: languages are represented through yes-no strings of length 53, each string position corresponding to a syntactic feature which can be present or absent. However, due to a complex network of logical implications which constrain features, some positions might be undefined (logically inconsistent). To take into account linguistic inconsistency, the distances we use are Steinhaus metric distances generalizing the normalized Hamming distance. To validate the robustness of classifications based on Longobardi's data we resort to randomized transforms. Experimental results are provided and commented upon.

Possibilistic Bounds for Granular Counting

Corrado Mencar

Uncertain data are observations that cannot be uniquely mapped to a referent. In the case of uncertainty due to incompleteness, possibility theory can be used as an appropriate model for processing such data. In particular, granular counting is a way to count data in presence of uncertainty represented by possibility distributions. Two algorithms were proposed in literature to compute granular counting: exact granular counting, with quadratic time complexity, and approximate granular counting, with linear time complexity. This paper extends approximate granular counting by computing bounds for exact granular count. In this way, the efficiency of approximate granular count is combined with certified bounds whose width can be adjusted in accordance to user needs.

Keywords: Granular Counting – Possibility Theory – Uncertain Data

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A fuzzy model for interval-valued time series modeling and application in exchange rate forecasting

Leandro Maciel, Rosangela Ballini and Fernando Gomide

Financial interval time series (ITS) is a time series whose value at each time step is an interval composed by the low and the high price of an asset. The low-high price range is related to the concept of volatility because it inherits intraday price variability. Accurate forecasting of price ranges is essential for derivative pricing, trading strategies, risk management, and portfolio allocation. This paper suggests a fuzzy rule-based approach to model and to forecast interval-valued time series. The model is a collection of functional fuzzy rules with affine consequents capable to express the nonlinear relationships encountered in interval-valued data. An application concerning one-step-ahead forecast of interval-valued EUR/USD exchange rate using actual data is also addressed. The forecast performance of the fuzzy rule-based model is compared to that of traditional econometric time series methods and alternative interval models employing statistical criteria for both, low and high exchange rate prices. The results show that fuzzy rule-based modeling approach developed in this paper outperforms the random walk, and other competitive approaches in out-of-sample interval-valued exchange rate forecasting.

Keywords: Interval-valued data; exchange rate forecast; fuzzy modeling

Tuesday, June 16 – Parallel Session 1

Image Processing

Thin Structures Segmentation Using Anisotropic Neighborhoods

Christophe Ribal, Nicolas Lermé and Sylvie Le Hégarat-Mascle

Bayesian and probabilistic models are widely used in image processing to handle noise due to various alteration phenomena. To benefit from the spatial information in a tractable way, Markov Random Fields (MRF) are often assumed with isotropic neighborhoods, that is however at the detriment of the preservation of thin structures. In this study, we aim at relaxing this assumption on stationarity and isotropy of the neighborhood shape in order to get a prior probability term that is relevant not only within the homogeneous areas but also close to object borders and within thin structures. To tackle the issue of neighborhood shape estimation, we propose to use tensor voting, that allows for the estimation of structure direction and saliency at various scales. We propose three main ways to derive anisotropic neighborhoods, namely shape-based, target-based and cardinal-based neighborhood. Then, having defined the neighborhood field, we introduce an energy that will be minimized using graph cuts, and illustrate the benefits of our approach against the use of isotropic neighborhoods in the applicative context of crack detection. First results on such a challenging problem are very encouraging.

Keywords: Thin structures – Segmentation – Anisotropic neighborhoods – Superpixels

– Graph cuts.

Dempster-Shafer Parzen-Rosenblatt Hidden Markov Fields for Multichannel Image Segmentation

Mohamed El Yazid Boudaren, Ali Hamache and Islam Debicha

Theory of evidence has been successfully used in many areas covering pattern recognition and image processing due to its effectiveness in both information fusion and reasoning under uncertainty. Such notoriety led to extension of many existing Bayesian tools such as hidden Markov models, extensively used for image segmentation. This paper falls under this category of frameworks and aims to propose a new hidden Markov field that better handles nonGaussian forms of noise, designed for multichannel image segmentation. To this end, we use a recent kernel smoothing- based noise density estimation combined with a genuine approach of mass determination from data. The proposed model is validated on sampled and real remote sensing images and the results obtained outperform those produced by conventional hidden Markov fields.

Keywords: Data classification, Dempster-Shafer Theory, Hidden Markov Field, Multichannel image segmentation.

Automatic detection of symmetry in dermoscopic images based on shape and texture

Vincent Toureau, Pedro Bibiloni, Lidia Talavera-Martínez and Manuel González-Hidalgo

In this paper we present computational methods to detect the symmetry in dermoscopic images of skin lesions. Skin lesions are assessed by dermatologists based on a number of factors. In the literature, the asymmetry of lesions appears recurrently since it may indicate irregular growth. We aim at developing an automatic algorithm that can detect symmetry in skin lesions, as well as indicating the axes of symmetry. We tackle this task based on skin lesions' shape, based on their color and texture, and based on their combination. To do so, we consider symmetry axes through the center of mass, random forests classifiers to aggregate across different orientations, and a purposely-built dataset to compare textures that are specific of dermoscopic imagery. We obtain 84-88% accuracy in comparison with samples manually labeled as having either 1-axis symmetry, 2-axes symmetry or as being asymmetric. Besides its diagnostic value, the symmetry of a lesion also explains the reasons that might support such diagnosis. Our algorithm does

so by indicating how many axes of symmetry were found, and by explicitly computing them.

Keywords: dermoscopic images– skin lesion – computational methods – symmetry detection– shape – texture – color– machine learning – random forest

SS21: Formal Concept Analysis, Rough Sets, General Operators and Related Topics, part I

Towards a logic-based view of some approaches to classification tasks

Didier Dubois and Henri Prade

This paper is a plea for revisiting various existing approaches to the handling of data, for classification purposes, based on a set-theoretic view, such as version space learning, formal concept analysis, or analogical proportion-based inference, which rely on different paradigms and motivations and have been developed separately. The paper also exploits the notion of conditional object as a proper tool for modeling if-then rules. It also advocates possibility theory for handling uncertainty in such settings. It is a first, and preliminary, step towards a unified view of what these approaches contribute to machine learning.

Keywords: data, classification, version space, conditional object, if-then rule, analogical proportion, formal concept analysis, possibility theory, possibilistic logic, bipolarity, uncertainty

Fuzzy relatinal mathematical morphology: erosion and dilation

Alexander Sostak, Ingrida Uljane and Patrik Eklund

In the recent years, the subject if fuzzy mathematical morphology entered the field of interest of many researchers. In our recent paper [**?**], we have have developed the basis of the (unstructured) L-fuzzy relation mathematical morphology where L is a quantale. In this paper we extend it to the structured case. We introduce structured L-fuzzy relational erosion and dilation operators, study their basic properties, show that under some

conditions these operators are dual and form an adjunction pair. Basing on the topological interpretation of these operators, we introduce the category of L-fuzzy relational morphological spaces and their continuous transformations.

Keywords: L-fuzzy relational erosion, L-fuzzy relational dilation, L-fuzzy relational morphological spaces, duality, adjointness, continuous transformations

Isotone L-Fuzzy Formal Concept Analysis and L-valued Fuzzy Measure and Integral

Ondrej Kridlo

The main idea of the paper is to generalize the concept of lattice valued fuzzy measures and integrals for data from complete residuated lattice where double negation law holds and then to show their relationship to isotone $\mathcal{L}$-fuzzy concept forming operators.

Keywords: Fuzzy measure – Fuzzy integral – Formal concept analysis.

SS9: Computational Intelligence for Logistics and Transportation Problems

A Genetic Approach to the Job Shop Scheduling Problem with Interval Uncertainty

Hernán Díaz, Inés González-Rodríguez, Juan José Palacios, Irene Díaz and Camino R. Vela

In this paper we tackle a variant of the job shop scheduling problem where task durations are uncertain and only an interval of possible values for each task duration is known. We propose a genetic algorithm to minimise the schedule's makespan that takes into account the problem's uncertainty during the search process. The behaviour of the algorithm is experimentally evaluated and compared with other state-of-the-art algorithms. Further analysis in terms of solution robustness proves the advantage of taking into account interval uncertainty during the search process with respect to considering only the expected processing times and solving the problem's crisp counterpart. This robustness analysis also illustrates the relevance of the interval ranking method used to compare schedules during the search.

Keywords: Job shop scheduling – Interval processing time – Genetic algorithms – Robustness

A Fuzzy Goal Programming Approach To Fully Fuzzy Linear Regression

Boris Pérez-Cañedo, Alejandro Rosete, José Luis Verdegay and Eduardo René Concepción-Morales

Traditional linear regression analysis aims at finding a linear functional relationship between predictor and response variables based on available data of a given system, and, when this relationship is found, it is used to predict the future behaviour of the system. The difference between the observed and predicted data is supposed to be due to measurement errors. In fuzzy linear regression, on the other hand, this difference is supposed to be mainly due to the indefiniteness of the system. In this paper, we assume that predictor and response variables are LR-type fuzzy numbers, and so are all regression coefficients; this is known as fully fuzzy linear regression (FFLR) problem. We transform the FFLR problem into a fully fuzzy multiobjective linear programming (FFMOLP) problem. Two fuzzy goal programming methods based on linear and Chebyshev scalarisations are proposed to solve the FFMOLP problem. The proposed methods are compared with a recently published method and show promising results.

Keywords: fully fuzzy linear regression – fully fuzzy multiobjective linear programming – fuzzy goal programming – linear scalarisation – Chebyshev scalarisation.

Planning Wi-Fi access points activation in Havana City: proposal and preliminary results

Cynthia Porras Nodarse, Jenny Fajardo Calderín, Alejandro Rosete Súarez and David A. Pelta

The availability of Wi-Fi connection points or hotspots in places such as parks, transport stations, libraries, and so on is one of the key aspects to allow people the usage of Internet resources (to study, work or meet). This is even more important in Central America and Caribbean countries where the deployment of huge cost infrastructure (like optical fiber) to provide Internet access at home is not envisaged neither in the short or mid term. And this is clearly the case in Havana, Cuba.

This contribution presents the problem of planning the Wi-Fi access points activation, where each point can have different signal power levels and availability along the time.

Due to power consumption constraints, it is impossible to have all the points activated simultaneously with maximum signal strength.

The problem is modelled as a dynamic maximal covering location one with facility types and time dependant availability. A metaheuristic approach is used to solve the problem by using an Algorithm portfolio and examples on how solutions can be analyzed (beyond the coverage provided) are shown.

Keywords: signal levels – Wi-Fi access points.

SS11: Soft Methods in Statistics and Data Analysis, part II

A method to generate soft reference data for topic identication

Daniel Vélez, Guillermo Villarino Martínez, J. Tinguaro Rodríguez and Daniel Gomez

Text mining and topic identification models are becoming increasingly relevant to extract value from the huge amount of unstructured textual information that companies obtain from their users and clients nowadays. Soft approaches to these problems are also gaining relevance, as in some contexts it may be unrealistic to assume that any document has to be associated to a single topic without any further consideration of the involved uncertainties. However, there is an almost total lack of reference documents allowing a proper assessment of the performance of soft classifiers in such soft topic identification tasks. To address this lack, in this paper a method is proposed that generates topic identification reference documents with a soft but objective nature, and which proceeds by combining, in random but known proportions, phrases of existing documents dealing with different topics. We also provide a computational study illustrating the application of the proposed method on a well-known benchmark for topic identification, as well as showing the possibility of carrying out an informative evaluation of soft classifiers in the context of soft topic identification.

Keywords: Soft classification – Text mining – Topic identification.

SK-MOEFS: A Library in Python for Designing Accurate and Explainable Fuzzy Models

Gionatan Gallo, Vincenzo Ferrari, Francesco Marcelloni and Pietro Ducange

Recently, the explainability of Artificial Intelligence (AI) models and algorithms is becoming an important requirement in real-world applications. Indeed, although AI allows us to address and solve very difficult and complicated problems, AI-based tools act as a black box and, usually, do not explain how/why/when a specific decision has been taken. Among AI models, Fuzzy Rule-Based Systems (FRBSs) are recognized world-wide as transparent and interpretable tools: they can provide explanations in terms of linguistic rules. Moreover, FRBSs may achieve accuracy comparable to those achieved by less transparent models, such as neural networks and statistical models. In this work, we introduce SK-MOEFS (acronym of SciKit-Multi Objective Evolutionary Fuzzy System), a new Python library that allows the user to easily and quickly design FRBSs, employing Multi-Objective Evolutionary Algorithms. Indeed, a set of FRBSs, characterized by different trade-offs between their accuracy and their explainability, can be generated by SK-MOEFS. The user, then, will be able to select the most suitable model for his/her specific application.

Keywords: Explainable Artificial Intelligence – Multi-objective Evolutionary Algorithms – Fuzzy Rule-Based Systems – Python – Scikit-Learn.

Two-Sample Dispersion Problem for Fuzzy Data

Przemyslaw Grzegorzewski

The problem of comparing variability of two populations with fuzzy data is considered. A new permutation two-sample test for dispersion based on fuzzy random variables is proposed. A case-study illustrating the applicability of the suggested testing procedure is also presented.

Keywords: Fuzzy data – Fuzzy number – Fuzzy random variable – Permutation test – Test for dispersion – Test for scale

Tuesday, June 16 – Parallel Session 2

Decision making, preference & votes

Generalized Weak Transitivity of Preference

Thomas A. Runkler

Decision making processes are often based on (pairwise) preference relations. An important property of preference relations is transitivity. Many types of transitivity have been proposed in the literature, such as max–min and max–max transitivity, restricted max–min and max–max transitivity, additive and multiplicative transitivity, or Łukasiewicz transitivity. This paper focuses on weak transitivity. Weak transitivity has been defined for additive preference relations. We extend this definition to multiplicative preference relations and further introduce a generalized version called generalized weak transitivity. We show that for reciprocal additive and multiplicative preference relations weak transitivity is equivalent to generalized weak transitivity, and we also illustrate generalized weak transitivity for preference relations that are neither additive nor multiplicative. Finally, we show how a total order (ranking of the options) can be constructed for any generalized weak transitive preference relation.

Keywords: preference relations, weak transitivity, decision making

Investigation of Ranking Methods within the Military Value of Information (VoI) Problem Domain

Behrooz Etesamipour and Robert J. Hammell II

Determining the relative importance among vast amounts of individual pieces of information is a challenge in the military environment. By aggregating various military intelligence experts' knowledge, decision support tools can be created. A next step in the continuing research in this area is to investigate the use of three prominent ranking methods for aggregating opinions of military intelligence analysts with respect to the Value of Information (VoI) problem domain. This paper offers discussion about ongoing VoI research and demonstrates outcomes from a military-related experiment using Borda count, Condorcet voting, and Instant-runoff voting (IRV) methods as ranking aggregation models. These ranking methods are compared to the "ground truth" as generated by the current fuzzy-based VoI prototype system. The results by incorporating the ranking models on the experiment's data demonstrate the efficacy of these methods in aggregating Subject Matter Expert (SME) opinions and clearly demonstrate the "wisdom of the crowd" effect. Implications related to ongoing VoI research are discussed along with future research plans.

Keywords: value of information, decision support, information aggregation, Borda count, Condorcet voting, Instant-runoff voting, rank aggregation

Combining Multi-Agent Systems and Subjective Logic to Develop Decision Support Systems

Cesar Gonzalez Fernandez, Javier Cabezas Givica, Alberto Fernandez and Isaac Martin de Diego

Nowadays, the rise of the interconnected computer networks and the increase of processed data have led to producing distributed systems. These systems usually separate multiple tasks into other simpler with the goal of maintaining efficiency. This paradigm has been observed for a long time in different animal organisations as insect colonies and fish shoals. For this reason, distributed systems that emulate the biological rules that govern their collective behaviour have been developed. *Multi-Agent Systems* (MAS) have shown their ability to address this issue. This paper proposes *Ant Colony based Architecture with Subjective Logic* (ACA-SL). It is a bio-inspired model based on ant colony structures. It makes use of MAS to distribute tasks and *Subjective Logic* (SL) to produce *Decision Support Systems* (DSS) according to the combination of individual opinions. A system implementation based on the proposed architecture has been generated to illus-

trate the viability of the proposal. The proposed architecture is intended to be the starting point for developing systems that solve a variety of problems.

Keywords: Multi-agent system – Subjective logic – Bio-inspired system – Distributed organisation – Decision Support system

Decision under ignorance: a comparison of existing criteria

Zoé Krug, Romain Guillaume and Olga Battaïa

In this study, we compare the behavior of classic Hurwicz criterion with three more recent criteria τ-anchor, R^* and R_*. This evaluation is realized on linear optimization problems with uncertain costs coefficients taking into account the risk aversion of the decision maker. The uncertainty is represented by a scenario set.

Multi-agent systems and voting: how similar are voting procedures

Janusz Kacprzyk, Jose M. Merigo, Hannu Nurmi and Slawomir Zadrozny

We consider the problem of the evaluation of similarity of voting procedures which are crucial in voting, social choice and related fields. We extend our approach proposed in our former works and compare the voting procedures against some well established and intuitively appealing criteria, and using the number of criteria satisfied as a point of departure for analysis. We also indicate potential of this approach for extending the setting to a fuzzy setting in which the criteria can be satisfied to a degree, and to include a distance based analysis. A possibility to use elements of computational social choice is also indicated.

Keywords: voting, social choice, voting procedure, similarity, binary pattern

SS5: Aggregation: Theory and Practice, part I

A note on aggregation of intuitionistic values

Anna Kolesárová and Radko Mesiar

Atanassov's intuitionistic fuzzy set theory is based on the lattice L^* of intuitionistic values and their aggregation. There are lots of works dealing with this topic, but mostly considering some particular cases. In this contribution, we offer a rather general view on aggregation of intuitionistic values with transparent proofs of several properties which significantly shorten the related proofs for particular cases known from the literature.

Keywords: Aggregation function, intuitionistic values, representable aggregation function, t-norm, t-conorm

BIOWA operators

Andrea Stupnanova and Lesheng Jin

Based on bi-capacities and related Choquet integral introduced by Grabisch and Labreuche, a new generalization of OWA operators, namely BIOWA operators are introduced. Our approach is exemplified by several examples. Bi-capacities leading to the standard Yager's OWA operators on real line are completely characterized.

Keywords: Aggregation function, Bi-capacity, Choquet integral, OWA operator.

On compatibility of two approaches to generalization of the Lovász extension formula

Lubomíra Horanská

We present a method of generalization of the Lovász extension formula combining two known approaches - the first of them based on the replacement of the product operator by some suitable binary function F and the second one based on the replacement of the minimum operator by a suitable aggregation function A. We propose generalization by simultaneous replacement of both product and minimum operators and investigate pairs (F, A) yielding an aggregation function for all capacities.

Keywords: Aggregation function – Choquet integral – Capacity – Möbius transform.

The Formalization of Asymmetry in Disjunctive Evaluation

Miroslav Hudec and Radko Mesiar

The main property of disjunction is substitutability, i.e., the fully satisfied predicate substitutes the rejected one. But, in many real–world cases disjunction is expressed as the fusion of full and optional alternatives, which is expressed as *OR ELSE* connective. Generally, this logical connective provides a solution lower than or equal to the *MAX* operator, and higher than or equal to the projection of the full alternative, i.e., the solution does not go below any averaging function and above *MAX* function. Therefore, the optional alternative does not influence the solution when it is satisfied with a degree lower than the degree of full alternative. In this work, we propose further generalization by other disjunctive functions in order to allow upward reinforcement of asymmetric disjunction. Finally, the obtained results are illustrated and discussed.

Keywords: Asymmetric disjunction – Averaging functions – Probabilistic sum – Łukasiewicz t–conorm – Generalization – Upward reinforcement.

Fuzzy inference system as an aggregation operator - Application to the design of a soil chemical quality index

Denys Yohana Mora-Herrera, Serge Guillaume, Didier Snoeck and Orlando Zuniga Escobar

Fuzzy logic is widely used in linguistic modeling. In this work, fuzzy logic is used in a multicriteria decision making framework in two different ways. First, fuzzy sets are used to model an expert preference relation for each of the individual information sources to turn raw data into satisfaction degrees. Second, fuzzy rules are used to model the interaction between sources to aggregate the individual degrees into a global score. The whole framework is implemented as an open source software called *GeoFIS*. The potential of the method is illustrated using an agronomic case study to design a soil chemical quality index from expert knowledge for cacao production systems. The data come from three municipalities of Tolima department in Colombia. The output inferred by the fuzzy inference system was used as a target to learn the weights of classical numerical aggregation operators. Only the *Choquet Integral* proved to have a similar modeling ability, but the weights would have been difficult to set from expert knowledge without learning.

Keywords: Fusion – Multicriteria – Preference – Decision.

SS15: Mathematical Methods Towards Dealing with Uncertainty in Applied Sciences, part I

On the relationship among relational categories of fuzzy topological structures

Jiří Močkoř

Relational variants of categories of Čech closure or interior L-valued operators, categories of L-fuzzy pretopological and L-fuzzy co-pretopological operators, category of L-valued fuzzy relation, categories of upper and lower F-transforms and the category of spaces with fuzzy partitions are introduced. The existence of relationships defined by functors among these categories are investigated and a key role of a relational category of spaces with fuzzy partitions is described.

Interactive Fuzzy Fractional Differential Equation: Application on HIV Dynamics

Vinícius Wasques, Beatriz Laiate, Francielle Santo Pedro, Estevão Esmi and Laécio C. Barros

This work presents an application of interactive fuzzy fractional differential equation, with Caputo derivative, to an HIV model for seropositive individuals under antiretroviral treatment. The initial condition of the model is given by a fuzzy number and the differentiability is given by a fuzzy interactive derivative. A discussion about the model considering these notions are presented. Finally, a numerical solution to the problem is provided, in order to illustrate the results.

Keywords: Fuzzy fractional differential equation. Interactive arithmetic. F-correlated fuzzy process. HIV dynamics.

HIV Dynamics under Antiretroviral Treatment with Interactivity

Beatriz Laiate, Francielle Santo Pedro, Estevão Esmi and Laécio C. Barros

This manuscript presents a model for HIV dynamics of seropositive individuals under antiretroviral treatment described from fuzzy set theory by two different approaches considering interactivity: differential equation with interactive derivative and differential equation with Fréchet derivative. It also establishes an identity between interactive derivative and fuzzy Fréchet derivative. With this identity, we establish when the solutions of the two differential equations coincide. Lastly, we present biological interpretations for both cases.

Keywords: HIV – Antiretroviral Treatment – Fuzzy Interactive Differential Equation – Fréchet Derivative – Fuzzy Interactive Derivative.

On categories of L-fuzzifying approximation spaces, L-fuzzifying pretopological spaces and L-fuzzifying closure spaces

Anand Pratap Singh and Irina Perfilieva

This paper investigates the essential connections among several categories with a weaker structure than that of L-fuzzifying topology, namely category of L-fuzzifying approximation spaces based on reflexive L-fuzzy relations, category of L-fuzzifying pretopological spaces and category of L-fuzzifying interior (closure) spaces. The interrelations among these structures are established in categorical setup.

Keywords: L-fuzzifying approximation space – L-fuzzifying pretopological space – Čech L-fuzzifying interior (closure) spaces – Galois connection

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Measure of lattice-valued direct F-transforms and its topological interpretations

Anand Pratap Singh and Irina Perfilieva

The goal is to introduce and study the measure of quality of approximation of a given fuzzy set by its lattice-valued F-transform. Further, we show that this measure is connected with an Alexandroff LM-fuzzy topological (co-topological) spaces. Finally, we discuss the categorical relationship between the defined structures.

Keywords: M-valued partition – direct F-transforms – fuzzy inclusion measure – LM-fuzzy (co)topology – ditopology.

SS16: Statistical Image Processing and Analysis, with Applications in Neuroimaging

High Dimensional Bayesian Regularization in Regressions Involving Symmetric Tensors

Rajarshi Guhaniyogi

This article develops a regression framework with a symmetric tensor response and vector predictors. The existing literature involving symmetric tensor response and vector predictors proceeds by vectorizing the tensor response to a multivariate vector, thus ignoring the structural information in the tensor. A few recent approaches have proposed novel regression frameworks exploiting the structure of the symmetric tensor and assume symmetric tensor coefficients corresponding to scalar predictors to be low-rank. Although low-rank constraint on coefficient tensors are computationally efficient, they might appear to be restrictive in some real data applications. Motivated by this, we propose a novel class of regularization or shrinkage priors for the symmetric tensor coefficients. Our modeling framework a-priori expresses a symmetric tensor coefficient as sum of low rank and sparse structures, with both these structures being suitably regularized using Bayesian regularization techniques. The proposed framework allows identification of tensor nodes significantly influenced by each scalar predictor. Our framework is implemented using an efficient Markov Chain Monte Carlo algorithm. Empirical results in simulation studies show competitive performance of the proposed approach over its competitors.

Keywords: Low-rank Structure – Symmetric Tensor Predictor – Shrinkage Prior – Spike and Slab Prior.

A Publicly Available, High Resolution, Unbiased CT Brain Template

John Muschelli and John Muschelli

Clinical imaging relies heavily on X-ray computed tomography (CT) scans for diagnosis and prognosis. Many research applications aim to perform population-level analyses, which require images to be put in the same space, usually defined by a population average, also known as a template. We present an open-source, publicly available, high-resolution CT template. With this template, we provide voxel-wise standard deviation and median images, a basic segmentation of the cerebrospinal fluid spaces, in-

cluding the ventricles, and a coarse whole brain labeling. This template can be used for spatial normalization of CT scans and research applications, including deep learning. The template was created using an anatomically-unbiased template creation procedure, but is still limited by the population it was derived from, an open CT data set without demographic information. The template and derived images are available at https://github.com/muschellij2/high_res_ct_template.

Keywords: CT imaging and CT Template and Brain Template and Computed Tomography

Statistical methods for processing neuroimaging data from two different sites with a Down syndrome population application

Davneet Minhas, Zixi Yang, John Muschelli, Charles Laymon, Joseph Mettenburg, Matthew Zammit, Sterling Johnson, Chester Mathis, Ann Cohen, Benjamin Handen, William Klunk, Ciprian Crainiceanu, Bradley Christian and Dana Tudorascu

Harmonization of magnetic resonance imaging (MRI) and positron emission tomography (PET) scans from multi-scanner and multi-site studies presents a challenging problem. We applied the Removal of Artificial Voxel Effect by Linear regression (RAVEL) method to normalize T1-MRI intensities collected on two different scanners across two different sites as part of the Neurodegeneration in Aging Down syndrome (NiAD) study. The effects on FreeSurfer regional cortical thickness and volume outcome measures, in addition to FreeSurfer-based regional quantification of amyloid PET standardized uptake value ratio (SUVR) outcomes, were evaluated. A neuroradiologist visually assessed the accuracy of FreeSurfer hippocampus segmentations with and without the application of RAVEL. Quantitative results demonstrated that the application of RAVEL intensity normalization prior to running FreeSurfer significantly impacted both FreeSurfer volume and cortical thickness outcome measures. Visual assessment demonstrated that the application of RAVEL significantly improved FreeSurfer hippocampal segmentation accuracy. The RAVEL intensity normalization had little impact on PET SUVR measures.

Keywords: Harmonization, MRI, PET

Bayesian image analysis in Fourier space using data-driven priors (DD-BIFS)

John Kornak, Ross Boylan, Karl Young, Amy Wolf, Yann Cobigo and Howard Rosen

Statistical image analysis is an extensive field that includes problems such as noise-

reduction, de-blurring, feature enhancement, and object detection/identification, to name a few. Bayesian image analysis can improve image quality, by balancing a priori expectations of image characteristics, with a model for the noise process via Bayes Theorem. We have previously given a reformulation of the conventional Bayesian image analysis paradigm in Fourier space, i.e. the prior distribution (the prior) and likelihood are given in terms of spatial frequency signals. By specifying the Bayesian model in Fourier space, spatially correlated priors, that are relatively difficult to model and compute in conventional image space, can be efficiently modeled as a set of independent processes across Fourier space. The originally inter-correlated and high-dimensional problem in image space is thereby broken down into a series of (trivially parallelizable) independent one-dimensional problems. In this paper we adapt this Fourier space process into a data-driven framework in which the Fourier space priors are built empirically from a database of images and then used to enhance future images. We will describe the data-driven Bayesian image analysis in Fourier space (DD-BIFS) modeling approach, illustrate it's computational efficiency and speed. Finally, we give specific applications of DD-BIFS to improve the quality of arterial-spin-labeling (ASL) perfusion images via a database of human brain positron emission tomography (PET) images.

Keywords: Bayesian image analysis – data-driven priors – Fourier space.

Covariate-Adjusted Hybrid Principal Components Analysis

Aaron Scheffler, Abigail Dickinson, Charlotte DiStefano, Shafali Jeste and Damla Senturk

Electroencephalography (EEG) studies produce region-referenced functional data in the form of EEG signals recorded across electrodes on the scalp. The high-dimensional data capture underlying neural dynamics and it is of clinical interest to model differences in neurodevelopmental trajectories between diagnostic groups, for example typically developing (TD) children and children with autism spectrum disorder (ASD). In such cases, valid group-level inference requires characterization of the complex EEG dependency structure as well as covariate-dependent heteroscedasticity, such as changes in variation over developmental age. In our motivating study, resting state EEG is collected on both TD and ASD children aged two to twelve years old. The peak alpha frequency (PAF), defined as the location of a prominent peak in the alpha frequency band of the spectral density, is an important biomarker linked to neurodevelopment and is known to shift from lower to higher frequencies as children age. To retain the most amount of information from the data, we model patterns of alpha spectral variation, rather than just the peak location, regionally across the scalp and chronologically across development for both the TD and ASD diagnostic groups. We propose a covariate-adjusted hybrid principal components analysis (CA-HPCA) for region-referenced functional EEG data, which utilizes both vector and functional principal components analysis while simultaneously adjusting

for covariate-dependent heteroscedasticity. CA-HPCA assumes the covariance process is weakly separable conditional on observed covariates, allowing for covariate-adjustments to be made on the marginal covariances rather than the full covariance leading to stable and computationally efficient estimation. A mixed effects framework is proposed to estimate the model components coupled with a bootstrap test for group-level inference. The proposed methodology provides novel insights into neurodevelopmental differences between TD and ASD children.

Keywords: Electroencephalography; Autism Spectrum Disorder; Functional data analysis; Marginal covariances; Functional principal components analysis; Covariate-adjustments

Tuesday, June 16 – Parallel Session 3

SS2: Theoretical and Applied Aspects of Imprecise Probabilities, part III

Coherent and Archimedean choice in general Banach spaces

Gert de Cooman

I introduce and study a new notion of Archimedeanity for binary and non-binary choice between options that live in an abstract Banach space, through a very general class of choice models, called sets of desirable option sets. In order to be able to bring horse lottery options into the fold, I pay special attention to the case where these linear spaces do not include all 'constant' options. I consider the frameworks of conservative inference associated with Archimedean choice models, and also pay quite a lot of attention to representation of general (non-binary) choice models in terms of the simpler, binary ones. The representation theorems proved here provide an axiomatic characterisation of, amongst other choice methods, Levi's E-admissibility and Walley–Sen maximality.

Keywords: Choice function – coherence – Archimedean – set of desirable option sets.

Archimedean Choice Functions: an Axiomatic Foundation for Imprecise Decision Making

Jasper De Bock

If uncertainty is modelled by a probability measure, decisions are typically made by choosing the option with the highest expected utility. If an imprecise probability model is used instead, this decision rule can be generalised in several ways. We here focus on two such generalisations that apply to sets of probability measures: E-admissibility and maximality. Both of them can be regarded as special instances of so-called choice functions, a very general mathematical framework for decision making. For each of these two decision rules, we provide a set of necessary and sufficient conditions on choice functions that uniquely characterises this rule, thereby providing an axiomatic foundation for imprecise decision making with sets of probabilities. A representation theorem for Archimedean choice functions in terms of coherent lower previsions lies at the basis of both results.

Keywords: E-admissibility – Maximality – Archimedean choice functions – Decision Making – Imprecise probabilities.

Dynamic portfolio selection under ambiguity in the ϵ-contaminated binomial model

Paride Antonini, Davide Petturiti and Barbara Vantaggi

Investors often need to look for an optimal portfolio acting under ambiguity, as they may not be able to single out a unique real-world probability measure. In this paper a discrete-time dynamic portfolio selection problem is studied, referring to an ϵ-contaminated binomial market model and assuming investors' preferences are consistent with the Choquet expected utility theory. We formulate the portfolio selection problem for a CRRA utility function in terms of the terminal wealth, and provide a characterization of the optimal solution in the case stock price returns are uniformly distributed. In this case, we further investigate the effect of the contamination parameter ϵ on the optimal portfolio.

Keywords: Ambiguity – Optimal portfolio – ϵ-Contamination model – Choquet integral.

Limit Behaviour of Upper and Lower Expected Time Averages in Discrete-Time Imprecise Markov Chains

Natan T'Joens and Jasper De Bock

We study the limit behaviour of upper and lower bounds on expected time averages in imprecise Markov chains; a generalised type of Markov chain where the local dynamics, traditionally characterised by transition probabilities, are now represented by sets of

'plausible' transition probabilities. Our main result is a necessary and sufficient condition under which these upper and lower bounds, called upper and lower expected time averages, will converge as time progresses towards infinity to limit values that do not depend on the process' initial state. Remarkably, our condition is considerably weaker than those needed to establish similar results for so-called limit—or steady state—upper and lower expectations, which are often used to provide approximate information about the limit behaviour of time averages as well. We show that such an approximation is sub-optimal and that it can be significantly improved by directly using upper and lower expected time averages.

SS5: Aggregation: Theory and Practice, part II

Necessary and possible interaction between criteria in a general Choquet integral model

Paul Alain Kaldjob Kaldjob, Brice Mayag and Denis Bouyssou

This paper deals with interaction between criteria in a general Choquet integral model. When the preference of the Decision Maker (DM) contains no indifference, we first give a necessary and sufficient condition for them to be representable by a Choquet integral model. Using this condition, we show that it is always possible to choose from the numerical representations, one relatively for which all the Shapley interaction indices are strictly positive. We illustrate our results with an example.

Keywords: Interaction index, General Choquet integral model, Shapley interaction indices.

Construction of nullnorms based on closure and interior operators on bounded lattices

Gül Deniz Çaylı

In this paper, we introduce two rather effective methods for constructing new families of nullnorms with a zero element on the basis of the closure operators and interior operators on a bounded lattice under some additional conditions. Our constructions can be seen as a generalization of the ones in [**?**]. As a by-product, two types of idempotent nullnorms

on bounded lattices are obtained. Several interesting examples are included to get a better understanding of the structure of new families of nullnorms.

Keywords: Bounded lattice; Construction method; Closure operator; Interior operator; Nullnorm.

General grouping functions

Helida Santos, Graçaliz P. Dimuro, Tiago C. Asmus, Giancarlo Lucca, Eduardo N. Borges, Benjamin Bedregal, José A. Sanz, Javier Fernández and Humberto Bustince

Some aggregation functions that are not necessarily associative, namely overlap and grouping functions, have called the attention of many researchers in the recent past. This is probably due to the fact that they are a richer class of operators whenever one compares with other classes of aggregation functions, such as t-norms and t-conorms, respectively. In the present work we introduce a more general proposal for disjunctive n-ary aggregation functions entitled general grouping functions, in order to be used in problems that admit n dimensional inputs in a more flexible manner, allowing their application in different contexts. We present some new interesting results, like the characterization of that operator and also provide different construction methods.

Keywords: Grouping functions – n-dimensional grouping functions – General grouping functions – General overlap functions.

The necessary and possible importance relation among criteria in a 2-additive Choquet integral model

Brice Mayag and Bertrand Tchantcho

In the context of the representation of a preference information by a 2-additive Choquet integral, we introduce the necessary and possible importance relations allowing to compare the Shapley values of two criteria. We present some sufficient conditions, using a set of binary alternatives, to get a necessary importance relation among two criteria.

Keywords: MCDA, Binary alternatives, Shapley Value, Choquet integral, Necessary relations

Temporal Data Processing

Modeling the Costs of Trade Finance during the Financial Crisis of 2008-2009: An Application of Dynamic Hierarchical Linear Model

Shantanu Mullick, Ashwin Malshe and Nicolas Glady

The authors propose a dynamic hierarchical linear model (DHLM) to study the variations in the costs of trade finance over time and across countries in dynamic environments such as the global financial crisis of 2008-2009. The DHLM can cope with challenges that a dynamic environment entails: nonstationarity, parameters changing over time and cross-sectional heterogeneity. The authors employ a DHLM to examine how the effects of four macroeconomic indicators – GDP growth, inflation, trade intensity and stock market capitalization - on trade finance costs varied over a period of five years from 2006 to 2010 across 8 countries. We find that the effect of these macroeconomic indicators varies over time, and most of this variation is present in the year preceding and succeeding the financial crisis. In addition, the trajectory of time-varying effects of GDP growth and inflation support the "flight to quality" hypothesis: cost of trade finance reduces in countries with high GDP growth and low inflation, during the crisis. The authors also note presence of country-specific heterogeneity in some of these effects. The authors propose extensions to the model and discuss its alternative uses in different contexts.

Keywords: Trade Finance, Financial Crisis, Bayesian Methods, Time Series Analysis

Dynamic pricing using Thompson Sampling with fuzzy events

Jason Rhuggenaath, Paulo Roberto de Oliveira da Costa, Yingqian Zhang, Alp Akcay and Uzay Kaymak

In this paper we study a repeated posted-price auction between a single seller and a single buyer that interact for a finite number of periods or rounds. In each round, the seller offers the same item for sale to the buyer. The seller announces a price and the buyer can decide to buy the item at the announced price or the buyer can decide not to buy the item. In this paper we study the problem from the perspective of the buyer who only gets to observe a stochastic measurement of the valuation of the item after he buys the item. Furthermore, in our model the buyer uses fuzzy sets to describe his satisfaction with the observed

valuations and he uses fuzzy sets to describe his dissatisfaction with the observed price. In our problem, the buyer makes decisions based on the probability of a fuzzy event. His decision to buy or not depends on whether the satisfaction from having a high enough valuation for the item out weights the dissatisfaction of the quoted price. We propose an algorithm based on Thompson Sampling and demonstrate that is performs well using numerical experiments.

Keywords: dynamic pricing – Bayesian modeling – exploration-exploitation trade-off – probability of fuzzy events

Electrical power grid frequency estimation with Fuzzy Boolean Nets

Nuno Rodrigues, Joao Paulo Carvalho, Fernando Janeiro and Pedro Ramos

Power quality analysis involves the measurement of quantities that characterize a power supply waveform such as its frequency. The measurement of those quantities are regulated by internationally accepted standards from IEEE or IEC. Monitoring the delivered power quality is even more important due to recent advances in power electronics and also due to the increasing penetration of renewable energies in the electrical power grid. The primary suggested method by IEC to measure the power grid frequency is to count the number of zero crossings in the voltage waveform that occur during 0.2 s. The standard zero crossing method is usually applied to a filtered signal that has a non deterministic and frequency dependent delay. For monitoring the power grid a range between 42.5 and 57.5 Hz should be considered which means that the filter must be designed in order to attenuate the delay compensation error. Fuzzy Boolean Nets can be considered a neural fuzzy model where the fuzziness is an inherent emerging property that can ignore some outliers acting as a filter. This property can be useful to apply zero crossing without false crossing detection and estimate the real timestamp without the non deterministic delay concern. This paper presents a comparison between the standard frequency estimation, a Goertzel interpolation method, and the standard method applied after a FBN network instead of a filtered signal.

Keywords: Power quality – Frequency estimation – Zero crossing – Neural Networks – FBN.

Fuzzy Clustering Stability Evaluation of Time Series

Gerhard Klassen, Martha Tatusch, Ludmila Himmelspach and Stefan Conrad

The discovery of knowledge by analyzing time series is an important field of research. In this paper we investigate multiple multivariate time series, because we assume a higher information value than regarding only one time series at a time. There are several approaches which make use of the granger causality or the cross correlation in order to analyze the influence of time series on each other. In this paper we extend the idea of mutual influence and present FCSETS (**F**uzzy **C**lustering **S**tability **E**valuation of **T**ime **S**eries), a new approach which makes use of the membership degree produced by the fuzzy c-means (FCM) algorithm. We first cluster time series per timestamp and then compare the relative assignment agreement (introduced by Eyke Hüllermeier and Maria Rifqi) of all subsequences. This leads us to a stability score for every time series which itself can be used to evaluate single time series in the data set. It is then used to rate the stability of the entire clustering. The stability score of a time series is higher the more the time series sticks to its peers over time. This not only reveals a new idea of mutual time series impact but also enables the identification of an optimal amount of clusters per timestamp. We applied our model on different data, such as financial, country related economy and generated data, and present the results.

Keywords: Time Series Analysis – Fuzzy Clustering – Evaluation

SS20: Mathematical Fuzzy Logic and Graded Reasoning Models, part I

Converting Possibilistic Networks by using Uncertain Gates

Guillaume Petiot

The purpose of this paper is to define a general frame to convert the Conditional Possibility Tables (CPT) of an existing possibilistic network into uncertain gates. In possibilistic networks, CPT parameters must be elicited by an expert but when the number of parents of a variable grows, the number of parameters to elicit grows exponentially. This problem generates difficulties for experts to elicit all parameters because it is time-consuming. One solution consists in using uncertain gates to compute automatically CPTs. This is useful in knowledge engineering. When possibilistic networks already exist, it can be interesting to transform them by using uncertain gates because we can highlight the combination behaviour of the variables. To illustrate our approach, we will present at first a simple example of the estimation for 3 test CPTs with behaviours MIN, MAX and weighted average. Then, we will perform a more significant experimentation which will consist in converting a set of Bayesian networks into possibilistic networks to perform the estimation of CPTs by uncertain gates.

Keywords: Possibilistic networks – Possibility theory – Uncertain logical gates – Estimation.

Depth-Bounded Approximations of Probability

Paolo Baldi, Marcello D'Agostino and Hykel Hosni

We introduce measures of uncertainty that are based on *Depth-Bounded Logics* [**?**] and resemble belief functions. We show that our measures can be seen as approximation of classical probability measures over classical logic, and that a variant of the PSAT [**?**] problem for them is solvable in polynomial time.

Unification in Lukasiewicz logic with a finite number of variables

Marco Abbadini, Federica Di Stefano and Luca Spada

We prove that the unification type of Łukasiewicz logic with a finite number of variables is either infinitary or nullary. To achieve this result we use Ghilardi's categorical characterisation of unification types in terms of projective objects, the categorical duality between finitely presented MV-algebras and rational polyhedra, and a homotopy-theoretic argument.

Keywords: Łukasiewicz logic – MV-algebras – unification – universal cover

Two dualities for weakly pseudo-complemented quasi-Kleene algebras

Umberto Rivieccio, Ramon Jansana and Thiago N. Silva

Quasi-Nelson algebras are a non-involutive generalisation of Nelson algebras that can be characterised in several ways, e.g. as (i) the variety of bounded commutative integral (not necessarily involutive) residuated lattices that satisfy the Nelson identity; (ii) the class of $(0, 1)$-congruence orderable commutative integral residuated lattices; (iii) the algebraic counterpart of quasi-Nelson logic, i.e. the (algebraisable) extension of the substructural logic $\mathcal{FL}_{ew}$ by the Nelson axiom. In the present paper we focus on the subreducts of

quasi-Nelson algebras obtained by eliding the implication while keeping the two term-definable negations. These form a variety that (following A. Sendlewski, who studied the corresponding fragment of Nelson algebras) we dub *weakly pseudo-complemented quasi-Kleene algebras*. We develop a Priestley-style duality for these algebras (in two different guises) which is essentially an application of the general approach proposed in the paper *A duality for two-sorted lattices* by A. Jung and U. Rivieccio.

Keywords: Quasi-Nelson algebras – Kleene algebras with weak pseudo-complement – Residuated lattices – Two-sorted duality – Semi-De Morgan.

Wednesday, June 17 – Parallel Session 1

SS19: Current Techniques to Model, Process and Describe Time Series

Predicting S&P500 Monthly Direction with Informed Machine Learning

David Romain Djoumbissie and Philippe Langlais

We propose a systematic framework based on a dynamic functional causal graph in order to capture complexity and uncertainty on the financial markets, and then to predict the monthly direction of the S&P500 index. Our results highlight the relevance of (i) using the hierarchical causal graph model instead of modelling directly the S&P500 with its causal drivers (ii) taking into account different types of contexts (short and medium term) through latent variables (iii) using unstructured forward looking data from the Beige Book. The small size of our training data is compensated by the a priori knowledge on financial market. We obtain accuracy and F1-score of 70.9% and 67% compared to 64.1% and 50% for the industry benchmark on a period of over 25 years. By introducing a hierarchical interaction between drivers through a latent context variable, we improve performance of two recent works on same inputs.

Keywords: Financial knowledge representation – functional causal graph – Prediction & informed machine learning.

A fuzzy approach for similarity measurement in time series, case study for stocks

Soheyla Mirshahi and Vilem Novak

In this paper, we tackle the issue of assessing similarity among time series under the assumption that a time series can be additively decomposed into a trend-cycle and an irregular fluctuation. It has been proved before that the former can be well estimated using the fuzzy transform. In the suggested method, first, we assign to each time series an adjoint one that consists of a sequence of trend-cycle of a time series estimated using fuzzy transform. Then we measure the distance between local trend-cycles. An experiment is conducted to demonstrate the advantages of the suggested method. This method is easy to calculate, well interpretable, and unlike standard euclidean distance, it is robust to outliers.

Keywords: similarity measurements – stock markets similarity – time series analysis – time series data mining.

Fuzzy k-NN based classifiers for time series with soft labels

Nicolas Wagner, Violaine Antoine, Jonas Koko and Romain Lardy

Time series are temporal ordered data available in many fields of science such as medicine, physics, astronomy, audio, etc. Various methods have been proposed to analyze time series. Amongst them, time series classification consists in predicting the class of a time series according to a set of already classified data. However, the performance of a time series classification algorithm depends on the quality of the known labels. In real applications, time series are often labeled by an expert or by an imprecise process, leading to noisy classes. Several algorithms have been developed to handle uncertain labels in case of non-temporal data sets. As an example, the fuzzy k-NN introduces for labeled objects a degree of membership to belong to classes. In this paper, we combine two popular time series classification algorithms, Bag of SFA Symbols (BOSS) and the Dynamic Time Warping (DTW) with the fuzzy k-NN. The new algorithms are called Fuzzy DTW and Fuzzy BOSS. Results show that our fuzzy time series classification algorithms outperform the non-soft algorithms especially when the level of noise is high.

Keywords: time series classification – BOSS – fuzzy k-NN – soft labels.

SS21: Formal Concept Analysis, Rough Sets, General Operators and Related Topics, part II

Galois connections between unbalanced structures in a fuzzy framework

Inma P. Cabrera, Pablo Cordero, Emilio Muñoz-Velasco and Manuel Ojeda-Aciego

The construction of Galois connections between unbalanced structures has received considerable attention in the recent years. In a nutshell, the problem is to find a right adjoint of a mapping defined between sets with unbalanced structure; in this paper we survey recent results obtained in this framework, focusing specially on the fuzzy structures that have been considered so far in this context: fuzzy preposets, fuzzy preordered structures, and fuzzy T-digraphs.

Impact of local congruences in attribute reduction

Roberto G. Aragón, Jesús Medina and Eloísa Ramírez-Poussa

Local congruences are equivalence relations whose equivalence classes are convex sublattices of the original lattice. In this paper, we present a study that relates local congruences to attribute reduction in FCA. Specifically, we will analyze the impact in the context of the use of local congruences, when they are used for complementing an attribute reduction.

Keywords: formal concept analysis, size reduction, attribute reduction, local congruence

Towards a classification of rough set bireducts

M. José Benítez-Caballero, Jesús Medina and Eloisa Ramírez Poussa

Size reduction mechanisms are very important in several mathematical fields. In rough set theory, bireducts arose to reduce simultaneously the set of attributes and the set of objects of the considered dataset, providing subsystems with the minimal sets of attributes that connect the maximum number of objects preserving the information of the original

dataset. This paper presents the main properties of bireducts and how they can be used for removing inconsistencies.

Keywords: Rough Set Theory, Bireducts, Size Reduction.

SS6: Aggregation: Pre-aggregation Functions and other Generalizations of Monotonicity

Analyzing non-deterministic computable aggregations

Luis Magdalena, Luis Garmendia, Daniel Gómez and Javier Montero

Traditionally, the term aggregation is associated with an aggregation function, implicitly assuming that any aggregation process can be represented by a function. However, the concept of computable aggregation considers that the core of the aggregation processes is the program that enables it. This new concept of aggregation introduces the scenario where the aggregation can even be non-deterministic. In this work, this new class of aggregation is formally defined, and some desirable properties related with consistency, robustness and monotonicity are proposed.

Keywords: Aggregation – Computable aggregation – nondeterministic aggregation

Dissimilarity based Choquet integrals

Humberto Bustince, Radko Mesiar, Javier Fernandez, Mikel Galar, Daniel Paternain, Abdulrahman Altalhi, Gracaliz Dimuro, Benjamin Bedregal and Zdenko Takac

In this paper, in order to generalize the Choquet integral, we replace the difference between inputs in its definition by a restricted dissimilarity function and refer to the obtained function as d-Choquet integral. For some particular restricted dissimilarity function the corresponding d-Choquet integral with respect to a fuzzy measure is just the 'standard' Choquet integral with respect to the same fuzzy measure. Hence, the class of all d-Choquet integrals encompasses the class of all 'standard' Choquet integrals. This approach allows us to construct a wide class of new functions, d-Choquet integrals, that are possibly, unlike the 'standard' Choquet integral, outside of the scope of aggregation functions since the monotonicity is, for some restricted dissimilarity function, violated and also the range of such functions can be wider than $[0, 1]$, in particular it can be $[0, n]$.

Keywords: Choquet integral – d-Choquet integral – dissimilarity – pre-aggregation function – aggregation function – monotonicity – directional monotonicity.

SS20: Mathematical Fuzzy Logic and Graded Reasoning Models, part II

On the logic of left-continuous t-norms and right-continuous t-conorms

Lluis Godo, Martin Socola-Ramos and Francesc Esteva

Double residuated lattices are expansions of residuated lattices with an extra monoidal operator, playing the role of a strong disjunction operation, together with its dual residuum. They were introduced by Orłowska and Radzikowska. In this paper we consider the subclass of double residuated structures that are expansions of MTL-algebras, that is, prelinear, bounded, commutative and integral residuated lattices. MTL-algebras constitute the algebraic semantics for the MTL logic, the system of mathematical fuzzy logic that is complete w.r.t. the class of residuated lattices on the real unit interval $[0, 1]$ induced by left-continuous t-norms. Our aim is to axiomatise the logic whose intended semantics are commutative and integral double residuated structures on $[0, 1]$, that are induced by an arbitrary left-continuous t-norm, an arbitrary right-continuous t-conorm, and their corresponding residual operations.

Keywords: Mathematical fuzzy logic, Double residuated lattices, MTL, DMCTL, Semilinear logics, Standard completeness

Automorphism groups of finite BL-algebras

Brunella Gerla and Stefano Aguzzoli

Using a category dual to finite $\mathbb{BL}$-algebras and their homomorphisms, in this paper we characterise the structure of the automorphism group of any given finite $\mathbb{BL}$-algebra. Further, we specialise our result to the case of the variety generated by the k-element $\mathbb{MV}$-algebra, for each $k > 1$.

Keywords: $\mathbb{BL}$-algebras, Automorphism group, Substitutions.

Fuzzy Neighborhood Semantics for Multi-Agent Probabilistic Reasoning in Games

Martina Dankova and Libor Behounek

In this contribution we apply fuzzy neighborhood semantics to multiple agents' reasoning about each other's subjective probabilities, especially in game-theoretic situations. The semantic model enables representing various game-theoretic notions such as payoff matrices or Nash equilibria, as well as higher-order probabilistic beliefs of the players about each other's choice of strategy. In the proposed framework, belief-dependent concepts such as the strategy with the best expected value are formally derivable in higher-order fuzzy logic for any finite matrix game with rational payoffs.

Keywords: Probabilistic reasoning – Fuzzy logic – Modal logic – Neighborhood semantics – Matrix game.

Wednesday, June 17 – Parallel Session 2

SS7: Aggregation: Aggregation of Different Data Structures

A S-QFD Approach with Bipolar Fuzzy Hamacher Aggregation Operators and Its Application on E-Commerce

Esra Çakir and Ziya Ulukan

In a global competitive environment, companies' ability to develop products and respond to customer demands is crucial to their success. Quality Function Deployment is an approach that companies use to meet customer needs and expectations in the product design process. It provides competitive advantage to the firm by shortening the development period of products that meet customer expectations. The purpose of this research is to explore the feasibility of the QFD approach in the design of an e-commerce web site. In this context, the QFD application has been implemented to meet customer expectations and increase competitive power of the site to be designed. Bipolar fuzzy numbers are used to express customers' decisions. This research contributes to the literature with a new QFD approach with bipolar fuzzy numbers and practice by expanding QFD's application field in software sector.

Keywords: Bipolar Fuzzy Set, Hamacher Aggregation Operator, House of Quality, Software Quality Function Deployment

An undesirable behaviour of a recent extension of OWA operators to the setting of multidimensional data

Raúl Pérez-Fernández

OWA operators have been ubiquitous in many disciplines since they were introduced by Yager in 1988. Aside of some other intuitive properties (e.g. monotonicity and idempotence), OWA operators are known to be continuous and, for some carefully constructed weighing vectors, very robust in the presence of outliers. In a recent paper, a natural extension of OWA operators to the setting of multidimensional data has been proposed based on the use of a linear extension of the product order by means of several weighted arithmetic means. Unfortunately, OWA operators constructed in such a way focus too strongly on the level sets of one of the weighted arithmetic means. It is here shown that this focus ultimately results in a forfeit of the properties of continuity and robustness in the presence of outliers.

Keywords: OWA operator – Multidimensional data – Linear extension – Weighted arithmetic mean.

Combining absolute and relative information with frequency distributions for ordinal classification

Mengzi Tang, Raúl Pérez-Fernández and Bernard De Baets

A large amount of labelled data (absolute information) is usually needed for an ordinal classifier to attain a good performance. As shown in a recent paper by the present authors, the lack of a large amount of absolute information can be overcome by additionally considering some side information in the form of relative information, thus augmenting the method of nearest neighbors. In this paper, we adapt the method of nearest neighbors for dealing with a specific type of relative information: frequency distributions of pairwise comparisons (rather than a single pairwise comparison). We test the proposed method on some classical machine learning datasets and demonstrate its effectiveness.

Keywords: Ordinal classification – Nearest neighbors – Absolute information – Relative information – Frequency distributions.

A Bidirectional Subsethood Based Fuzzy Measure for Aggregation of Interval-Valued Data

Shaily Kabir and Christian Wagner

Recent advances in the literature have leveraged the fuzzy integral (FI), a powerful multi-source aggregation operator, where a fuzzy measure (FM) is used to capture the worth of all combinations of subsets of sources. While in most applications, the FM is defined either by experts or numerically derived through optimization, these approaches are only viable if additional information on the sources is available. When such information is unavailable, as is commonly the case when sources are unknown a priori (e.g., in crowdsourcing), prior work has proposed the extraction of valuable insight (captured within FMs) directly from the evidence or input data by analyzing properties such as specificity or agreement amongst sources. Here, existing agreement-based FMs use established measures of similarity such as Jaccard and Dice to estimate the source agreement. Recently, a new similarity measure based on bidirectional subsethood was put forward to compare evidence, minimizing limitations such as *aliasing* (where different inputs result in the same similarity output) present in traditional similarity measures. In this paper, we build on this new similarity measure to develop a new instance of the agreement-based FM for interval-valued data. The proposed FM is purposely designed to support aggregation, and unlike previous agreement FMs, it degrades gracefully to an average operator for cases where no overlap between sources exists. We validate that it respects all requirements of a FM and explore its impact when used in conjunction with the Choquet FI for data fusion as part of both synthetic and real-world datasets, showing empirically that it generates robust and qualitatively superior outputs for the cases considered.

Keywords: Data aggregation – Fuzzy measures – Fuzzy integrals – Subsethood – Similarity measure – Interval-valued data.

SS15: Mathematical Methods Towards Dealing with Uncertainty in Applied Sciences, part II

Gold Price: Trend-cycle Analysis Using Fuzzy Techniques

Nguyen Linh, Novak Vilem and Holcapek Michal

In this paper, we apply special fuzzy techniques to analyze the gold price historical data. The main tools are the higher degree fuzzy transform and specific methods of fuzzy natural logic. First, we show how to apply the former for the estimation of the trend-cycle.

Then, we provide methodologies for identifying monotonous periods in the trend-cycle and describe them by sentences in natural language.

Keywords: fuzzy transform, fuzzy modeling, financial time series, data mining

On PSO-based approximation of Zadeh's extension principle

Nicole Skorupova and Jiri Kupka

Zadeh's extension is a powerful principle in fuzzy set theory which allows to extend a real-valued continuous map to a map having fuzzy sets as its arguments. In our previous work we introduced an algorithm which can compute Zadeh's extension of given continuous piecewise linear functions and then to simulate fuzzy dynamical systems given by them. The purpose of this work is to present results which generalize our previous approach to a more complex class of maps. For that purpose we present an adaptation on optimization algorithm called particle swarm optimization and demonstrate its use for simulation of fuzzy dynamical systems.

Keywords: Zadeh's extension – Particle swarm optimization – Fuzzy dynamical systems.

On uncertain discontinuous functions and quasi-equilibrium in some economic models

Inese Bula

In the paper is studied some properties of uncertain discontinuous mappings, the so-called w-discontinuous mappings. Based on them, the existence of a quasi-equilibrium for a new economic model is proved.

Keywords: Discontinuity – Fixed point theorem – Market equilibrium – Quasi-equilibrium.

Nonlocal Laplace Operator in a Space with the Fuzzy Partition

Hana Zámečníková and Irina Perfilieva

Differential operators play an important role in the mathematical modeling of dynamic processes and the analysis of various structures. However, there are certain limitations in

their use. To remove them, nonlocal differential operators have been proposed. In this work, we focus on nonlocal Laplace operator, which has become increasingly useful in image processing. We introduce the representation of

F-transform based Laplace operator in a space with a fuzzy partition. Many useful properties of this operator are proposed and their proofs are also included.

Keywords: Nonlocal Laplace operator – Proximity – Basic functions –

Fuzzy transform.

A Comparison of Explanatory Measures in Abductive Inference

Jiandong Huang, David Glass and Mark Mccartney

Computer simulations have been carried out to investigate the performance of two measures for abductive inference, Maximum Likelihood (ML), and Product Coherence Measure (PCM), by comparing them with a third approach, Most Probable Explanation (MPE). These have been realized through experiments that compare outcomes from a specified model (the correct model) with those from incorrect models which assume that the hypotheses are mutually exclusive or independent. The results show that PCM tracks the results of MPE more closely than ML when the degree of competition is greater than 0 and hence is able to infer explanations that are more likely to be true under such a condition. Experiments on the robustness of the measures with respect to incorrect model assumptions show that ML is more robust in general, but that MPE and PCM are more robust when the degree of competition is positive. The results also show that in general it is more reasonable to assume the hypotheses in question are independent than to assume they are mutually exclusive.

Keywords: Inference to the Best Explanation (IBE). Explanatory reasoning. Hypotheses competition. Abduction

Machine Learning, part I

Possibilistic Estimation of Distributions to Leverage Sparse Data in Machine Learning

Andrea Tettamanzi, David Emsellem, Célia Da Costa Pereira, Alessandro Venerandi

and Giovanni Fusco

Prompted by an application in the area of human geography using machine learning to study housing market valuation based on the urban form, we propose a method based on possibility theory to deal with sparse data, which can be combined with any machine learning method to approach weakly supervised learning problems. More specifically, the solution we propose constructs a possibilistic loss function to account for an uncertain supervisory signal. Although the proposal is illustrated on a specific application, its basic principles are general. The proposed method is then empirically validated on real-world data.

Maximal Clique based Influence Maximization in Networks

Nizar Mhadhbi and Badran Raddaoui

Influence maximization is a fundamental problem in several real life applications such as viral marketing, recommendation system, collaboration and social networks. Maximizing influence spreading in a given network aims to find the initially active vertex set of size k called seed nodes (or initial spreaders [1]) which maximizes the expected number of the infected vertices. The state-of-the-art local-based techniques developed to solve this problem are based on local structure information such as degree centrality, nodes clustering coefficient, and others utilize the whole network structure, such as k-core decomposition, and node betweeness. In this paper, we aim at solving the problem of influence maximization using maximal clique problem. Our intuition is based on the fact that the presence of a dense neighborhood around a node is fundamental to the maximization of influence. Our approach follows the following three steps: (1) discovering all the maximal cliques from the complex network; (2) filtering the set of maximal cliques; we then denote the vertices belonging to the rest of maximal cliques as superordinate vertices, and (3) ranking the superordinate nodes according to some indicators. We evaluate the proposed framework empirically against several high-performing methods on a number of real-life datasets. The experimental results show that our algorithms outperform existing state-of-the-art methods in finding the best initial spreaders in networks.

Keywords: Influence Maximization – Maximal Clique – Independent Cascade Model.

[1] In this paper, we use seed set and initial spreaders interchangeably.

A Probabilistic Approach for Discovering Daily Human Mobility Patterns with Mobile Data

Weizhu Qian, Fabrice Lauri and Franck Gechter

Analyzing human mobility with geo-location data collected from smartphones has been a hot research topic in recent years. In this paper, we attempt to discover daily mobile patterns using the GPS data. In particular, we view this problem from a probabilistic perspective. A non-parametric Bayesian modeling method, the Infinite Gaussian Mixture Model (IGMM) is used to estimate the probability density of the daily mobility. We also utilize the Kullback-Leibler (KL) divergence as the metrics to measure the similarity of different probability distributions. Combining the IGMM and the KL divergence, we propose an automatic clustering algorithm to discover mobility patterns for each individual user. Finally, the effectiveness of our method is validated on the real user data collected from different real users.

Keywords: probabilistic model – infinite Gaussian mixture model – Kullback-Leibler divergence – human mobility.

Feature Reduction in Superset Learning using Rough Sets and Evidence Theory

Andrea Campagner, Davide Ciucci and Eyke Hüllermeier

Supervised learning is an important branch of machine learning (ML), which requires a complete annotation (labeling) of the involved training data. This assumption, which may constitute a severe bottleneck in the practical use of ML, is relaxed in weakly supervised learning. In this ML paradigm, training instances are not necessarily precisely labeled. Instead, annotations are allowed to be imprecise or partial. In the setting of superset learning, instances are assumed to be labeled with a set of *possible* annotations, which is assumed to contain the correct one. In this article, we study the application of *rough set theory* in the setting of superset learning. In particular, we consider the problem of feature reduction as a mean for *data disambiguation*, i.e., for the purpose of figuring out the most plausible precise instantiation of the imprecise training data. To this end, we define appropriate generalizations of decision tables and reducts, using information-theoretic techniques based on evidence theory. Moreover, we analyze the complexity of the associated computational problems.

Keywords: Feature Selection, Superset Learning, Rough Sets, Evidence Theory.

Graphical Causal Models and Imputing Missing Data: A Preliminary Study

Rui Jorge Almeida, Greetje Adriaans and Yuliya Shapovalova

Real-world datasets often contain many missing values due to several reasons. This is usually an issue since many learning algorithms require complete datasets. In certain cases, there are constraints in the real world problem that create difficulties in continuously observing all data. In this paper, we investigate if graphical causal models can be used to impute missing values and derive additional information on the uncertainty of the imputed values. Our goal is to use the information from a complete dataset in the form of graphical causal models to impute missing values in an incomplete dataset. This assumes that the datasets have the same data generating process. Furthermore, we calculate the probability of each missing data value belonging to a specified percentile. We present a preliminary study on the proposed method using synthetic data, where we can control the causal relations and missing values.

Keywords: Missing Data – Graphical Causal Models – Uncertainty in Missing Values

Optimization and uncertainty

Softening the robustness of optimization problems: a new budgeted uncertainty approach

Romain Guillaume, Adam Kasperski and Pawel Zielinski

In this paper an optimization problem with uncertain parameters is discussed. In the traditional robust approach a pessimistic point of view is assumed. Namely, a solution is computed under the worst possible parameter realizations, which can lead to large deterioration of the objective function value. In this paper a new approach is proposed, which assumes a less pessimistic point of view. The complexity of the resulting problem is explored and some methods of solving its special cases are presented.

Keywords: Robustness – Uncertainty – Optimization.

Hierarchical reasoning and knapsack problem modelling to design the ideal assortment in retail

Jocelyn Poncelet, Pierre-Antoine Jean, Jacky Montmain and Michel Vasquez

The survival of a supermarket chain is heavily dependent on its capacity to maintain the loyalty of its customers. Proposing adequate products to customers is the issue of the store's assortment. With tens thousands of products on shelves, designing the ideal assortment is theoretically a thorny combinatorial optimization problem. The approach we propose includes prior knowledge on the hierarchical organization of products by family to formalize the ideal assortment problem into a knapsack problem. The main difficulty of the optimization problem remains the estimation of the expected benefits associated to changes in the product range of products' families. This estimate is based on the accounting results of similar stores. The definition of the similarity between two stores is then crucial. It is based on the prior knowledge on the hierarchical organization of products that allows approximate reasoning to compare any two stores and constitutes the major contribution of this paper.

Keywords: Optimal Assortment in Mass Distribution, Semantic Similarity Measures, Knapsack problem.

Towards multi-perspective conformance checking with aggregation operations

Sicui Zhang, Laura Genga, Lukas Dekker, Hongchao Nie, Xudong Lu, Huilong Duan and Uzay Kaymak

Conformance checking techniques are widely adopted to validate process executions against a set of constraints describing the expected behavior. However, most approaches adopt a crisp evaluation of deviations, with the result that small violations are considered at the same level of significant ones. Furthermore, in the presence of multiple data constraints the overall deviation severity is assessed by summing up each single deviation. This approach easily leads to misleading diagnostics; furthermore, it does not take into account user's needs, that are likely to differ depending on the context of the analysis. We propose a novel methodology based on the use of aggregation functions, to assess the level of deviation severity for a set of constraints, and to customize the tolerance to deviations of multiple constraints.

Keywords: conformance checking – fuzzy aggregation – data perspective

On the impact of fuzzy constraints in the variable size and cost bin packing problem

Jorge Herrera-Franklin, Alejandro Rosete, Milton Garcia-Borroto, David Pelta and Carlos Cruz

The Variable Size and Cost Bin Packing Problem (VSCBPP) consists of minimizing the cost of all bins used to pack a set of items without exceeding the bins capacities. It is a well known NP-Hard problem with many practical applications.

In this contribution we assume that the capacity of a bin can be understood in a flexible way (so it may allow some overload) thus leading to a fuzzy version of the VSCBPP with fuzzy constraints.

We solve the proposed fuzzy VSCBPP by using the parametric approach based on α-cuts, thus defining a set of related crisp problems.

By using three different solving algorithms and several instances, we explore the impact of different degrees of relaxation not only in terms of cost, but also in the structure of the solutions.

Keywords: combinatorial optimization, variable size and cost bin packing problem, fuzzy constraint, parametric approach

Artificial Bee Colony Algorithm Applied toDynamic Flexible Job Shop Problems

Inês Ferreira, Bernardo Firme, Miguel Martins, Tiago Coito, Joaquim Viegas, João Figueiredo, Susana Vieira and João Sousa

This work introduces a scheduling technique using the Artificial Bee Colony (ABC) algorithm for static and dynamic environments. The ABC algorithm combines different initial populations and generation of new food source methods, including a moving operations technique and a local search method increasing the variable neighbourhood search that, as a result, improves the solution quality. The algorithm is validated and its performance is tested in a static environment in 9 instances of Flexible Job Shop Problem (FJSP) from Brandimarte dataset obtaining in 5 instances the best known for the instance under study and a new best known in instance mk05. The work also focus in developing tools to process the information on the factory through the development of solutions when facing disruptions and dynamic events. Three real-time events are considered on the dynamic environment: jobs cancellation, operations cancellation and new jobs arrival. Two

scenarios are studied for each real-time event: the first situation considers the minimization of the disruption between the previous schedule and the new one and the second situation generates a completely new schedule after the occurrence. Summarizing, six adaptations of ABC algorithm are created to solve dynamic environment scenarios and their performances are compared with the benchmarks of two case studies outperforming both.

Keywords: Dynamic environment – New Jobs Arrival – Operations Cancellation – Jobs Cancellation – Flexible Job Shop Rescheduling

Wednesday, June 17 – Parallel Session 3

SS5: Aggregation: Theory and Practice, part III

Measuring polarization: A fuzzy set theoretical approach

Juan Antonio Guevara, Daniel Gómez, José Manuel Robles and Francisco Javier Montero

The measurement of polarization has been studied over the last thirty years. Despite the different applied approaches, since polarization concept is complex, we find a lack of consensus about how it should be measured. This paper proposes a new approach to the measurement of the polarization phenomenon based on fuzzy set. Fuzzy approach provides a new perspective whose elements admit degrees of membership. Since reality is not black and white, a polarization measure should include this key characteristic. For this purpose we analyze polarization metric properties and develop a new risk of polarization measure using aggregation operators and overlapping functions. We simulate a sample of $N = 391315$ cases across a 5-likert-scale with different distributions to test our measure. Other polarization measures were applied to compare situations where fuzzy set approach offers different results, where membership functions have proved to play an essential role in the measurement. Finally, we want to highlight the new and potential contribution of fuzzy set approach to the polarization measurement which opens a new field to research on.

Keywords: Polarization – Fuzzy set – Ordinal variation.

New Methods for Comparing Interval-Valued Fuzzy Cardinal Numbers

Barbara Pękala, Jarosław Szkoła, Krzysztof Dyczkowski and Tomasz Piłka

In this contribution the concept how to solve the problem of comparability in the interval-valued fuzzy setting and its application in medical diagnosis is presented. Especially, we consider comparability of interval-valued fuzzy sets cardinality, where order of its elements is most important. We propose an algorithm for comparing interval-valued fuzzy cardinal numbers (IVFCNs) and we evaluate it in a medical diagnosis decision support system.

Keywords: Interval-valued Fuzzy Set (IVFS), Interval-valued fuzzy cardinal number (IVFCN); IV-order; Comparing IVFCN, Medical diagnosis

Aggregation functions transformed by 0 - 1 valued monotone systems of functions

Martin Kalina

In the paper Jin et al. [2019] the authors introduced a generalized phi-transformation of aggregation functions. This is a kind of two-step aggregation. This transformation was further developed in Jin et al. [2020] into a Generalized-Convex-Sum-Transformation. A special case of the proposed Generalized-Convex-Sum-Transformation is the well-known *-product, also known as the Darsow product of copulas. This approach covers also the discrete Choquet integral. In this paper we study the monotone systems of functions, particularly the case when functions in these systems are just two-valued.

Keywords: aggregation function, copula, generalized-convex-sum transformation, monotone system of functions

SS15: Mathematical Methods Towards Dealing with Uncertainty in Applied Sciences, part III

On integral transforms for residuated lattice-valued functions

Michal Holcapek and Viec Bui

The article aims to introduce four types of integral transforms for functions whose function values belong to a complete residuated lattice. The integral transforms are defined using so-called qualitative residuum based fuzzy integrals and integral kernels in the form of binary fuzzy relations. We present some of the basic properties of proposed integral transforms including a linearity property that is satisfied under specific conditions for comonotonic functions.

Keywords: Integral transform – Fuzzy transform – Residuated lattice – Integral kernel – Fuzzy integral

Optimal control under fuzzy conditions for dynamical systems associated with the second order linear differential equations

Svetlana Asmuss and Natalja Budkina

This paper is devoted to an optimal trajectory planning problem with uncertainty in location conditions considered as a problem of constrained optimal control for dynamical systems. Fuzzy numbers are used to incorporate uncertainty of constraints into the classical setting of the problem under consideration. The proposed approach applied to dynamical systems associated with the second order linear differential equations allows to find an optimal control law at each α-level using spline-based methods developed in the framework of the theory of splines in convex sets. The solution technique is illustrated by numerical examples.

Keywords: Dynamical system – Fuzzy constraints – Optimal control.

Text Analysis and Processing

Creating Classification Models from Textual Descriptions of Companies using Crunchbase

Marco Felgueiras, Fernando Batista and Joao Paulo Carvalho

This paper compares different models for multilabel text classification, using information collected from Crunchbase, a large database that holds information about more than 600000 companies. Each company is labeled with one or more categories, from a subset of 46 possible categories, and the proposed models predict the categories based solely

on the company textual description. A number of natural language processing strategies have been tested for feature extraction, including stemming, lemmatization, and part-of-speech tags. This is a highly unbalanced dataset, where the frequency of each category ranges from 0.7% to 28%. Our findings reveal that the description text of each company contain features that allow to predict its area of activity, expressed by its corresponding categories, with about 70% precision, and 42% recall. In a second set of experiments, a multiclass problem that attempts to find the most probable category, we obtained about 67% accuracy using SVM and Fuzzy Fingerprints. The resulting models may constitute an important asset for automatic classification of texts, not only consisting of company descriptions, but also other texts, such as web pages, text blogs, news pages, etc.

Keywords: Text Mining – Multilabel Classification – Text Classification – Document Classification – Machine Learning – Crunchbase

Automatic Truecasing of Video Subtitles using BERT: A multilingual adaptable approach

Ricardo Rei, Nuno Miguel Guerreiro and Fernando Batista

This paper describes an approach for automatic capitalization of text without case information, such as spoken transcripts of video subtitles, produced by automatic speech recognition systems. Our approach is based on pre-trained contextualized word embeddings, requires only a small portion of data for training when compared with traditional approaches, and is able to achieve state-of-the-art results. The paper reports experiments both on general written data from the European Parliament, and on video subtitles, revealing that the proposed approach is suitable for performing capitalization, not only in each one of the domains, but also in a cross-domain scenario. We have also created a versatile multilingual model, and the conducted experiments show that good results can be achieved both for monolingual and multilingual data. Finally, we applied domain adaptation by finetuning models, initially trained on general written data, on video subtitles, revealing gains over other approaches not only in performance but also in terms of computational cost.

Keywords: Automatic capitalization – Automatic Truecasing – BERT – Contextualized Embeddings – Domain Adaptation.

Feature Extraction with TF-IDF and Game-theoretic Shadowed Sets

Yan Zhang, Yue Zhou and Jingtao Yao

TF-IDF is one of the most commonly used weighting metrics for measuring the relationship of words to documents. It is widely used for word feature extraction. In many research and applications, the thresholds of TF-IDF for selecting relevant words are only based on trial or experiences. Some cut-off strategies have been proposed in which the thresholds are selected based on Zipf's law or feedbacks from model performances. However, the existing approaches are restricted in specific domains or tasks, and they ignore the imbalance of the number of representative words in different categories of documents. To address these issues, we apply game-theoretic shadowed set model to select the word features given TF-IDF information. Game-theoretic shadowed sets determine the thresholds of TF-IDF using game theory and repetition learning mechanism. Experimental results on real world new category dataset show that our model not only outperforms all baseline cut-off approaches, but also speed up the classification algorithms.

Keywords: Feature Extraction– TF-IDF– Text Classification – Game-theoretic Shadowed Sets

To BERT or not to BERT Dealing with possible BERT failures in an Entailment task

Pedro Fialho, Luísa Coheur and Paulo Quaresma

In this paper we focus on an Natural Language Inference task. Being given two sentences, we classify their relation as NEUTRAL, ENTAILMENT or CONTRADICTION. Considering the achievements of BERT (Bidirectional Encoder Representations from Transformers) in many Natural Language Processing tasks, we use BERT features to create our base model for this task. However, several questions arise: can other features improve the performance obtained with BERT? If we are able to predict the situations in which BERT will fail, can we improve the performance by providing alternative models for these situations? We test several strategies and models, as alternatives to the standalone BERT model in the possible failure situations, and we take advantage of semantic features extracted from Discourse Representation Structures.

Keywords: Natural Language Inference – Feature Engineering – Failure Prediction Model.

SS17: Interval Uncertainty, part I

On Statistics, Probability, and Entropy of Interval-Valued Datasets

Chenyi Hu and Zhihui Hu

Applying interval-valued data and methods, researchers have made solid accomplishments in information processing and uncertainty management. Although interval-valued statistics and probability are available for interval-valued data, current inferential decision making schemes rely on point-valued statistic and probabilistic measures mostly. To enable direct applications of these point-valued schemes on interval-valued datasets, we present point-valued variational statistics, probability, and entropy for interval-valued datasets. Related algorithms are reported with illustrative examples.

A computational study on the entropy of interval-valued datasets from the stock market

Chenyi Hu and Zhihui Hu

Using interval-valued data and computing, researchers have reported significant quality improvements of the stock market annual variability forecasts recently. Through studying the entropy of interval-valued datasets, this work provides both information theoretic and empirical evidences on that the significant quality improvements are very likely come from interval-valued datasets. Therefore, using interval-valued samples rather than point-valued ones is preferable in making variability forecasts. This study also computationally investigates the impacts of data aggregation methods and probability distributions on the entropy of interval-valued datasets. Computational results suggest that both min-max and confidence intervals can work well in aggregating point-valued data into intervals. However, assuming uniform probability distribution should be a good practical choice in calculating the entropy of an interval-valued dataset in some applications at least.

Enhancing the efficiency of the interval-valued fuzzy rule-based classifier with tuning and rule selection

José Antonio Sanz, Tiago da Cruz Asmus, Borja de la Osa and Humberto Bustince

Interval-Valued fuzzy rule-based classifier with TUning and Rule Selection, IVTURS, is a state-of-the-art fuzzy classifier. One of the key point of this method is the usage of interval-valued restricted equivalence functions because their parametrization allows one to tune them to each problem, which leads to obtaining accurate results. However, they require the application of the exponentiation several times to obtain a result, which is a time demanding operation implying an extra charge to the computational burden of the method.

In this contribution, we propose to reduce the number of exponentiation operations executed by the system, so that the efficiency of the method is enhanced with no alteration of the obtained results. Moreover, the new approach also allows for a reduction on the search space of the evolutionary method carried out in IVTURS. Consequently, we also propose four different approaches to take advantage of this reduction on the search space to study if it can imply an enhancement of the accuracy of the classifier. The experimental results prove: 1) the enhancement of the efficiency of IVTURS and 2) the accuracy of IVTURS is competitive versus that of the approaches using the reduced search space.

Keywords: Interval-Valued Fuzzy Rule-based Classification Systems – Interval-Valued Fuzzy Sets – Interval Type-2 Fuzzy Sets – Evolutionary Fuzzy Systems.

Dealing with inconsistent measurements in inverse problems: an approach based on sets and intervals.

Krushna Shinde, Pierre Feissel and Sébastien Destercke

We consider the (inverse) problem of finding back the parameter values of a physical model given a set of measurements. As the deterministic solution to this problem is sensitive to measurement error in the data, one way to resolve this issue is to take into account uncertainties in the data. In this paper, we explore how interval-based approaches can be used to obtain a solution to the inverse problem, in particular when measurements are inconsistent with one another. We show on a set of experiments, in which we compare the set-based approach with the Bayesian one, that this is particularly interesting when some measurements can be suspected of being outliers.

Keywords: Inverse problem – Interval uncertainty – Outlier detection.

Thursday, June 18 – Parallel Session 1

SS8: Fuzzy methods in Data Mining and Knowledge Discovery

Hybrid model for Parkinson's disease prediction

Augusto Junio Guimarães, Paulo Vitor Campos Souza and Edwin Lughofer

Parkinson's is a chronic, progressive neurological disease with no known cause that affects the central nervous system of older people and compromises their movement. This disorder can impair daily aspects of people and therefore identify their existence early, helps in choosing treatments that can reduce the impact of the disease on the patient's routine. This work aims to identify Parkinson's traces through a voice recording replications database applied to a fuzzy neural network to identify their patterns and enable the extraction of knowledge about situations present in the data collected in patients. The results obtained by the hybrid model were superior to state of the art for the theme, proving that it is possible to perform hybrid models in the extraction of knowledge and the classification of behavioral patterns of high accuracy Parkinson's.

Keywords: Parkinson's Disease – Fuzzy Neural Network – Hybrid Models.

A Word Embedding Model for Mapping Food Composition Databases using Fuzzy Logic

Andrea Morales-Garzón, Juan Gomez-Romero and Maria J. Martin-Bautista

This paper addresses the problem of mapping equivalent items between two databases based on their textual descriptions. Specifically, we will apply this technique to link the elements of two food composition databases by calculating the most likely match of each item in another given database. A number of experiments have been carried by employing different distance metrics, some of them involving Fuzzy Logic. The experiments show that the mappings are highly accurate and Fuzzy Logic improves the precision of the model.

Keywords: Word embedding – Fuzzy distance – Database Alignment

Mining text patterns over fake and real tweets

J. Angel Diaz-Garcia, Carlos Fernandez-Basso, M. Dolores Ruiz and Maria J. Martin-Bautista

With the exponential growth of users and user-generated content present on online social networks, fake news and its detection have become a major problem. Through these, smear campaigns can be generated, aimed for example at trying to change the political orientation of some people. Twitter has become one of the main spreaders of fake news in the network. Therefore, in this paper, we present a solution based on Text Mining that tries to find which text patterns are related to tweets that refer to fake news and which patterns in the tweets are related to true news. To test and validate the results, the system faces a pre-labelled dataset of fake and real tweets during the U.S. presidential election in 2016. In terms of results interesting patterns are obtained that relate the size and subtle changes of the real news to create fake news. Finally, different ways to visualize the results are provided.

Keywords: Association Rules, social media mining, fake news, Text Mining, Twitter

SS9: Computational Intelligence for Logistics and Transportation Problems

Fuzzy Set Based Models Comparative Study for the TD TSP with Rush Hours and Traffic Regions

Ruba Almahasneh, Boldizsar Tuu-Szabo, Peter Foldesi and Laszlo T. Koczy

This study compares three fuzzy based model approaches for solving a realistic extension of the Time Dependent Traveling Salesman Problem. First, the triple Fuzzy (3FTD TSP) model, where the uncertain costs between the nodes depend on time are expressed by fuzzy sets. Second, the intuitionistic fuzzy (IFTD TSP) approach, where including hesitation was suitable for quantifying the jam regions and the bimodal rush hour periods during the day. Third, the interval-valued intuitionistic fuzzy sets model, that calculates the interval-valued intuitionistic fuzzy weighted arithmetic average (IIFWAA) of the edges' confirmability degrees and non-confirmability degrees, was contributing in minimizing the information loss in cost (delay) calculation between nodes.

Keywords: Rush hours, Jam regions, Interval-valued fuzzy sets, Intuitionistic fuzzy set, Fuzzy set

Fuzzy Greedy Randomized Adaptive Search Procedure and Simulation Model to solve the Team Orienteering Problem with Time Windows

Airam Expósito Márquez, Christopher Expósito Izquierdo, Belén Melian Batista and José Marcos Moreno Vega

Tourism is a relevant economic activity that provides important resources (income, employment,...) to countries. When a tourist visits a country or city, he/she wants to know their points of interest. To do this, he/she must select some of the places according to his/her preferences and design routes to visit them. This problem can be adequately modeled as a Team Orienteering Problem with Time Windows (TOPTW). In this paper we propose a fuzzy GRASP and a multi-agent simulation model to solve the TOPTW. Our proposal incorporates two criteria to build the restricted candidate list. The computational results obtained show the validity of the proposal.

Keywords: Tourism – GRASP – Fuzzy – Simulation model.

General-purpose Automated Machine Learning for Transportation: A Case study of Auto-sklearn for Traffic Forecasting

Juan S Angarita-Zapata, Antonio D Masegosa and Isaac Triguero

Currently, there are no guidelines to determine what are the most suitable machine learning pipelines (i.e. the workflow from data preprocessing to model selection and validation) to approach Traffic Forecasting (TF) problems. Although automated machine learning (AutoML) has proved to be successful dealing with the model selection problem in other applications areas, only a few papers have explored the performance of general-purpose AutoML methods, purely based on optimisation, when tackling TF. In this paper, we provide a thorough exploration of the benefits of Auto-sklearn for TF, as a general-purpose AutoML method that follows a hybrid search strategy combining optimisation with meta-learning and ensemble learning. Particularly, we focus on how well Auto-sklearn is able to recommend competitive machine learning pipelines to forecast traffic, modelled as a TF multi-class imbalanced classification problem, along different time horizons at two spatial scales (point and road segment) and two environments (freeway and urban). Concretely, we test the following scenarios: I) a hybrid search strategy with the three components (optimisation, meta-learning, ensemble learning), II) a strategy based on meta-learning and ensemble learning, and III) a strategy based on the estimation of the best performing pipeline from those suggested by the meta-learning. Experimental results show that the meta-learning component of Auto-sklearn does not work properly on TF problems, and on the other hand, that the optimisation does not contribute too much to the final performance of predictions.

Keywords: Traffic forecasting – Transportation – Supervised learning – Machine learning – Automated machine learning – Computational intelligence.

SS17: Interval Uncertainty, part II

Tolerance and control solutions of two-sided interval linear system and their applications

Worrawate Leela-Apiradee, Phantipa Thipwiwatpotjana and Artur Gorka

This work investigates tolerance and control solutions to a two-sided interval linear sys-

tem. Their semantics are different, even though, we would be able to interchange the role of the interval information algebraically. We present necessary and sufficient conditions of their solvabilities as the inequalities depending on center and radius of coefficient interval matrices on both sides of the system. In a situation when the vector of variables is nonnegative, the conditions can simply be modified as the inequalities depending on boundaries of the interval matrices. This result helps with the feasible solutions of a quadratic programming problem with two-sided interval linear equation constraints.

Keywords: Interval linear system– Tolerance solution– Control solution

Robust Predictive-Reactive Scheduling : an Information-Based Decision Tree Model

Tom Portoleau, Christian Artigues and Romain Guillaume

In this paper we introduce a proactive-reactive approach to deal with uncertain scheduling problems. The method constructs a robust decision tree for a decision maker that is reusable as long as the problem parameters remain in the uncertainty set. At each node of the tree we assume that the scheduler has access to some knowledge about the ongoing scenario, reducing the level of uncertainty and allowing the computation of less conservative solutions with robustness guarantees. However, obtaining information on the uncertain parameters can be costly and frequent rescheduling can be disturbing. We first formally define the robust decision tree and the information refining concepts in the context of uncertainty scenarios. Then we propose algorithms to build such a tree. Finally, focusing on a simple single machine scheduling problem, we provide experimental comparisons highlighting the potential of the decision tree approach compared with reactive algorithms for obtaining more robust solutions with fewer information updates and schedule changes.

Orders preserving the convexity under intersections for interval-valued fuzzy sets

Pedro Huidodro, Pedro Alonso, Vladimir Janis and Susana Montes

Convexity is a very important property in many areas and the studies of this property are frequent. In this paper, we have extended the notion of convexity for interval-valued fuzzy sets based on different order between intervals. The considered orders are related and their behavior analyzed. In particular, we study the preservation of the convexity

under intersections, where again the chosen order is essential. After this study, we can conclude the appropriate behavior of the admissible orders for this purpose.

Keywords: Interval-valued fuzzy sets – Order between intervals – Intersection – Convexity.

Thursday, June 18 – Parallel Session 2

Foundations and Mathematics

Why Spiking Neural Networks Are Efficient: A Theorem

Michael Beer, Julio Urenda, Olga Kosheleva and Vladik Kreinovich

Current artificial neural networks are very successful in many machine learning applications, but in some cases they still lag behind human abilities. To improve their performance, a natural idea is to simulate features of biological neurons which are not yet implemented in machine learning. One of such features is the fact that in biological neural networks, signals are represented by a train of spikes. Researchers have tried adding this spikiness to machine learning and indeed got very good results, especially when processing time series (and, more generally, spatio-temporal data). In this paper, we provide a possible theoretical explanation for this empirical success.

Keywords: Spiking neural networks – Shift-invariance – Scale-invariance.

Which Distributions (or Families of Distributions) Best Represent Interval Uncertainty: Case of Permutation-Invariant Criteria

Michael Beer, Julio Urenda, Olga Kosheleva and Vladik Kreinovich

In many practical situations, we only know the interval containing the quantity of interest, we have no information about the probabilities of different values within this interval. In contrast to the cases when we know the distributions and can thus use Monte-Carlo simulations, processing such interval uncertainty is difficult – crudely speaking, because we need to try all possible distributions on this interval. Sometimes, the problem can be simplified: namely, for estimating the range of values of some characteristics of the distribution, it is possible to select a single distribution (or a small family of distributions) whose analysis provides a good understanding of the situation. The most known case is when we are estimating the largest possible of Shannon's entropy: in this case, it is sufficient to consider the uniform distribution on the interval. Interesting, estimating other characteristics leads to the selection of the same uniform distribution: e.g., estimating the largest possible values of generalized entropy or of some sensitivity-related characteristics. In this paper, we provide a general explanation of why uniform distribution appears in different situations – namely, it appears every time we have a permutation-invariant optimization problem with the unique optimum. We also discuss what happens if we have an optimization problem that attains its optimum at several different distributions – this happens, e.g., when we are estimating the smallest possible value of Shannon's entropy (or of its generalizations).

Keywords: Interval uncertainty – Maximum Entropy approach – Uniform distribution – Sensitivity analysis

A L1 minimization optimal corrective explanation procedure for probabilistic databases

Marco Baioletti and Andrea Capotorti

We propose to use a, recently introduced, efficient $L1$ distance minimization through mixed-integer linear programming for minimizing the number of valuations to be modified inside an incoherent probabilistic assessment. This is in line with one basic principle of optimal corrective explanation for decision makers.

A shrewd use of constraints and of slack variables permit to steer the correction of incoherent assessments towards aimed directions, like e.g. the minimal number of changes.

Such corrective explanations can be searched alone, as minimal changes, or jointly with the property of being also inside the $L1$ distance minimizers (in a bi-optimal point of view).

The detection of such bi-optimal solutions can be performed efficiently by profiting from the geometric characterization of the whole set of $L1$ minimizers and from the properties of $L1$ topology.
Keywords: Incoherence corrections, $L1$ constrained minimization, mixed integer programming, optimal corrective explanation, probabilistic databases.

Suffcient Solvability Conditions for Systems of Partial Fuzzy Relational Equations

Nhung Cao and Martin Stepnicka

This paper focuses on searching sufficient conditions for the solvability of systems of partial fuzzy relational equations. In the case of solvable systems, we provide solutions of the systems. Two standard systems of fuzzy relational equations – namely the systems built on the basic composition and on the Bandler-Kohout subproduct – are considered under the assumption of partiality. Such an extension requires to employ partial algebras of operations for dealing with undefined values. In this investigation, we consider seven most-known algebras of undefined values in partial fuzzy set theory such as the Bochvar, Bochvar external, Sobociński, McCarthy, Nelson, Kleene, and the Łukasiewicz algebra. Conditions that are sufficient for the solvability of the systems are provided. The crucial role will be played by the so-called boundary condition.

Keywords: Fuzzy relational equations – Partial fuzzy logics – Partial fuzzy set theory – Undefined values – Boundary condition.

Polar representation of bipolar information: a case study to compare intuitionistic entropies

Christophe Marsala and Bernadette Bouchon-Meunier

In this paper, a new approach to compare measures of entropy in the setting of the intuitionistic fuzzy sets introduced by Atanassov. A polar representation is introduced to represent such bipolar information and it is used to study the three main intuitionistic fuzzy sets entropies of the literature. A theoretical comparison and some experimental results highlight the interest of such a representation to gain knowledge on these entropies.

Keywords: Entropy – Intuitionistic fuzzy set – Bipolar information

SS3: Similarities in Artificial Intelligence

On Ruspini's models of similarity-based approximate reasoning

Francesc Esteva, Lluis Godo, Ricardo Oscar Rodriguez and Thomas Vetterlein

In his 1991 seminal paper, Enrique H. Ruspini proposed a similarity-based semantics for fuzzy sets and approximate reasoning which has been extensively used by many other authors in various contexts. This brief note, which is our humble contribution to honor Ruspini's great legacy, describes some of the main developments in the field of logic that essentially rely on his ideas.

Keywords: Fuzzy similarity, Approximate reasoning, Graded entailments, Modal logic

An interval-valued divergence for interval-valued fuzzy sets

Susana Diaz, Irene Diaz and Susana Montes

Characterizing the degree of similarity or difference between two sets is a very important topic, since it has many applications in different areas, including image processing or decision making. Several studies have been done about the comparison of fuzzy sets and its extensions, in particular for interval-valued fuzzy sets. However, in most of the cases, the results of the comparison is just a number. In order to avoid this reduction of the information, we have introduced a measure for comparing two interval-valued fuzzy sets such that it is an interval itself, which can be reduced to a number if it is necessary. Thus, a richer class of measures is now considered.

Keywords: Interval-valued fuzzy set – Order between intervals – Dissimilarity – Divergence measure.

The fuzzy processing of metaphors

Charles Tijus

The question under investigation about verbal metaphor is what kind of thinking and reasoning can help catching the metaphorical target category (e.g., octopus meaning citrus press, child meaning son or daughter, pizzas meaning people) from a source category (children, pizzas or octopuses); knowing that this kind of "logically false" way of talking/understanding and of reasoning appears to be the most prominent kind of human of thinking. We are reviewing some of the prominent work of Bernadette Bouchon-Meunier with her team to evaluate how much the fuzzy logic computation of metaphorical reasoning and schemes can be used to model the human computation of metaphors.

Keywords: Thinking, Reasoning, Similarity, Analogy, Metaphor

A measurement theory characterizationof a class of dissimilarity measures for fuzzy description profiles

Giulianella Coletti, Davide Petturiti and Bernadette Bouchon-Meunier

We consider objects associated with a fuzzy set-based representation. By using a classic method of measurement theory, we characterize dissimilarity relations agreeing with a particular class of fuzzy dissimilarity measures. Dissimilarity measures in the considered class are those only depending on the attribute-wise distance of fuzzy description profiles. In particular, we analyze the subclass of weighted Manhattan dissimilarity measures.

Keywords: Dissimilarity relation – Fuzzy description profiles – Axioms – Weighted Manhattan dissimilarity measure.

Learning Tversky Similarity

Javad Rahnama and Eyke Hüllermeier

In this paper, we advocate Tversky's ratio model as an appropriate basis for computational approaches to semantic similarity, that is, the comparison of objects such as images in a semantically meaningful way. We consider the problem of learning Tversky similarity measures from suitable training data indicating whether two objects tend to be similar or dissimilar. Experimentally, we evaluate our approach to similarity learning on two image datasets, showing that is performs very well compared to existing methods.

Keywords: Similarity – Machine Learning – Semantic features – Image data

Machine Learning, part II

Competitive online quantile regression

Raisa Dzhamtyrova and Yuri Kalnishkan

Interval prediction often provides more useful information compared to a simple point forecast. For example, in renewable energy forecasting, while the initial focus has been on deterministic predictions, the uncertainty observed in energy generation raises an interest in producing probabilistic forecasts. One aims to provide prediction intervals so that outcomes lie in the interval with a given probability. Therefore, the problem of estimating the quantiles of a variable arises. The contribution of our paper is two-fold. First, we propose to apply the framework of prediction with expert advice for the prediction of quantiles. Second, we propose a new competitive online algorithm Weak Aggregating Algorithm for Quantile Regression (WAAQR) and prove a theoretical bound on the cumulative loss of the proposed strategy. The theoretical bound ensures that WAAQR is asymptotically as good as any quantile regression. In addition, we provide an empirical survey where we apply both methods to the problem of probability forecasting of wind and solar powers and show that they provide good results compared to other predictive models.

Keywords: prediction with expert advice – online learning – sequential prediction – Weak Aggregating Algorithm – quantile regression – probabilistic forecasting.

On the Analysis of Illicit Supply Networks using Variable State Resolution-Markov Chains

Jorge González Ordiano, Lisa Finn, Anthony Winterlich, Gary Moloney and Steven Simske

The trade in illicit items, such as counterfeits, not only leads to the loss of large sums of private and public revenue, but also poses a danger to individuals, undermines governments, and—in the most extreme cases—finances criminal organizations. It is estimated that in 2013 trade in illicit items accounted for 2.5% of the global commerce. To combat illicit trade, it is necessary to understand its illicit supply networks. Therefore, we present in this article an approach that is able to find an optimal description of an illicit supply network using a series of Variable State Resolution-Markov Chains. The new method is

applied to a real-world dataset stemming from the Global Product Authentication Service of Micro Focus International. The results show how an illicit supply network might be analyzed with the help of this method.

Keywords: Data Mining – Markov Chain – Illicit Trade

Deep conformal prediction for robust models

Soundouss Messoudi, Sylvain Rousseau and Sébastien Destercke

Deep networks, like some other learning models, can associate high trust to unreliable predictions. Making these models robust and reliable is therefore essential, especially for critical decisions. This experimental paper shows that the conformal prediction approach brings a convincing solution to this challenge. Conformal prediction consists in predicting a set of classes covering the real class with a user-defined frequency. In the case of atypical examples, the conformal prediction will predict the empty set. Experiments show the good behavior of the conformal approach, especially when the data is noisy.

Keywords: Deep learning – Conformal prediction – Robust and reliable models.

Continuous analogical proportions-based classier

Marouane Essid, Myriam Bounhas and Henri Prade

Analogical proportions, often denoted $A : B :: C : D$, are statements of the form "A is to B as C is to D" that involve comparisons between items. They are at the basis of an inference mechanism that has been recognized as a suitable tool for classification and has led to a variety of analogical classifiers in the last decade. Given an object D to be classified, the basic idea of such classifiers is to look for triples of examples (A, B, C), in the learning set, that form an analogical proportion with D, on a maximum set of attributes. In the context of classification, objects A, B, C and D are assumed to be represented by vectors of feature values. Analogical inference relies on the fact that if a proportion $A : B :: C : D$ is valid, one of the four components of the proportion can be computed from the three others. Based on this principle, analogical classifiers have a cubic complexity due to the search for all possible triples in a learning set to make a single prediction. A special case of analogical proportions involving only three items A, B and C are called *continuous* analogical proportions and are of the form "A is to B as B is to C" (hence denoted $A : B :: B : C$). In this paper, we develop a new classification algorithm based on continuous analogical proportions and applied to numerical features. Focusing on pairs rather than triples, the proposed classifier enables

us to compute an unknown midpoint item B given a pair of items (A, C). Experimental results of such classifier show an efficiency close to the previous analogy-based classifier while maintaining a reduced quadratic complexity.

Keywords: Classification, Analogical proportions, Continuous analogical proportions

Evaluation of uncertainty quantification in deep learning

Niclas Ståhl, Göran Falkman, Alexander Karlsson and Gunnar Mathiason

Artificial intelligence (AI) is nowadays included into an increasing number of critical systems. Inclusion of AI in such systems may, however, pose a risk, since it is, still, infeasible to build AI systems that know how to function well in situations that differ greatly from what the AI has seen before. Therefore, it is crucial that future AI systems have the ability to not only function well in known domains, but also understand and show when they are uncertain when facing something unknown. In this paper, we evaluate four different methods that have been proposed to correctly quantifying uncertainty when the AI model is faced with new samples. We investigate the behaviour of these models when they are applied to samples far from what these models have seen before, and if they correctly attribute those samples with high uncertainty. We also examine if incorrectly classified samples are attributed with an higher uncertainty than correctly classified samples. The major finding from this simple experiment is, surprisingly, that the evaluated methods capture the uncertainty differently and the correlation between the quantified uncertainty of the models is low. This inconsistency is something that needs to be further understood and solved before AI can be used in critical applications in a trustworthy and safe manner.

SS4: Belief Function Theory and its Applications, part I

Belief Functions for the Importance Assessment in Multiplex Networks

Natalia Meshcheryakova and Alexander Lepskiy

We apply Dempster-Shafer theory in order to reveal important elements in undirected weighted networks. We estimate cooperation of each node with different groups of vertices that surround it via construction of belief functions. The obtained intensities of

cooperation are further redistributed over all elements of a particular group of nodes that results in pignistic probabilities of node-to-node interactions. Finally, pairwise interactions can be aggregated into the centrality vector that ranks nodes with respect to derived values. We also adapt the proposed model to multiplex networks. In this type of networks nodes can be differently connected with each other on several levels of interaction. Various combination rules help to analyze such systems as a single entity, that has many advantages in the study of complex systems. In particular, Dempster rule takes into account the inconsistency in initial data that has an impact on the final centrality ranking. We also provide a numerical example that illustrates the distinctive features of the proposed model. Additionally, we establish analytical relations between a proposed measure and classical centrality measures for particular graph configurations.

Keywords: Belief Functions – Network Analysis – Centrality Measures.

Correction of Belief Function to improve the performances of a Fusion System

Didier Coquin, Reda Boukezzoula and Rihab Ben Ameur

Our application concerns the fusion of classifiers for the recognition of trees from their leaves, in the framework of belief functions theory. In order to improve the rate of good classification it is necessary to correct Bayesian mass functions. This correction will be done from the meta-knowledge which is estimated from the confusion matrix. The corrected mass functions considerably improve the recognition rate based on the decisions provided by the classifiers.

Keywords: Belief functions theory – Mass correction – Meta-knowledge – Fusion of classifiers.

Evaluation of Probabilistic Transformations For Evidential Data Association

Mohammed Boumediene and Jean Dezert

Data association is one of the main tasks to achieve in perception applications. Its aim is to match the sensor detections to the known objects. To treat such issue, recent research focus on the evidential approach using belief functions, which are interpreted as an extension of the probabilistic model for reasoning about uncertainty. The data fusion process begins by quantifying sensor data by belief masses. Thereafter, these masses

are combined in order to provide more accurate information. Finally, a probabilistic approximation of these combined masses is done to make-decision on associations. Several probabilistic transformations have been proposed in the literature. However, to the best of our knowledge, these transformations have been evaluated only on simulated examples. For this reason, the objective of this paper is to benchmark most of interesting probabilistic transformations on real-data in order to evaluate their performances for the autonomous vehicle perception problematic.

Keywords: Data Association – Evidential Theory – Belief Functions – Probabilistic Transformation.

A Belief Classification Approach based on Artificial Immune Recognition System

Rihab Abdelkhalek and Zied Elouedi

Artificial Immune Recognition Systems (AIRS) are supervised classification methods inspired by the immune system metaphors. They enjoy a great popularity in the filed of machine learning by achieving good and competitive classification results. Nonetheless, while these approaches work properly under a certain framework, they present some weaknesses basically related to their inability to deal with uncertainty. This is considered as an important challenge in real-world classification problems. Furthermore, using traditional AIRS approaches, all memory cells are considered with the same importance during the classification process which may affect the final generated results. To tackle these issues, we propose in this paper a new AIRS approach under the belief function framework. Our approach tends to handle the uncertainty pervaded in the classification stage while taking into account the number of training antigens represented by each memory cell. The performance of the proposed evidential AIRS approach is validated on real-world data sets and compared to state of the art AIRS under certain and uncertain frameworks.

Keywords: Machine learning – Classification – · Artificial immune recognition systems – Uncertainty – Belief function theory.

Evidential Group Spammers Detection

Malika Ben Khalifa, Zied Elouedi and Eric Lefevre

Online reviews are considered as one of the most prevalent reference indicators for people to evaluate the quality of different products or services before purchasing. Since these

reviews affect the buying decision of customers and control the success of the different e-commerce websites, the activity of fake reviews posting is more and more increasing. These fraudulent reviews are posted by a large number of spammers who try to promote or demote target products or companies. The reviewers spammers generally work collaboratively under group of spammers to take control of reviews given to some products, which seriously damage the review system. To deal with this issue, we propose a novel method aim to detect group spammers while relying on various group spamming behavioral indicators. Our approach is based on the K-nearest neighbors algorithm under the belief function theory to treat the uncertainty in the used behavioral indicators. Our method succeeds in distinguishing between genuine and fraudulent group of reviewers. It was tested on two large real datasets extracted from yelp.com.

Keywords: Fake reviews, Group spammers, Uncertainty, Belief Function Theory, Evidential KNN, E-commerce.

Thursday, June 18 – Parallel Session 3

SS1: Fuzzy Interval Analysis

An Introduction to Differential Algebraic Equations Under Interval Uncertainty: A First Step Toward Generalized Uncertainty DAEs

Weldon Alexander Lodwick and Marina Tuyako Mizukoshi

This presentation introduces the theory leading to solution methods for differential algebraic equations (DAEs) under interval uncertainty in which the uncertainty is in the initial conditions of the differential equation and/or the entries of the coefficients of the differential equation and algebraic restrictions. While we restrict these uncertainties to be *intervals,*other types of uncertains like generalized uncetainties such as fuzzy intervals are done in a similar manner albeit leading to more complex analyses. Linear constant coefficient DAEs and then interval linear constant coefficient problems will illustrate both the theoretically challenges and solution approaches. The way the interval uncertainty is handled is novel and serves as a basis for more general uncertainty analysis.

Classification of Hyperbolic Singularities in Interval 3-dimensional Linear Differential Systems

Marina Tuyako Mizukoshi, Alain Jacquemard and Weldon Alexandre Lodwick

We study the classification of the hyperbolic singularities to 3-dimensional interval linear differential equations as an application of interval eigenvalues using the Constraint Interval Arithmetic(CIA). We also present the ideas to calculate the interval eigenvalues using the standard interval arithmetic.

Keywords: Interval Eigenvalues – Dynamical Systems – Classification of Singularities.

New results in the calculus of fuzzy-valued using mid-point representation

Luciano Stefanini, Laerte Sorini and Mina Shahidi

We present new results in the calculus for fuzzy-valued functions of a single real variable. We adopt extensively the midpoint-radius representation of intervals in the real half-plane and show its usefulness in fuzzy calculus. Concepts related to convergence and limits, continuity, level-wise gH-differentiability of first and second orders have nice and useful midpoint expressions. Using mid-point representation of fuzzy-valued functions, partial orders and properties of monotonicity and convexity are discussed and analysed in detail. Periodicity is easy to represent and identify. Graphical examples and pictures accompany the presentation.

Keywords: Fuzzy-valued function – Midpoint representation – Monotonic fuzzy function – Convexity of fuzzy function – Periodic fuzzy function.

On sum of generalized Hukuhara differentiable fuzzy functions

Yurilev Chalco-Cano, A Khastan and Antonio Rufián-Lizana

In this article we present new results on the sum of gH-differentiable fuzzy functions. We give conditions so that the sum of two gH-differentiable fuzzy functions become gH-differentiable. We present also practical rules for obtaining the gH-derivative of the sum of fuzzy functions.

Keywords: Fuzzy functions – gH-differentiable fuzzy functions – Algebra of gH-differentiable fuzzy functions.

SS14: Fuzzy and Generalized Quantifier Theory

Graded decagon of opposition with fuzzy quantifier-based concept-forming operators

Stefania Boffa, Petra Murinova and Vilem Novak

We introduce twelve operators called *fuzzy quantifier-based operators*. They are proposed as a new tool to help to deepen the analysis of data in fuzzy formal concept analysis. Moreover, we employ them to construct a graded extension of Aristotle's square, namely the *graded decagon of opposition*.

Keywords: Fuzzy formal concept analysis; Evaluative linguistic expressions; Square of opposition; Łukasiewicz MV-algebra.

Graded cube of opposition with intermediate in fuzzy natural logic

Petra Murinová and Vilém Novák

In our previous papers, we formally analyzed the generalized Aristotle's square of opposition using tools of higher-order fuzzy logic. Namely, we introduced general definitions of selected intermediate quantifiers, constructed a generalized square of opposition consisting of them and syntactically analyzed the emerged properties. The main objective of this paper is to extend the graded Peterson's square of opposition into the graded cube of opposition with intermediate quantifiers.

Keywords: Intermediate quantifiers; fuzzy natural logic; evaluative linguistic expressions; generalized Peterson square; graded cube of opposition

On the properties of intermediate quantifiers and the quantifier "MORE-THAN"

Vilém Novák, Petra Murinová and Stefania Boffa

This paper continues the research in formal theory of intermediate quantifiers. We present some new properties, introduce intermediate quantifiers of type $\langle 1 \rangle$, and also new quantifiers MORE-THAN and LESS-THAN.

Keywords: Generalized quantifiers; Fuzzy quantifiers; Fuzzy type theory; Mathematical fuzzy logic.

On semantic properties of fuzzy quantifiers over fuzzy universes: restriction and living on

Michal Holcapek and Antonín Dvořák

The article investigates important semantic properties of fuzzy quantifiers, namely restriction and living on a (fuzzy) set. These properties are introduced in the novel frame of fuzzy quantifiers over fuzzy universes.

Keywords: Generalized quantifiers – Fuzzy quantifiers – Semantic properties

SS23: Computational Intelligence Methods in Information Modelling, Representation and Processing

Fast Convergence of Competitive Spiking Neural Networks with Sample-Based Weight Initialization

Paolo Gabriel Cachi Delgado, Sebastián Ventura and Krzysztof Cios

Recent work on spiking neural networks showed good progress towards unsupervised feature learning. In particular, networks called Competitive Spiking Neural Networks (CSNN) achieve reasonable accuracy in classification tasks. However, two major disadvantages limit their practical applications: high computational complexity and slow convergence. While the first problem has partially been addressed with the development

of neuromorphic hardware, no work has addressed the latter problem. In this paper we show that the number of samples the CSNN needs to converge can be reduced significantly by a proposed new weight initialization. The proposed method uses input samples as initial values for the connection weights. Surprisingly, this simple initialization reduces the number of training samples needed for convergence by an order of magnitude without loss of accuracy. We use the MNIST dataset to show that the method is robust even when not all classes are seen during initialization.

Keywords: Spiking Neural Networks – Competitive Learning – Unsupervised Feature Learning.

Intelligent Detection of Information Outliers using Linguistic Summaries with Non-monotonic Quantifiers

Agnieszka Duraj, Piotr S. Szczepaniak and Łukasz Chomątek

In the processing of imprecise information, principally in big data analysis, it is very advantageous to transform numerical values into the standard form of linguistic statements. This paper deals with a novel method of outlier detection using linguistic summaries. Particular attention is devoted to examining the usefulness of non-monotonic quantifiers, which represent a fuzzy determination of the amount of analyzed data.The answer is positive. The use of non-monotonic quantifiers in the detection of outliers can provide a more significant value of the degree of truth of a linguistic summary. At the end, this paper provides a computational example of practical importance.

Keywords: intelligent data analysis, linguistic summaries, monotonic and non-monotonic quantifiers, intelligent outlier detection

Network of Fuzzy Comparators for Ovulation Window Prediction

Łukasz Sosnowski, Iwona Szymusik and Tomasz Penza

This paper presents the problem and the solution of ovulation date prediction based on simple data acquired by a woman in home environment. It describes a method of processing collected data as a multivariate time series. The novelty of this algorithm lies in its ability to predict the ovulation date and not only to retrospectively detect it. This is achieved by applying the fuzzy network of comparators (NoC) to compare the menstrual cycle being analyzed with the reference set of historical cycles.

Contextualizing Naive Bayes Predictions

Marcelo Loor and Guy De Tré

A classification process can be seen as a set of actions by which several objects are evaluated in order to predict the class(es) those objects belong to. In situations where transparency is a necessary condition, predictions resulting from a classification process are needed to be interpretable. In this paper, we propose a novel variant of a naive Bayes (NB) classification process that yields such interpretable predictions. In the proposed variant, augmented appraisal degrees (AADs) are used for the contextualization of the evaluations carried out to make the predictions. Since an AAD has been conceived as a mathematical representation of the connotative meaning in an experience-based evaluation, the incorporation of AADs into a NB classification process helps to put the resulting predictions in context. An illustrative example, in which the proposed version of NB classification is used for the categorization of newswire articles, shows how such contextualized predictions can favor their interpretability.

Keywords: Explainable artificial intelligence – Augmented appraisal degrees – Naive Bayes classification – Context handling.

SS4: Belief Function Theory and its Applications, part II

Dempster-Shafer Theory: How Constraint Programming Can Help

Alexandros Kaltsounidis and Isambo Karali

Dealing with uncertainty has always been a challenging topic in the area of knowledge representation. Nowadays, as the internet provides a vast platform for knowledge exploitation, the need becomes even more imminent. The kind of uncertainty encountered in most of these cases as well as its distributed nature make Dempster-Shafer (D-S) Theory to be an appropriate framework for its representation. However, we have to face the drawback of the computation burden of Dempster's rule of combination due to its combinatorial behavior. Constraint Programming (CP) has proved to be an efficient tool in cases where results have to satisfy some specified properties and pruning of the computation space can be achieved. As D-S theory measures' computation fulfills this requirement, CP seems a promising framework to employ for this purpose. In this paper, we present our approach to use CP to compute the belief and plausibility measures of D-S

Theory and Dempster's rule of combination as well as the results of the effort. As it was expected, the results are quite promising and in many cases impressive.

Keywords: Dempster-Shafer Theory, Uncertainty, Constraint Programming, ECLiPSe Prolog

Bayesian smoothing of decision tree soft predictions and evidential evaluation

Nicolas Sutton-Charani

As for many classifiers, decision trees predictions are naturally probabilistic, with a frequentist probability distribution on labels associated to each leaf of the tree. Those probabilities have the major drawback of being potentially unreliable in the case where they have been estimated from a limited number of examples. Empirical Bayes methods enable the updating of observed probability distributions for which the parameters of the *prior* distribution are estimated from the data. This paper presents an approach of smoothing decision trees predictive binary probabilities with an empirical Bayes method. The update of probability distributions associated with tree leaves creates a correction concentrated on small-sized leaves, which improves the quality of probabilistic tree predictions. The amplitude of these corrections is used to generate predictive belief functions which are finally evaluated through the ensemblist extension of three evaluation indexes of predictive probabilities.

Keywords: Smoothing – Correction – predictive probabilities – decision trees – Bayesian empirical methods – predictive belief functions – uncertain evaluation.

On Solutions of Marginal Problem in Evidence Theory

Jirina Vejnarova

Recently introduced marginal problem – which addresses the question of whether or not a common extension exists for a given set of marginal basic assignments – in the framework of evidence theory is recalled. Sets of solutions are studied in more detail and it is shown, by a simple example, that their structure is much more complicated (i.e. the number of extreme vertices of the convex set of solutions is substantially greater) than that in an analogous problem in probabilistic framework. The concept of product extension of two basic assignments is generalized (via operator of composition) to a finite sequence of basic assignments. This makes possible not only to express the extension, if it exists, in a closed form, but also enables us to find the sufficient condition for the existence of an

extension of evidential marginal problem. Presented approach is illustrated by a simple example.

Keywords: Marginal problem – Extension – Product extension.

Handling mixture optimisation problem using cautious prediction and belief functions

Lucie Jacquin, Abdelhak Imoussaten and Sébastien Destercke

Predictions from classification models are most often used as final decisions. Yet, there are situations where the prediction serves as an input for another constrained decision problem. In this paper, we consider such an issue where the classifier provides imprecise and/or uncertain predictions that need to be managed within the decision problem. More precisely, we consider the optimisation of a mix of material pieces of different types in different containers. Information about those pieces is modelled by a mass function provided by a cautious classifier. Our proposal concerns the statement of the optimisation problem within the framework of belief function. Finally, we give an illustration of this problem in the case of plastic sorting for recycling purposes.

Keywords: Belief functions – Sum rule of mass functions – Mixture optimisation – Plastic sorting.

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