

Article

Exploring Ensemble-Based Class Imbalance Learners for Intrusion Detection in Industrial Control Networks

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Abstract: Classifier ensembles have been utilized in the industrial cybersecurity sector for many years. However, their efficacy and reliability for intrusion detection systems remain questionable in current research, owing to the particularly imbalanced data issue. The purpose of this article is to address a gap in the literature by illustrating the benefits of ensemble-based models for identifying threats and attacks in a cyber-physical power grid. We provide a framework that compares nine cost-sensitive individual and ensemble models designed specifically for handling imbalanced data, including cost-sensitive C4.5, roughly balanced bagging, random oversampling bagging, random undersampling bagging, synthetic minority oversampling bagging, random undersampling boosting, synthetic minority oversampling boosting, AdaC2, and EasyEnsemble. Each ensemble's performance is tested against a range of benchmarked power system datasets utilizing balanced accuracy, Kappa statistics, and AUC metrics. Our findings demonstrate that EasyEnsemble outperformed significantly in comparison to its rivals across the board. Furthermore, undersampling and oversampling strategies were effective in a boosting-based ensemble but not in a bagging-based ensemble.

Keywords: imbalanced data; cost-sensitive learning; ensemble-based models; intrusion detection; industrial control networks



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1. Introduction

As of today, a large number of cyber-attack vectors have put many organizations' critical infrastructure in jeopardy. A successful attack could have serious consequences, such as revenue loss, operational halting, and the disclosure of sensitive information. Furthermore, the complex nature of the infrastructure may lead to vulnerabilities and other unexpected risks. As a result, security mitigation and protection techniques should be prioritized. A potential defense system, such as an intrusion detection and prevention system, is required because it provides an alert when a signature match is detected and actively blocks traffic. It is deployed to supplement firewalls and access control to filter out any malicious activities within the computer network.

Classifier ensembles combine numerous weak learners, for example, base classifiers, to form a more robust learner. Each base learner is programmed and decides concerning a certain target class, while a combiner helps in making estimations [1]. Any classification method, such as decision trees, lazy classifiers, neural networks, or other types of learners, may be used as the base learner. According to its diversity, an ensemble scheme may use a single classifier to create a homogenous ensemble. In contrast, others may employ a variety of learners to create a heterogeneous ensemble [2]. Kuncheva [3] defined ensemble learners on four different perspectives—mixture level, learning algorithm level, attribute level, and data level. Similarly, Rokach [2] argued that an ensemble approach could be characterized by five critical components, namely mixer, diversification, orchestration structure, orchestration size, and commonality.

Such ensemble learners have been used in intrusion detection systems (IDSs) for decades, leading to increased detection accuracy as compared to any individual learners that comprise the ensemble [4]. Creating IDS aims to provide a security system that includes preventative actions against network attack activities. As the primary backbone of an IDS, a machine learning algorithm must be developed and configured appropriately to provide optimum security protection [5]. Because an IDS does not just need performance enhancement, the efficiency of the classifier (e.g., reduced computational cost) is also beneficial in providing a real-time detection method.

Intrusion detection in critical infrastructure (e.g., industrial control networks) is a domain research problem, where choosing a seemingly and computationally efficient algorithm is very challenging. It is a problematic task as each intrusion dataset is unique in terms of network architecture and skewed cyber-attack distributions (e.g., imbalanced data). Recognizing the importance of the aforementioned issues, this article conducts a comparative analysis of various class imbalance ensemble-based intrusion detection models, allowing researchers in this field to understand better the available best-performing ensemble models developed specifically for dealing with imbalanced data. This study focuses on class imbalance individual, bagging, boosting, and hybrid ensemble-based learners applied to power system attack detection, an area that has actually gained insufficient consideration in the present studies. In this work, we examine nine implementations, including cost-sensitive decision tree (CC4.5) [6], roughly balanced bagging (RBBagging) [7], random oversampling bagging (ROSBagging), random undersampling bagging (RUSBagging), synthetic minority oversampling bagging (SMOTEBagging) [8], random undersampling boosting (RUSBoosting) [9], synthetic minority oversampling boosting (SMOTEBoosting) [10], AdaC2 [11], and EasyEnsemble [12].

The aims of the paper lie in two different axes:

- To evaluate the effectiveness of class imbalance learners over a range of imbalance ratios.
- To provide an informed choice in choosing best-performing methods for identifying attacks in terms of performance accuracy and computational complexity.

The rest of this article is divided into four parts. The state-of-the-art techniques for detecting intrusion into a cyber-physical system are summarized in Section 2. Section 3 has a concise summary of the datasets and techniques utilized. Section 4 examines and delves into the result of the experiment benchmark, while Section 5 brings the study to a conclusion.

2. Related Work

A review study usually attempts to identify and classify previously published studies to represent their findings visually. Such an approach is restricted to reviewing the literature on the most frequent techniques for detecting attacks. It is, however, regarded as an unreliable guideline for identifying the best-performing classifiers. For instance, Alimi et al. [13] provided a survey map of research addressing supervised machine learning approaches for intrusion detection and classification in SCADA networks. The study analyzes and contrasts various conventional machine learning methods without considering other essential factors such as class imbalance. By using five publicly available standard intrusion datasets, Shahraki et al. [14] compared three different Adaboost ensembles, i.e., Real Adaboost, Gentle Adaboost, and Modest Adaboost. The study has several limitations despite providing an informed decision about using a boosting-based ensemble for intrusion detection. The performance benchmark is restricted to a small number of ensemble models and the absence of a statistical significance test. Modest Adaboost, on the other hand, has a greater prediction error than the rest algorithms.

Next, we present the most recent solutions for identifying threats and malicious activities in industrial control networks using ensemble techniques. The work of Anton et al. [15] compared SVM and random forest, finding that random forest outperformed SVM marginally. Khan et al. [16] used SMOTE algorithm to tackle the issue of class imbalance. At the same time, a two-level classifier is considered for classifying network anomalies in a gas pipeline

SCADA system. More recently, Upadhyay et al. [17] coupled recursive feature elimination using XGBoost and majority rule aggregation approaches for intrusion detection in a SCADA-based power grid. A total of nine base classifiers were considered to enhance the heterogeneity of the proposed ensemble model.

3. Material and Methods

3.1. Datasets

We use power grid datasets developed by the Oak Ridge National Laboratories to verify the effectiveness of benchmark classification models. There are 128 features in total in the power grid datasets. Such features were derived from four Phasor Measurement Units (PMUs), which estimate electrical pulses in a junction utilizing a standard time reference to guarantee proper time synchronization. The last feature denotes the marker that distinguishes between normal and attack occurrences. Around 5000 examples are included in each collection, with 294 examples of no occurrences, 1221 samples of natural occurrences, and 3711 samples of malicious occurrences, respectively, indicating that the provided datasets are imbalanced in nature (see Table 1). In this study, a total of fifteen binary datasets are considered, where each dataset is labeled with a letter from *a* to *o*. In addition, we estimate the imbalance ratio (*IR*) for each dataset, which is defined as a proportion of examples in the minority classes to majority classes. Consequently, highly skewed datasets have a low *IR*, and vice versa. We consider an $IR > 0.4$ criteria to indicate datasets with less severe imbalance. The *IR* value for each dataset is depicted in Figure 1.

Table 1. The characteristics of the power grid datasets w.r.t. the number of samples that belong to attack or natural class.

Class	Datasets														
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
# of natural examples	1100	1544	1604	1800	1481	1477	1326	1544	1770	1648	1282	1771	1153	1353	1861
# of attack examples	3866	3525	3811	3402	3680	3490	3910	3771	3570	3921	3969	3453	4118	3762	3415

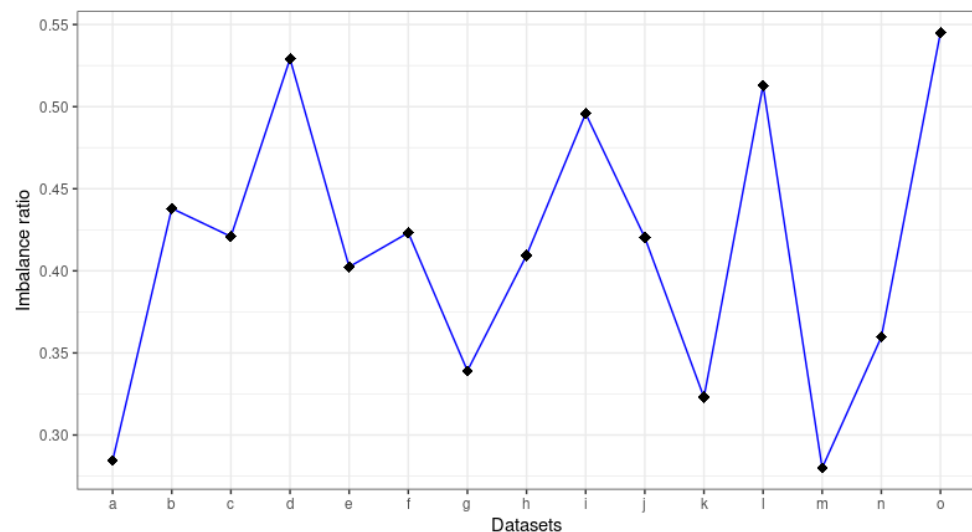


Figure 1. A plot illustrating imbalance ratio for each dataset in the power grid datasets. With the exception of dataset a, g, k, m, and n, all other datasets exhibit a less severe imbalance (e.g., $IR > 0.4$ in our case).

3.2. Methods

This study includes the implementation of nine class imbalance learning models in R [18]. The following section summarizes all classifiers. Each classifier is grouped by the family to which it belongs. Throughout the experiment, all hyperparameters were searched

in order to find the optimal ones. Unless otherwise specified, the default learning settings are utilized.

- Cost-sensitive tree learner.
We apply a pruning procedure and a minimum number of samples for splitting is 2. Additionally, cost ratio is determined by the IR of each dataset.
 - Cost-sensitive decision tree (CSC4.5) [6]. It is a cost associated with misclassifying minority occurrences and is used to alter the training set's class distribution in order to coerce cost-sensitive trees. This mechanism often results in a reduction in the overall misclassification cost, high-cost misclassification, and the size of the tree in a binary prediction task. When training datasets contain a reasonably skewed distribution of classes, smaller trees are a logical byproduct of the tree induction technique.
- Cost-sensitive bagging.
For the following bagging-based ensemble techniques, we used decision tree (e.g., J48) as a base classifier and set the number of bags to 100. Parallel technique is used to accelerate the training process.
 - RBBagging [7]. Compared to conventional bagging-based approaches for imbalanced data, which employ the same amount of dominant and less dominant samples for each training subset, individual models in RBBagging exhibit a greater degree of diversity, which is one of the essential characteristics of ensemble models. Additionally, the suggested strategy fully utilizes all minority examples through under-sampling, which is accomplished quickly through the use of negative binomial distributions.
 - ROSBagging and RUSBagging [8]. Each subset S_k is constructed in ROSBagging by randomly oversampling minority classes in order to form the k -th classifiers. Similarly, RUSBagging creates each subset by randomly under-sampling majority classes. A majority vote is applied when a new instance occurs after construction and each classifier votes. The class with the most votes ends up making the final decision.
 - SMOTEBagging [8]. It entails the production of synthetic instances as part of the subset formation process. According to SMOTE, two components must be determined: the number of nearest neighbors k and the extent to which the less majority class is over-sampled.
- Cost-sensitive boosting.
A large number of trees (100) is employed as a base learner, and the decision tree method is applied. The cost ratio is varied according to the IR of each dataset.
 - RUSBoosting [9]. It combines the Adaboost algorithm and random undersampling technique, which reduces examples from the dominant class at random intervals once that sufficient balance is attained.
 - SMOTEBoosting [10]. It incorporates SMOTE into the Adaboost algorithm. SMOTE creates new minority samples by extrapolating previous samples. SMOTEBoosting exacerbates higher model training time limitation as SMOTE is a more sophisticated and time-consuming data sampling strategy.
 - AdaC2 [11]. Introducing the cost items into the AdaBoost by incorporating the cost items into the weights update approach, AdaC2 directs the learning towards instances of the marginalized class. It thus increases the effectiveness of the learning framework. The resampling strategy of AdaC2 is based on the principle that false negatives gain more weight than false positives, whereas true positives lose more weight than true negatives.
- Cost-sensitive hybrid ensemble.
Similarly, 100 decision trees were used to construct the ensemble, while the cost ratio varies depending on the dataset's IR.

- EasyEnsemble [12]. It employs a two-stage ensemble technique that incorporates random undersampling during bagging iterations and trains the base classifier using AdaBoost. It trains the base classifier by doing bagging in an unsupervised manner.

4. Result and Discussion

In this study, we used nine cost-sensitive learners to analyze fifteen power grid-based intrusion datasets, resulting in a total of 135 classifier-dataset combinations. In order to avoid bias results due to performance results that could be acquired by chance, we used stratified multiple hold-outs (also known as subsampling). Subsampling is carried out by several runs (ten times in our case), partitioning the data set D into a training and a test set by a predetermined proportion, e.g., 75% training and 25% test set in our case. This stratified process allows us to keep the IR of the original dataset. The results of the test are the mean of ten different elements. Since we dealt with the imbalanced classification problem, we adopted three different metrics to measure the classifiers' performance: balance accuracy, Cohen's kappa, and area under ROC curve (AUC). These metrics are calculated in the following ways:

$$\text{Balanced accuracy} = \frac{TPR + TNR}{2} \quad (1)$$

$$Kappa = \frac{2 \times (TP \times TN - FN \times FP)}{(TP + FP) \times (FP + TN) + (TP + FN) \times (FN + TN)} \quad (2)$$

$$AUC = \int_0^1 \frac{TP}{TP + TN} d \frac{FP}{FP + FN} \quad (3)$$

The average performance of all classifiers over the benchmarked datasets is depicted in Figure 2. CSC4.5 exhibits greater variability in performance compared to other algorithms. This result is similar to that of [19], where the cost-sensitive tree such as CSC4.5 should be designed not only by considering the misclassification cost but also by considering the cost of the tests. Furthermore, our experiment revealed that EasyEnsemble is the top performer across all validation metrics, while AdaC2 is the worst performer in terms of balanced accuracy and kappa metrics. The results are pretty reasonable since EasyEnsemble is built using a two-level ensemble which is more advantageous than other standard ensemble models.

We run hierarchical clustering of classifiers and datasets based on their average performance value (see Figure 3). An Euclidean distance and Ward's clustering criterion were utilized to carry out the clustering task. Our study reveals three different clusters of classifiers and datasets. The clusters of classifiers are generally consistent with the original groups, such as bagging and boosting-based ensembles. However, the performance of AdaC2 does not appear to belong to any clusters when it is measured by balanced accuracy and kappa metrics. On the contrary, AdaC2 is somewhat comparable to other boosting and hybrid-based ensemble models w.r.t. AUC metric. The clusters also revealed significant performance differences across power grid datasets. For instance, the first cluster (e.g., red dendrogram) consists of the highly imbalanced datasets with low IR score, while, on the other hand, the third cluster (e.g., blue dendrogram) is comprised of less severe imbalanced datasets.



Figure 2. Violin plot showing a full performance distribution of classifiers as measured by balanced accuracy (a), Cohen's kappa (b), and AUC (c) metrics. Classifiers are arranged in descending order based on their mean value (shown as dots in the figure).

Consecutively, we assess the performance differences of classifiers across datasets based on the Nemenyi test. When the corresponding average ranks of two classifiers differ by at least the critical difference (CD), two classifiers are considered significantly different. Figure 4 confirms that EasyEnsemble is on the top rank, followed by RUSBoosting, and SMOTEBoosting. The performance of the top three algorithms is significantly different from any other algorithms in terms of balanced accuracy and kappa metrics. For overall assessment, the performance of EasyEnsemble is rather predictable, since it is a two-level ensemble method that involves bagging and boosting. In addition, our experimental findings confirm that oversampling strategies perform well in boosting-based ensemble, despite having the risk of adding extra noise to the training data sets. In similar fashion, introducing an undersampling strategy to boosting ensemble demonstrates an advantage, aside from its self-evident issue: by excluding examples from the dominant class, the classifier may overlook essential concepts associated with the dominant class. The performance difference of AdaC2 in various metrics implies that AUC is not necessarily the best metric for evaluating classification performance for the IDS data problem, particularly anomaly-based IDS that demands a low false alarm rate [20,21].

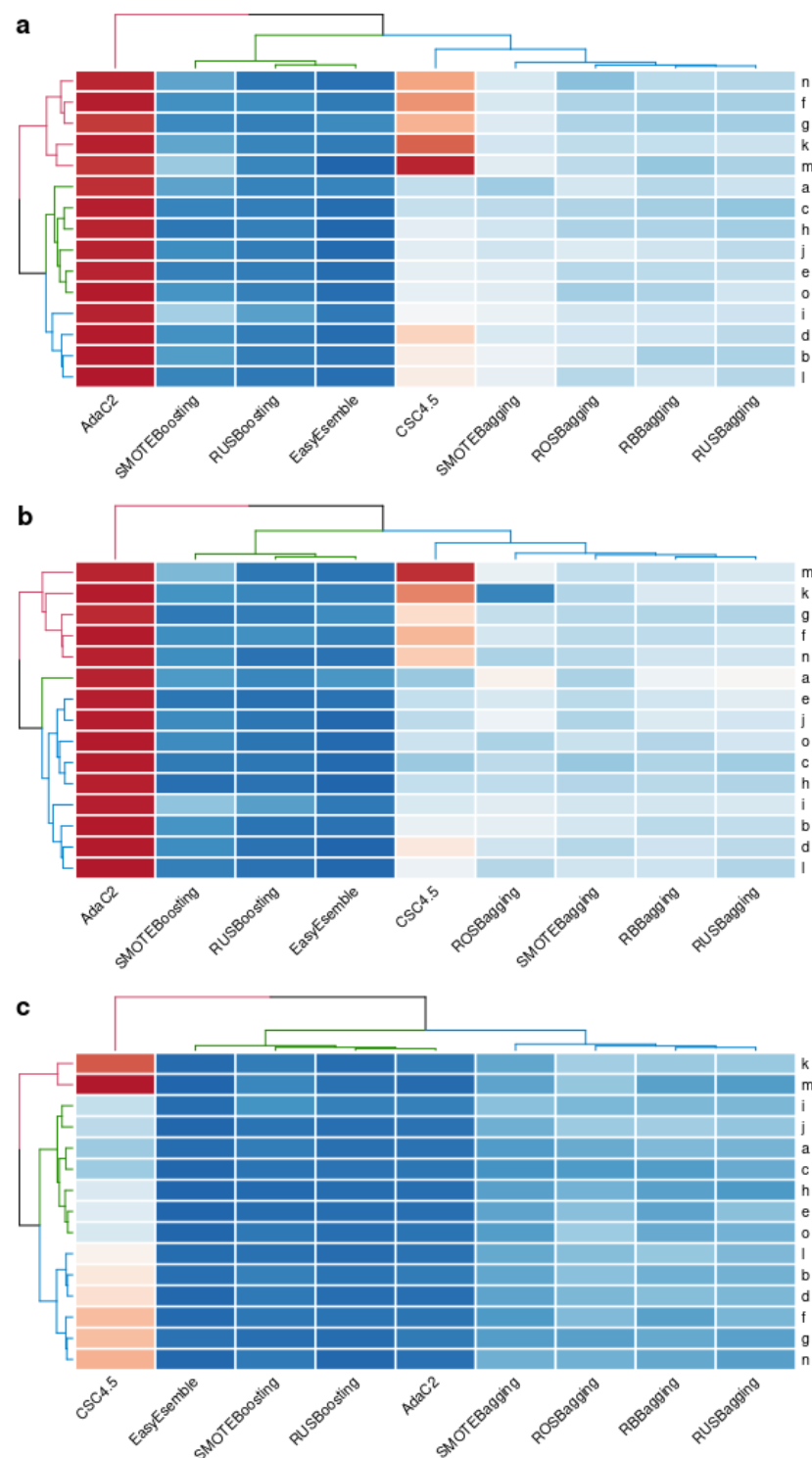
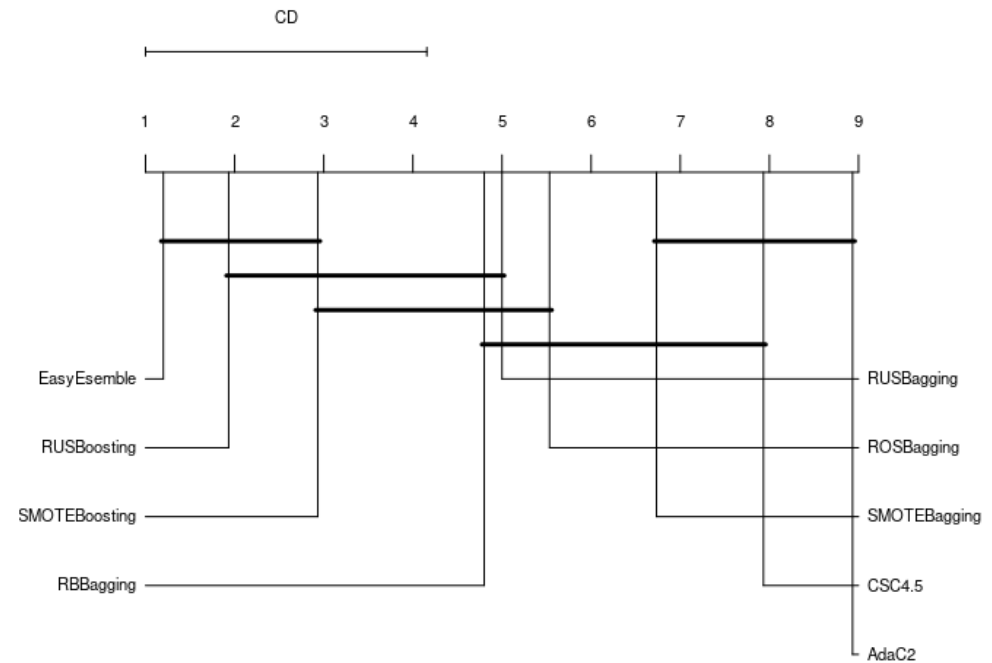


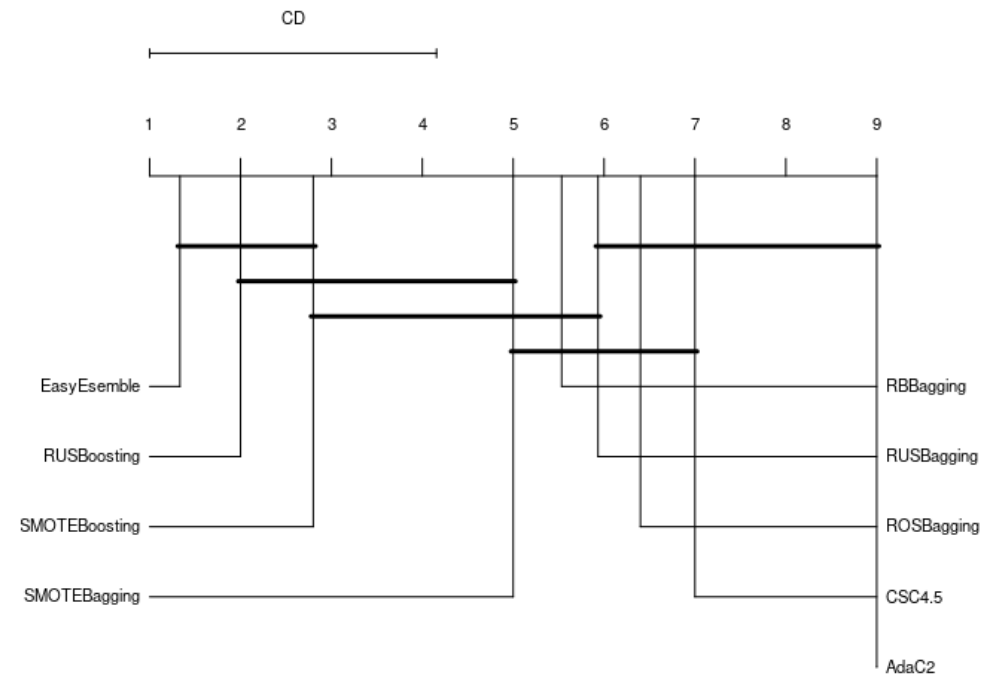
Figure 3. Hierarchical clusters of classifiers and datasets in terms of balanced accuracy (a), kappa (b), and AUC (c) metrics. The clusters are shown by three colors of dendrogram branches.

Finally, we report each algorithm’s complexity concerning the time required for training and testing. Note that training and testing time were captured at one time hold-out. As shown in Figure 5 and Table 2, CSC4.5 took a larger amount of time to complete the training but a shorter amount of time during the testing. The result is rather intuitive, as during the training stage of a dataset with n samples and d features, CSC4.5 is required to sort the data and determine the right threshold, which takes $O(n \times \log(n) \times d)$. The classifier is quite fast (e.g., $O(nodes)$) during the testing stage as it only identifies the nodes that are normally

stored as if-then rules. For overall comparison, despite outperforming other algorithms, EasyEnsemble took approximately 2.7 s to complete the testing task. EasyEnsemble is not the best choice, given that IDS models typically require a real-time detection approach. We suggest that RUSBoosting may be a viable method for implementing IDS in real-world industrial control networks settings.



(a)



(b)

Figure 4. Cont.

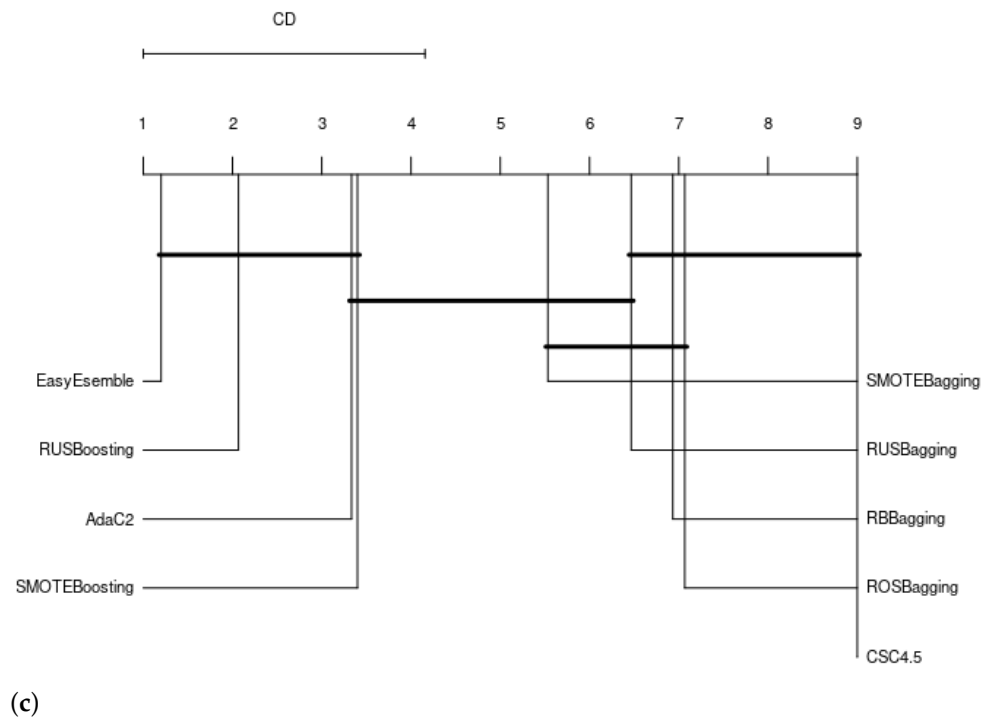


Figure 4. Comparison of the average performance values such as balanced accuracy (a), kappa (b), and AUC (c), across all datasets attained by all classifiers using the Nemenyi critical difference plot.

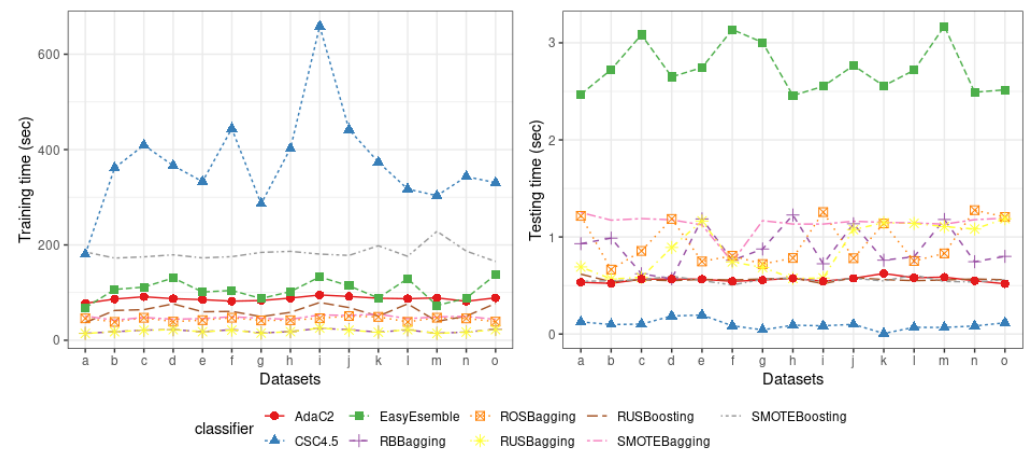


Figure 5. Time required by each classifier in the training and testing stage.

Table 2. Average training and testing time required for each algorithm measured in seconds.

Algorithm	Training Time	Testing Time
CSC4.5	370.09	0.097
RBBagging	19.39	0.887
ROSBagging	44.06	0.948
RUSBagging	19.16	0.881
SMOTEBagging	47.88	1.137
RUSBoosting	60.74	0.562
SMOTEBoosting	183.01	0.557
AdaC2	86.92	0.560
EasyEnsemble	105.10	2.736

5. Conclusions

This study filled the research gap by reporting the pros and cons of cost-sensitive ensemble-based classifiers for classifying and detecting cyberattacks in industrial control networks. Nine cost-sensitive classifiers and fifteen power grid datasets were utilized in the experiment. Despite being faster than the competitors, EasyEnsemble still took the most time throughout the testing stage, leading us to assume that this classifier is unsuitable for this application domain. Additionally, we identify the limitation of our study. This study concentrated on a small number of classifiers and datasets, making it unable to provide a complete validation. We believe that expanding the number of classifiers and datasets would be interesting for future works.

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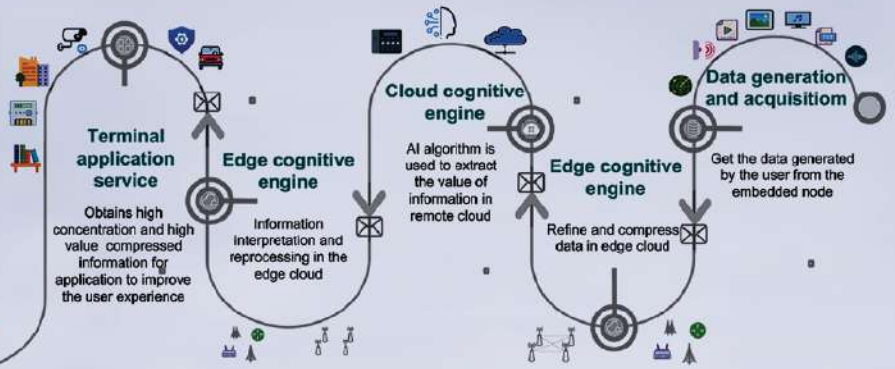
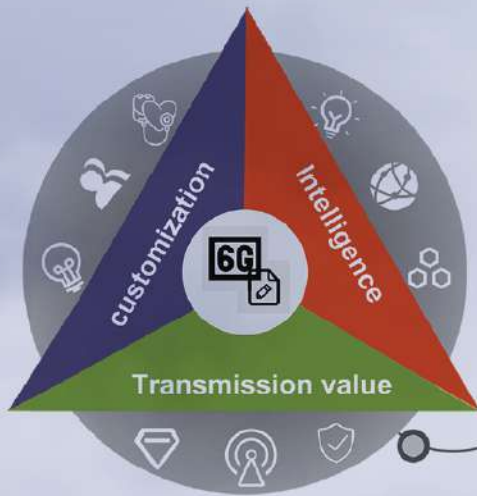
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Interests: body area networks; Internet of Things; agent-based computing

[Special Issues, Collections and Topics in MDPI journals](#)

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




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Interests: advanced data management; big data management; business intelligence; database management systems; data pre-processing; data stream management; data-intensive flows; data warehousing; metadata management; NOSQL tools; OLAP tools

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Dr. Moulay A. Akhloufi

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Interests: machine learning; deep learning; computer vision; robotics; medical imaging

Special Issues, Collections and Topics in MDPI journals

Special Issue in [Big Data and Cognitive Computing: Machine Learning and Data Analysis for Image Processing](#) (/journal/BDCC/special_issues/image_detection)

Special Issue in [International Journal of Environmental Research and Public Health: Smart Healthcare Services in Internet of Healthcare Things](#) (/journal/ijerph/special_issues/Smart_Healthcare_Services)

Special Issue in [Sensors: Deep Learning Methods for Remote Sensing](#) (/journal/sensors/special_issues/deep_learn_method_RS)

Topics: [Deep Learning and Transformers' Methods Applied to Remotely Captured Data](#) (/topics/remo_data_deep_learn)



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Special Issues, Collections and Topics in MDPI journals

Special Issue in [Algorithms: Algorithms for the Resource Management of Large Scale Infrastructures](#) (/journal/algorithms/special_issues/Algorithms_Resource_Management)



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Interests: risk assessment and management; intrusion detection; adversary simulation; distributed ledger

Special Issues, Collections and Topics in MDPI journals

Special Issue in [Big Data and Cognitive Computing: Cyber Security in Big Data Era](#) (/journal/BDCC/special_issues/cyb_bd)



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UC3M-BS Institute of Financial Big Data (IFiBiD), Departamento de Ingeniería Telemática, Universidad Carlos III de Madrid, 28911 Madrid, Spain

Interests: big data; industrial informatics; real-time systems; real-time Java; distributed systems



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Computing and Mathematics Department, Université Paris-Dauphine-PSL, 75016 Paris, France

Interests: data wrangling and integration; scientific workflows; data and process provenance; knowledge graphs; eScience



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Interests: cloud computing; Internet of Things; social graphs; big data; future internet; resource provisioning



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Interests: business intelligence & big data management; business analytics & data discovery; distributed data warehousing; intensive queries in big data warehouses; mapreduce and spark technologies; text warehousing & OLAP text cubes; semantic OLAP & social OLAP; analysis of social graphs cubes; community detection and evaluation

Special Issues, Collections and Topics in MDPI journals

Special Issue in [Electronics: Applications and Methodologies of Artificial Intelligence in Big Data Analysis \(/journal/electronics/special_issues/applications_\)](/journal/electronics/special_issues/applications_)



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Special Issues, Collections and Topics in MDPI journals

Special Issue in [Computers: Artificial Intelligence for Health \(/journal/computers/special_issues/AI_Health\)](/journal/computers/special_issues/AI_Health)

Special Issue in [Future Internet: Advances on Cloud Computing and Internet of Things \(/journal/futureinternet/special_issues/A_Cloud_Computing_IoT\)](/journal/futureinternet/special_issues/A_Cloud_Computing_IoT)

Special Issue in [Sensors: Intelligent Systems for Clinical Care and Remote Patient Monitoring \(/journal/sensors/special_issues/intelligent_systems_ccrpm\)](/journal/sensors/special_issues/intelligent_systems_ccrpm)

Special Issue in [Sensors: Digital Healthcare Leveraging Edge Computing and the Internet of Things \(/journal/sensors/special_issues/digihealth_IoT\)](/journal/sensors/special_issues/digihealth_IoT)

Special Issue in [Computers: Advances of Machine and Deep Learning in the Health Domain \(/journal/computers/special_issues/AI_health_2022\)](/journal/computers/special_issues/AI_health_2022)

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Special Issues, Collections and Topics in MDPI journals

Special Issue in [Big Data and Cognitive Computing: Machine Learning and Artificial Intelligence for Health Applications on Social Networks \(/journal/BDCC/special_issues/health_applications\)](/journal/BDCC/special_issues/health_applications)

Special Issue in [Sensors: Current Trends and Practices in Smart Health Monitoring \(/journal/sensors/special_issues/SHM_Health_Monitoring\)](/journal/sensors/special_issues/SHM_Health_Monitoring)



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Interests: recommender systems; social network analysis; machine learning; data mining



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Interests: machine learning; data science; data preprocessing; computational intelligence; big data analytics; deep learning



Mr. Felix Gessert

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Database and Information Systems Group, Computer Science Department, University of Hamburg, 20146 Hamburg, Germany

Interests: cloud computing, Database/Backend-as-a-Service; NoSQL, scalable databases, distributed Systems; Web Protocols, REST, Microservices; application architecture, mobile; probabilistic data structures, stream processing; polyglot persistence



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Interests: data management; computational analysis of natural languages; information retrieval; cognitive computing; high performance computing; natural language processing; and personalized learning



Prof. Dr. Mohsen Guizani

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Interests: wireless communications and mobile computing; computer networks; mobile cloud computing; security and smart grid

Special Issues, Collections and Topics in MDPI journals

Special Issue in [Sensors: Sensor Networks for Collaborative and Secure Internet of Things \(Journal/sensors/special_issues/of_Things\)](#)



Prof. Dr. Takahiro Hara

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Department of Multimedia Engineering, Osaka University, Osaka 565-0871, Japan

Interests: database systems; mobile computing; social computing; web mining; location privacy; time-series analysis

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Special Issues, Collections and Topics in MDPI journals

Special Issue in **Sensors: Algorithm and Distributed Computing for the Internet of Things** (/journal/sensors/special_issues/Algorithm_and_Distributed_Computing_for_IoTs)

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**Prof. Dr. Yoichi Hayashi**

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Special Issues, Collections and Topics in MDPI journals

Special Issue in **Big Data and Cognitive Computing: Big Data Analytic: From Accuracy to Interpretability** (/journal/BDCC/special_issues/Big_Data_Analytic)

Special Issue in **Machine Learning and Knowledge Extraction: Transparency of Deep Neural Networks** (/journal/make/special_issues/Transparency)

Special Issue in **Electronics: Interpretable Deep Learning in Electronics, Computer Science and Medical Imaging** (/journal/electronics/special_issues/interpretable_deep_learning)

Special Issue in **Electronics: 10th Anniversary of Electronics: Recent Advances in Artificial Intelligence** (/journal/electronics/special_issues/anniversary_in_AI_Electronics)

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Interests: data science; web and network science; user behavior; data mining; recommender systems; social computing; social media

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Interests: artificial intelligence; data mining; soft computing; parallel processing

Special Issues, Collections and Topics in MDPI journals

Special Issue in **Electronics: Recent Advances and Emerging Applications of Internet of Things** (/journal/electronics/special_issues/Advances_Applications_IoT)

Special Issue in **Electronics: Recent Advances and Emerging Applications of Internet of Things in Industrial 4.0 Era** (/journal/electronics/special_issues/8UHFOQHFS)

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Interests: cognitive computing; machine learning; artificial intelligence; big data; biomedical devices

Special Issues, Collections and Topics in MDPI journals

Special Issue in **Big Data and Cognitive Computing: COVID-19: Medical Internet of Things and Big Data Analytics** (/journal/BDCC/special_issues/medical_data)

Special Issue in **Brain Sciences: Neuroinformatics and Signal Processing** (/journal/brainsci/special_issues/Neuroinformatics_Signal)

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[Back to Top](#)

Interests: machine learning; affective computing; computational culture; serious games; player modelling; education; sentiment analysis



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Interests: data mining; machine learning; statistical relational artificial intelligence; lifted inference; web science; plant phenotyping



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Interests: machine learning; big data analytics; deep architectures for audio analysis; multimodal deep learning

Special Issues, Collections and Topics in MDPI journals

Special Issue in ***Big Data and Cognitive Computing: Applied Deep Learning: Business and Industrial Applications*** (/journal/BDCC/special_issues/Applied_Deep_Learning)



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Interests: blockchain systems; telecommunication networks information systems personal communications networking cloud and edge computing

Special Issues, Collections and Topics in MDPI journals

Special Issue in ***Big Data and Cognitive Computing: Cognitive Services Integrating with Big Data, Clouds and IoT*** (/journal/BDCC/special_issues/iot)

Special Issue in ***Sensors: The Architectures, Systems, and Applications of Internet of Things for Smart Cities*** (/journal/sensors/special_issues/smart_cities)

Special Issue in ***Sensors: Sensors for Information Technology, Electronics and Mobile Communication*** (/journal/sensors/special_issues/SITEMC)

Special Issue in ***Sensors: Blockchain as a Service: Architecture, Networking and Applications*** (/journal/sensors/special_issues/Blockchain_Architecture_Networking)

/Blockchain Architecture Networking

Special Issue in ***Sensors: AI-Driven Sensing for Small Object Recognition*** (/journal/sensors/special_issues/W474IZMB9S)



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Special Issues, Collections and Topics in MDPI journals

Special Issue in ***Sensors: Selected papers from Smart Data 2018 & Big Data Service 2018*** (/journal/sensors/special_issues/SmartData2018)

Special Issue in ***Applied Sciences: Big Data Analysis and Visualization*** (/journal/applsci/special_issues/Big_Data_Visualization)

Topical Collection in ***Applied Sciences: Big Data Analysis and Visualization II*** (/journal/applsci/special_issues/Big_Data_Analysis)

Special Issue in ***Applied Sciences: Latest Advances and Prospects in Big Data*** (/journal/applsci/special_issues/Advances_and_Prospects_in_Big_Data)

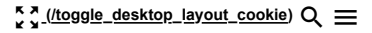
Special Issue in ***Mathematics: Soft Computing for Social Media Data Analytics*** (/journal/mathematics/special_issues/Soft_computing_data)

Topics: ***Social Computing and Social Network Analysis*** (/topics/Social_Computing_Network_Analysis)

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Special Issues, Collections and Topics in MDPI journals

Topics: **Complex Systems and Network Science** (/topics/Complex_Systems_Network_Science)



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Interests: big data analysis; social media analysis; cloud computing; data mining; machine learning

Special Issues, Collections and Topics in MDPI journals

Special Issue in **Applied Sciences: Cloud Computing for Big Data Analysis** (/journal/applsci/special_issues/Cloud_Computin_Big_Data_Analysis)

Special Issue in **Algorithms: Scalable Programming Models and Algorithms for Big Data** (/journal/algorithms/special_issues/Scalable_Programming_Big_Data)

Special Issue in **Electronics: Advances in Machine Learning, IoT and Big Data for Sustainable Communities** (/journal/electronics/special_issues/IE_2022)

Special Issue in **Big Data and Cognitive Computing: Review Papers in Big Data, Cloud-Based Data Analysis and Learning Systems** (/journal/BDCC/special_issues/Review_Big_Data)

Special Issue in **Future Internet: Big Data Analytics in Green Supply Chain and Social Media Influences** (/journal/futureinternet/special_issues/163853G02V)



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Special Issues, Collections and Topics in MDPI journals

Special Issue in **Sensors: Applied Data Science and Intelligence** (/journal/sensors/special_issues/ADSI)



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Department of Mathematics and Computer Sciences, University Of Catania, Catania, Italy

Interests: distributed systems; cloud computing; edge computing; Internet of Things (IoT); trust; reputation; intelligent systems

Special Issues, Collections and Topics in MDPI journals

Special Issue in **Big Data and Cognitive Computing: Data Mining and the Future of Cybersecurity** (/journal/BDCC/special_issues/data_cybersecurity)



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Interests: data science; big data analytics, geometry and topology of data and information; digital content analytics; computational science (including innovative models and paradigms from digital humanities and quantitative and qualitative social sciences); applications in engineering, psychoanalysis, astronomy and in many fields

Special Issues, Collections and Topics in MDPI journals

Special Issue in **Journal of Imaging: Big Visual Data Processing and Analytics** (/journal/jimaging/special_issues/processing_and_analytics)



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Interests: experimental design; statistical quality control; risk analysis and risk assessment; statistical modelling; computational statistics; data fusion; trend analysis; e-learning methodologies; computational statistics; Software R

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Interests: big data applications; parallel algorithms; clustering; machine learning algorithms

Special Issues, Collections and Topics in MDPI journals

Special Issue in ***Big Data and Cognitive Computing: Learning with Big Data: Scalable Algorithms and Novel Applications*** (/journal/BDCC/special_issues/Novel_Applications)

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Faculty of Science, Technology and Communication (FSTC), Interdisciplinary Centre for Security, Reliability and Trust (SnT), University of Luxembourg, 4365 Esch-sur-Alzette, Luxembourg

Interests: data mining; social media analysis; information networks; biological networks; security and privacy

Special Issues, Collections and Topics in MDPI journals

Special Issue in ***Computers: Formal Methods*** (/journal/computers/special_issues/formal_methods)

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Interests: High-Performance Data Analytics (HPDA); cognitive computing in education

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Interests: distributed systems; machine learning; IT security; internet of things

Prof. Dr. Philippe Rigaux

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Interests: music information retrieval; complex data modelling; temporal data

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School of Information, Systems and Modelling, Faculty of Engineering and IT, University of Technology Sydney, Sydney, NSW, Australia

Interests: data matching; machine learning; artificial intelligence; cognitive computing; crowdsourcing

Prof. Dr. Giuseppe Maria Luigi Sarne

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Interests: trust and reputation systems; Internet of Things; distributed artificial intelligence; intelligent transportation systems; multiagent systems

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




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Department of Computer Science, Universidad de Alcalá, Alcalá de Henares, Madrid, Spain

Interests: business analytics; machine learning; distributed systems; knowledge representation

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Interests: big data analysis; parallel machine learning; scalable data mining; distributed computing systems; parallel programming and data science

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Dr. Isaac Triguero

[Website1 \(http://www.cs.nott.ac.uk/~pszit/index.html\)](http://www.cs.nott.ac.uk/~pszit/index.html) [Website2 \(https://scholar.google.com/citations?hl=en&user=KogUP4YAAAAJ\)](https://scholar.google.com/citations?hl=en&user=KogUP4YAAAAJ)

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School of Computer Science, University of Nottingham, Jubilee Campus, Wollaton Road, Nottingham NG8 1BB, UK

Interests: machine learning; data mining, computational intelligence; big data analytics; data pre-processing; evolutionary algorithms



Prof. Dr. Paolo Trunfio

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Interests: big data; smart objects; distributed computing; cloud computing



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Interests: circular economy; technical-economic project evaluation; environmental and energy economics; environmental and energy behavior; environmental performance of firms; quantitative methods

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Interests: social network analysis; databases; artificial intelligence; business intelligence; social IoT

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Prof. Dr. Sebastián Ventura

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Interests: inconsistent databases; view updating; integration techniques; logic programming; health information system

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


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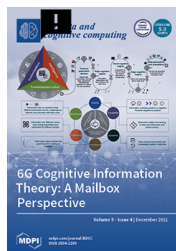
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Abstract Self-assessment is one of the strategies used in active teaching to engage students in the entire learning process, in the form of self-regulated academic learning. This study aims to assess the possibility of including self-evaluation in the student's final grade, not just as [...] [Read more.](#)

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Semantic Trajectory Analytics and Recommender Systems in Cultural Spaces. ([/2504-2289/5/4/80](#))

by [Sotiris Angelis \(https://sciprofiles.com/profile/1845110\)](https://sciprofiles.com/profile/1845110), [Konstantinos Kotis \(https://sciprofiles.com/profile/1022894\)](https://sciprofiles.com/profile/1022894) and [Dimitris Spiliotopoulos \(https://sciprofiles.com/profile/1016718\)](https://sciprofiles.com/profile/1016718)

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Abstract Semantic trajectory analytics and personalised recommender systems that enhance user experience are modern research topics that are increasingly getting attention. Semantic trajectories can efficiently model human movement for further analysis and pattern recognition, while personalised recommender systems can adapt to constantly changing user [...] [Read more.](#)

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Spatial Sound in a 3D Virtual Environment: All Bark and No Bite? ([/2504-2289/5/4/79](#))

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[Patrick Ruediger-Flore \(https://sciprofiles.com/profile/author/bkIKd01CdFjSE15dXpISGE5MFRsQWZxc2M0TStCskxlcTM0SjBzbTlVt0=\)](https://sciprofiles.com/profile/author/bkIKd01CdFjSE15dXpISGE5MFRsQWZxc2M0TStCskxlcTM0SjBzbTlVt0=),

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
Abstract Although the focus of Virtual Reality (VR) lies predominantly on the visual world, acoustic components enhance the functionality of a 3D environment. To study the interaction between visual and auditory modalities in a 3D environment, we investigated the effect of auditory cues on [...] [Read more](#).

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DASentimental: Detecting Depression, Anxiety, and Stress in Texts via Emotional Recall, Cognitive Networks, and Machine Learning (/2504-2289/5/4/77)by [Asra Fatima](#) (<https://sciprofiles.com/profile/author/VVpZZW9UMmMyemt1Sm1zUHpyU0tXSzN5eGhLODJ6TTZrRnA0bUhbUTHCVT0=>),[Ying Li](#) (<https://sciprofiles.com/profile/1772577>),[Thomas Trenholm Hills](#) (<https://sciprofiles.com/profile/author/SUZpbmd2NmJtYU1Ja1BuNFFIQ3BTWW1UUDFlEVLJ2ZTJrR0RwME1mUEE5MD0=>) and[Massimo Stella](#) (<https://sciprofiles.com/profile/397752>)*Big Data Cogn. Comput.* **2021**, *5*(4), 77; <https://doi.org/10.3390/bdcc5040077> (<https://doi.org/10.3390/bdcc5040077>) - 13 Dec 2021

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Abstract Most current affect scales and sentiment analysis on written text focus on quantifying valence/sentiment, the primary dimension of emotion. Distinguishing broader, more complex negative emotions of similar valence is key to evaluating mental health. We propose a semi-supervised machine learning model, DASentimental, to [...] [Read more](#).

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GO-E-MON: A New Online Platform for Decentralized Cognitive Science (/2504-2289/5/4/76)by [Satoshi Yazawa](#) (<https://sciprofiles.com/profile/1144405>),[Kikue Sakaguchi](#) (<https://sciprofiles.com/profile/author/Q1hVeIRyRnJiYzdKbG4yV3NFbMRDM1JndDJHMHAvdTNxaFB1Q0U4TVh3Zz0=>) and[Kazuo Hiraki](#) (<https://sciprofiles.com/profile/author/TWdPUiY3bVvaVmc3eUhYUjyODVkeTM2MXZMbDBqWTdSMETPNUNTfVfNRZz0=>)*Big Data Cogn. Comput.* **2021**, *5*(4), 76; <https://doi.org/10.3390/bdcc5040076> (<https://doi.org/10.3390/bdcc5040076>) - 13 Dec 2021

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Abstract Advances in web technology and the widespread use of smartphones and PCs have proven that it is possible to optimize various services using personal data, such as location information and search history. While considerations of personal privacy and legal aspects lead to situations [...] [Read more](#).



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Screening of Potential Indonesia Herbal Compounds Based on Multi-Label Classification for 2019 Coronavirus Disease ((2504-2289/5/4/75)by  **Aulia Fadli** (<https://sciprofiles.com/profile/author/bTE5bmdjTlc4eIE5U3pYRnICTFAxZkZPWkNIY2JGUU1YTJRgemZ1N1J5VT0=>), **Wisnu Ananta Kusuma** (<https://sciprofiles.com/profile/1855909>), **Annisa** (<https://sciprofiles.com/profile/author/WVY3eHR2aUhiY1hOWThGyK5PaFB1WVpoT3U4YjcvYmd5UlHNS2s4YVo4e20=>), **Irmanida Batubara** (<https://sciprofiles.com/profile/575887>) and **Rudi Heryanto** (<https://sciprofiles.com/profile/author/YUE4dFJqeGhrZVdqQ3dYZIdLUkRGZG5QNmg1Y1JneTQxaW9CLzJXQXZzbz0=>)*Big Data Cogn. Comput.* **2021**, *5*(4), 75; <https://doi.org/10.3390/bdcc5040075> (<https://doi.org/10.3390/bdcc5040075>) - 09 Dec 2021**Cited by 1** ((2504-2289/5/4/75#citedby) | Viewed by 1951**Abstract** Coronavirus disease 2019 pandemic spreads rapidly and requires an acceleration in the process of drug discovery. Drug repurposing can help accelerate the drug discovery process by identifying new efficacy for approved drugs, and it is considered an efficient and economical approach. Research in [...] **Read more.**(This article belongs to the Topic **Machine and Deep Learning** ([/topics/Machine_Deep_Learning](#)))**► Show Figures**[\(BDCC/BDCC-05-00075/article_deploy/html/images/BDCC-05-00075-g001-550.jpg\)](#), [\(BDCC/BDCC-05-00075/article_deploy/html/images/BDCC-05-00075-g002-550.jpg\)](#), [\(BDCC/BDCC-05-00075/article_deploy/html/images/BDCC-05-00075-g003-550.jpg\)](#), [\(BDCC/BDCC-05-00075/article_deploy/html/images/BDCC-05-00075-g004-550.jpg\)](#), [\(BDCC/BDCC-05-00075/article_deploy/html/images/BDCC-05-00075-g005-550.jpg\)](#), [\(BDCC/BDCC-05-00075/article_deploy/html/images/BDCC-05-00075-g006-550.jpg\)](#), [\(BDCC/BDCC-05-00075/article_deploy/html/images/BDCC-05-00075-g007-550.jpg\)](#), [\(BDCC/BDCC-05-00075/article_deploy/html/images/BDCC-05-00075-g008-550.jpg\)](#), [\(BDCC/BDCC-05-00075/article_deploy/html/images/BDCC-05-00075-g009-550.jpg\)](#)




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  [\(\(2504-2289/5/4/74/pdf?version=1638972672\)\)](#)**Fusion of Moment Invariant Method and Deep Learning Algorithm for COVID-19 Classification ((2504-2289/5/4/74)**by  **Ervin Gubin Moug** (<https://sciprofiles.com/profile/1273998>), **Chong Joon Hou** (<https://sciprofiles.com/profile/author/V2ZzblRHUmXvUkVius9kRkZYU1I0U21CYkQ4ZGdRUXFWdkiTWm5taUg5Yz0=>), **Maisarah Mohd Sufian** (<https://sciprofiles.com/profile/1889677>),  **Mohd Hanafi Ahmad Hijazi** (<https://sciprofiles.com/profile/1279595>), **Jamal Ahmad Dargham** (<https://sciprofiles.com/profile/author/Yi9sYwVtVeW5SeE5JYzdyZGE0RFVIOw5EWDZ0THFNvlpZbitueERrYVNCMD0=>) and **Sigeru Omatsu** (<https://sciprofiles.com/profile/author/VUJRM2x4TIN4MFQxM0xCL1VknVpuUUxtbFRnQTBkUnA4NS9WSVZpVnRNND0=>)*Big Data Cogn. Comput.* **2021**, *5*(4), 74; <https://doi.org/10.3390/bdcc5040074> (<https://doi.org/10.3390/bdcc5040074>) - 08 Dec 2021

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Abstract The COVID-19 pandemic has resulted in a global health crisis. The rapid spread of the virus has led to the infection of a significant population and millions of deaths worldwide. Therefore, the world is in urgent need of a fast and accurate COVID-19 [...] **Read more.****► Show Figures**[\(BDCC/BDCC-05-00074/article_deploy/html/images/BDCC-05-00074-g001-550.jpg\)](#), [\(BDCC/BDCC-05-00074/article_deploy/html/images/BDCC-05-00074-g002-550.jpg\)](#), [\(BDCC/BDCC-05-00074/article_deploy/html/images/BDCC-05-00074-g003-550.jpg\)](#), [\(BDCC/BDCC-05-00074/article_deploy/html/images/BDCC-05-00074-g004-550.jpg\)](#), [\(BDCC/BDCC-05-00074/article_deploy/html/images/BDCC-05-00074-g005-550.jpg\)](#), [\(BDCC/BDCC-05-00074/article_deploy/html/images/BDCC-05-00074-g006-550.jpg\)](#), [\(BDCC/BDCC-05-00074/article_deploy/html/images/BDCC-05-00074-g007-550.jpg\)](#), [\(BDCC/BDCC-05-00074/article_deploy/html/images/BDCC-05-00074-g008-550.jpg\)](#), [\(BDCC/BDCC-05-00074/article_deploy/html/images/BDCC-05-00074-g009-550.jpg\)](#), [\(BDCC/BDCC-05-00074/article_deploy/html/images/BDCC-05-00074-g010-550.jpg\)](#), [\(BDCC/BDCC-05-00074/article_deploy/html/images/BDCC-05-00074-g011-550.jpg\)](#), [\(BDCC/BDCC-05-00074/article_deploy/html/images/BDCC-05-00074-g012-550.jpg\)](#)

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  [\(\(2504-2289/5/4/73/pdf?version=1638873118\)\)](#)**Explainable COVID-19 Detection on Chest X-rays Using an End-to-End Deep Convolutional Neural Network Architecture ((2504-2289/5/4/73)**by  **Mohamed Chetoui** (<https://sciprofiles.com/profile/author/REJ6TDVYeXFZa0ZUM3RyVE54dEIYUGxQOXZPbGVMt5Eakhl2VRWkMrRT0=>), **Moulay A. Akhloufi** (<https://sciprofiles.com/profile/309135>), **Bardia Yousefi** (<https://sciprofiles.com/profile/author/ZHdNMjZ1Q0xzMVVwU1dUMDhGSjZncWF5ZGZyWZ6QWNCbTBXTmEvk1RYUT0=>) and **El Mostafa Bouattane** (<https://sciprofiles.com/profile/author/cExHSC9wS0hNTGloZjJReUpxdlJKVlIRcUk2bJBSFBwSig4QXROTU53MD0=>)*Big Data Cogn. Comput.* **2021**, *5*(4), 73; <https://doi.org/10.3390/bdcc5040073> (<https://doi.org/10.3390/bdcc5040073>) - 07 Dec 2021**Cited by 4** ((2504-2289/5/4/73#citedby) | Viewed by 2225**Abstract** The coronavirus pandemic is spreading around the world. Medical imaging modalities such as radiography play an important role in the fight against COVID-19. Deep learning (DL) techniques have been able to improve medical imaging tools and help radiologists to make clinical decisions for [...] **Read more.**(This article belongs to the Special Issue **COVID-19: Medical Internet of Things and Big Data Analytics** ([/journal/BDCC/special_issues/medical_data](#)))**► Show Figures**[\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-ag-550.jpg\)](#), [\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-g001-550.jpg\)](#), [\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-g002-550.jpg\)](#), [\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-g003-550.jpg\)](#), [\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-g004-550.jpg\)](#), [\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-g005-550.jpg\)](#), [\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-g006-550.jpg\)](#), [\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-g007-550.jpg\)](#), [\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-g008-550.jpg\)](#), [\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-g009-550.jpg\)](#), [\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-g010-550.jpg\)](#), [\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-g011-550.jpg\)](#), [\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-g012-550.jpg\)](#), [\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-g013-550.jpg\)](#), [\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-g014-550.jpg\)](#), [\(BDCC/BDCC-05-00073/article_deploy/html/images/BDCC-05-00073-g015-550.jpg\)](#)

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[Exploring Ensemble-Based Class Imbalance Learners for Intrusion Detection in Industrial Control Networks](#) (/2504-2289/5/4/72)

by [Maya Hilda Lestari Louk](#) (<https://sciprofiles.com/profile/1948671>) and [Bayu Adhi Tama](#) (<https://sciprofiles.com/profile/828102>)

Big Data Cogn. Comput. 2021, 5(4), 72; <https://doi.org/10.3390/bdcc5040072> (<https://doi.org/10.3390/bdcc5040072>) - 06 Dec 2021

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Abstract Classifier ensembles have been utilized in the industrial cybersecurity sector for many years. However, their efficacy and reliability for intrusion detection systems remain questionable in current research, owing to the particularly imbalanced data issue. The purpose of this article is to address a [...] [Read more](#).

(This article belongs to the Special Issue [Artificial Intelligence for Trustworthy Industrial Internet of Things](#) (/journal/BDCC/special_issues/Indus_IoT))

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[Customized Rule-Based Model to Identify At-Risk Students and Propose Rational Remedial Actions](#) (/2504-2289/5/4/71)

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[Saad Harous](#) (<https://sciprofiles.com/profile/author/bThqMzJUd1lCaGLV1JDVkJ5WZE91SU1xMHixYU15amxoWFRBR0M2MjZyRT0=>)

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Abstract Detecting at-risk students provides advanced benefits for improving student retention rates, effective enrollment management, alumni engagement, targeted marketing improvement, and institutional effectiveness advancement. One of the success factors of educational institutes is based on accurate and timely identification and prioritization of the students [...] [Read more](#).

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[Gambling Strategies and Prize-Pricing Recommendation in Sports Multi-Bets](#) (/2504-2289/5/4/70)

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[Moti Fridman](#) (<https://sciprofiles.com/profile/319499>) and [Gur Yaari](#) (<https://sciprofiles.com/profile/1851521>)

Big Data Cogn. Comput. 2021, 5(4), 70; <https://doi.org/10.3390/bdcc5040070> (<https://doi.org/10.3390/bdcc5040070>) - 29 Nov 2021

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Abstract A sports multi-bet is a bet on the results of a set of N games. One type of multi-bet offered by the Israeli government is WINNER 16, where participants guess the results of a set of 16 soccer games. The prizes in WINNER [...] [Read more](#).

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[Networks and Stories. Analyzing the Transmission of the Feminist Intangible Cultural Heritage on Twitter](#) (/2504-2289/5/4/69)

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[Julen Orbegozo-Terradillos](#) (<https://sciprofiles.com/profile/author/MVhYZXhkbk02NHpLN3JTRnhBcURJendEZi9SK2JPUW40Q1JNWNj2dUp1ND0=>),

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Abstract Internet social media is a key space in which the memorial resources of social movements, including the stories and knowledge of previous generations, are organised, disseminated, and reinterpreted. This is especially important for movements such as feminism, which places great emphasis on the [...] [Read more.](#) (This article belongs to the Special Issue [Big Data Analytics for Cultural Heritage](#) ([/journal/BDCC/special_issues/data_heritage](#)))




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The Impact of Big Data Adoption on SMEs' Performance ([/2504-2289/5/4/68](#))

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Big Data Cogn. Comput. **2021**, *5*(4), 68; <https://doi.org/10.3390/bdcc5040068> (<https://doi.org/10.3390/bdcc5040068>) - 24 Nov 2021



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Abstract The notion of Industry 4.0 encompasses the adoption of new information technologies that enable an enormous amount of information to be digitally collected, analyzed, and exploited in organizations to make better decisions. Therefore, finding how organizations can adopt big data (BD) components to [...] [Read more.](#)



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Spiking Neural Networks for Computational Intelligence: An Overview ([/2504-2289/5/4/67](#))

by  [Shirin Dora \(https://sciprofiles.com/profile/1833315\)](https://sciprofiles.com/profile/1833315) and  [Nikola Kasabov \(https://sciprofiles.com/profile/1040077\)](https://sciprofiles.com/profile/1040077)

Big Data Cogn. Comput. **2021**, *5*(4), 67; <https://doi.org/10.3390/bdcc5040067> (<https://doi.org/10.3390/bdcc5040067>) - 15 Nov 2021



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Abstract Deep neural networks with rate-based neurons have exhibited tremendous progress in the last decade. However, the same level of progress has not been observed in research on spiking neural networks (SNN), despite their capability to handle temporal data, energy-efficiency and low latency. This [...] [Read more.](#) (This article belongs to the Special Issue [Computational Intelligence: Spiking Neural Networks](#) ([/journal/BDCC/special_issues/spikingnn](#)))




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Kano Model Integration with Data Mining to Predict Customer Satisfaction ([/2504-2289/5/4/66](#))

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Abstract The Kano model is one of the models that help determine which features must be included in a product or service to improve customer satisfaction. The model is focused on highlighting the most relevant attributes of a product or service along with customers' [...] [Read more.](#) (This article belongs to the Topic [Machine and Deep Learning](#) ([/topics/Machine_Deep_Learning](#)))





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An Enhanced Parallelisation Model for Performance Prediction of Apache Spark on a Multinode Hadoop Cluster ([/2504-2289/5/4/65](#))

by  [Nasim Ahmed \(https://sciprofiles.com/profile/1723528\)](https://sciprofiles.com/profile/1723528),  [Andre L. C. Barczak \(https://sciprofiles.com/profile/1892891\)](https://sciprofiles.com/profile/1892891),  [Mohammad A. Rashid \(https://sciprofiles.com/profile/283174\)](https://sciprofiles.com/profile/283174) and  [Teo Susnjak \(https://sciprofiles.com/profile/1335495\)](https://sciprofiles.com/profile/1335495)

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Abstract Big data frameworks play a vital role in storing, processing, and analysing large datasets. Apache Spark has been established as one of the most popular big data engines for its efficiency and reliability. However, one of the significant problems of the Spark system [...] [Read more.](#)

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


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How Does Learning Analytics Contribute to Prevent Students' Dropout in Higher Education: A Systematic Literature Review (./2504-2289/5/4/64)

by  [Catarina Félix de Oliveira \(https://sciprofiles.com/profile/1779534\)](https://sciprofiles.com/profile/1779534),  [Sónia Rolland Sobral \(https://sciprofiles.com/profile/954423\)](https://sciprofiles.com/profile/954423),  [Maria João Ferreira \(https://sciprofiles.com/profile/1780014\)](https://sciprofiles.com/profile/1780014) and  [Fernando Moreira \(https://sciprofiles.com/profile/2075212\)](https://sciprofiles.com/profile/2075212)

Big Data Cogn. Comput. **2021**, *5*(4), 64; <https://doi.org/10.3390/bdcc5040064> (<https://doi.org/10.3390/bdcc5040064>) - 04 Nov 2021

Cited by 5 (./2504-2289/5/4/64#citedby) | Viewed by 2533



Abstract Retention and dropout of higher education students is a subject that must be analysed carefully. Learning analytics can be used to help prevent failure cases. The purpose of this paper is to analyse the scientific production in this area in higher education in [...] [Read more.](#)

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GANs and Artificial Facial Expressions in Synthetic Portraits (./2504-2289/5/4/63)

by  [Pilar Rosado \(https://sciprofiles.com/profile/1791337\)](https://sciprofiles.com/profile/1791337),  [Rubén Fernández \(https://sciprofiles.com/profile/1824899\)](https://sciprofiles.com/profile/1824899) and  [Ferran Reverter \(https://sciprofiles.com/profile/1888378\)](https://sciprofiles.com/profile/1888378)

Big Data Cogn. Comput. **2021**, *5*(4), 63; <https://doi.org/10.3390/bdcc5040063> (<https://doi.org/10.3390/bdcc5040063>) - 04 Nov 2021

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Abstract Generative adversarial networks (GANs) provide powerful architectures for deep generative learning. GANs have enabled us to achieve an unprecedented degree of realism in the creation of synthetic images of human faces, landscapes, and buildings, among others. Not only image generation, but also image [...] [Read more.](#)

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Prediction of Cloud Fractional Cover Using Machine Learning (./2504-2289/5/4/62)

by  [Hanna Svennevik \(https://sciprofiles.com/profile/1888373\)](https://sciprofiles.com/profile/1888373),  [Michael A. Riegler \(https://sciprofiles.com/profile/1330811\)](https://sciprofiles.com/profile/1330811),  [Steven Hicks \(https://sciprofiles.com/profile/1849591\)](https://sciprofiles.com/profile/1849591),  [Trude Storelvmo \(https://sciprofiles.com/profile/author/MGVRUkIzNWExQXBrU2diVHlhM0pSa012MUh0WVwvTDhHY1orVUxTdD1ZYcz0=\)](https://sciprofiles.com/profile/author/MGVRUkIzNWExQXBrU2diVHlhM0pSa012MUh0WVwvTDhHY1orVUxTdD1ZYcz0=) and  [Hugo L. Hammer \(https://sciprofiles.com/profile/1778889\)](https://sciprofiles.com/profile/1778889)

Big Data Cogn. Comput. **2021**, *5*(4), 62; <https://doi.org/10.3390/bdcc5040062> (<https://doi.org/10.3390/bdcc5040062>) - 03 Nov 2021

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Abstract Climate change is stated as one of the largest issues of our time, resulting in many unwanted effects on life on earth. Cloud fractional cover (CFC), the portion of the sky covered by clouds, might affect global warming and different other aspects of [...] [Read more.](#)

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Using Machine Learning in Business Process Re-Engineering (./2504-2289/5/4/61)

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by [Younis Al-Anquodi](https://sciprofiles.com/profile/1814541) (<https://sciprofiles.com/profile/1814541>), [Abdullah Al-Hamdani](https://sciprofiles.com/profile/2129498) (<https://sciprofiles.com/profile/2129498>),

[Mehmed Al-Badawi](https://sciprofiles.com/profile/1802957) (<https://sciprofiles.com/profile/1802957>) and

[Rachid Hedjam](https://sciprofiles.com/profile/author/dzi2bGtaRUVQd3lYZXFgOW1Qcnd4QmtyMzVyYU5LZDZtSUNmYkZJaGdnOD0=) (<https://sciprofiles.com/profile/author/dzi2bGtaRUVQd3lYZXFgOW1Qcnd4QmtyMzVyYU5LZDZtSUNmYkZJaGdnOD0=>)

Big Data Cogn. Comput. **2021**, *5*(4), 61; <https://doi.org/10.3390/bdcc5040061> (<https://doi.org/10.3390/bdcc5040061>) - 02 Nov 2021 [\(toggle desktop layout cookie\)](#)  


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Abstract A business process re-engineering value in improving the business process is undoubted. Nevertheless, it is incredibly complex, time-consuming and costly. This study aims to review available literature in the use of machine learning for business process re-engineering. The review investigates available literature in [...]. [Read more.](#)

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Fine-Grained Algorithm for Improving KNN Computational Performance on Clinical Trials Text Classification ([/2504-2289/5/4/60](#))

by [Jasmir Jasmir](https://sciprofiles.com/profile/1732338) (<https://sciprofiles.com/profile/1732338>), [Siti Nurmaini](https://sciprofiles.com/profile/423637) (<https://sciprofiles.com/profile/423637>) and

[Bambang Tutuko](https://sciprofiles.com/profile/author/YVp2UXFHZWw5WWRtQUt0TGNhYUVtSIhBdndpOXNIRkpYSI9vYmpVL01EWT0=) (<https://sciprofiles.com/profile/author/YVp2UXFHZWw5WWRtQUt0TGNhYUVtSIhBdndpOXNIRkpYSI9vYmpVL01EWT0=>)

Big Data Cogn. Comput. **2021**, *5*(4), 60; <https://doi.org/10.3390/bdcc5040060> (<https://doi.org/10.3390/bdcc5040060>) - 28 Oct 2021

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Abstract Text classification is an important component in many applications. Text classification has attracted the attention of researchers to continue to develop innovations and build new classification models that are sourced from clinical trial texts. In building classification models, many methods are used, including [...]. [Read more.](#)

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NERWS: Towards Improving Information Retrieval of Digital Library Management System Using Named Entity Recognition and Word Sense ([/2504-2289/5/4/59](#))

by [Ahmed Aliwy](https://sciprofiles.com/profile/1766134) (<https://sciprofiles.com/profile/1766134>), [Ayad Abbas](https://sciprofiles.com/profile/1864261) (<https://sciprofiles.com/profile/1864261>) and

[Ahmed Alkhayat](https://sciprofiles.com/profile/992448) (<https://sciprofiles.com/profile/992448>)

Big Data Cogn. Comput. **2021**, *5*(4), 59; <https://doi.org/10.3390/bdcc5040059> (<https://doi.org/10.3390/bdcc5040059>) - 28 Oct 2021

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Abstract An information retrieval (IR) system is the core of many applications, including digital library management systems (DLMS). The IR-based DLMS depends on either the title with keywords or content as symbolic strings. In contrast, it ignores the meaning of the content or what [...]. [Read more.](#)

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Preparing Datasets of Surface Roughness for Constructing Big Data from the Context of Smart Manufacturing and Cognitive Computing ([/2504-2289/5/4/58](#))

by [Saman Fattahi](https://sciprofiles.com/profile/1845853) (<https://sciprofiles.com/profile/1845853>), [Takuya Okamoto](https://sciprofiles.com/profile/1874494) (<https://sciprofiles.com/profile/1874494>) and

[Sharifu Ura](https://sciprofiles.com/profile/147430) (<https://sciprofiles.com/profile/147430>)

Big Data Cogn. Comput. **2021**, *5*(4), 58; <https://doi.org/10.3390/bdcc5040058> (<https://doi.org/10.3390/bdcc5040058>) - 25 Oct 2021

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Abstract In smart manufacturing, human-cyber-physical systems host digital twins and IoT-based networks. The networks weave manufacturing enablers such as CNC machine tools, robots, CAD/CAM systems, process planning systems, enterprise resource planning systems, and human resources. The twins work as the brains of the enablers; [...]. [Read more.](#)

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


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A Semantic Web Framework for Automated Smart Assistants: A Case Study for Public Health (/2504-2289/5/4/57)by [Yusuf Sermet](https://sciprofiles.com/profile/1666541) (https://sciprofiles.com/profile/1666541) and [Ibrahim Demir](https://sciprofiles.com/profile/1457137) (https://sciprofiles.com/profile/1457137)*Big Data Cogn. Comput.* **2021**, *5*(4), 57; <https://doi.org/10.3390/bdcc5040057> (https://doi.org/10.3390/bdcc5040057) - 18 Oct 2021

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Abstract The COVID-19 pandemic elucidated that knowledge systems will be instrumental in cases where accurate information needs to be communicated to a substantial group of people with different backgrounds and technological resources. However, several challenges and obstacles hold back the wide adoption of virtual [...] **Read more.** (This article belongs to the Special Issue **Knowledge Modelling and Learning through Cognitive Networks** (/journal/BDCC/special_issues/knowledge_modelling))

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 ((2504-2289/5/4/56/pdf?version=1646307987))**6G Cognitive Information Theory: A Mailbox Perspective** (/2504-2289/5/4/56)by [Yixue Hao](https://sciprofiles.com/profile/249156) (https://sciprofiles.com/profile/249156), [Yiming Miao](https://sciprofiles.com/profile/410703) (https://sciprofiles.com/profile/410703),[Min Chen](https://sciprofiles.com/profile/167324) (https://sciprofiles.com/profile/167324),[Hamid Gharavi](https://sciprofiles.com/profile/author/cUFRLzI4MGItVzV5S1AwSUo5TWMwaUFNZGQzK3FJUjha0p2c0d5YUY2WT0=) (https://sciprofiles.com/profile/author/cUFRLzI4MGItVzV5S1AwSUo5TWMwaUFNZGQzK3FJUjha0p2c0d5YUY2WT0=) and[Victor C. M. Leung](https://sciprofiles.com/profile/1437010) (https://sciprofiles.com/profile/1437010)*Big Data Cogn. Comput.* **2021**, *5*(4), 56; <https://doi.org/10.3390/bdcc5040056> (https://doi.org/10.3390/bdcc5040056) - 16 Oct 2021

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Abstract With the rapid development of 5G communications, enhanced mobile broadband, massive machine type communications and ultra-reliable low latency communications are widely supported. However, a 5G communication system is still based on Shannon's information theory, while the meaning and value of information itself are [...] **Read more.**

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 ((2504-2289/5/4/55/pdf?version=1634794702))**Unraveling the Impact of Land Cover Changes on Climate Using Machine Learning and Explainable Artificial Intelligence** (/2504-2289/5/4/55)by [Anastasiia Kolevatova](https://sciprofiles.com/profile/author/ei9mVjBvalVDakp2akRmY2Y0S0xKOSsrV1NnZnRrRTVMb2NTMUQzTzBBND0=) (https://sciprofiles.com/profile/author/ei9mVjBvalVDakp2akRmY2Y0S0xKOSsrV1NnZnRrRTVMb2NTMUQzTzBBND0=),[Michael A. Riegler](https://sciprofiles.com/profile/1330811) (https://sciprofiles.com/profile/1330811), [Francesco Cherubini](https://sciprofiles.com/profile/544371) (https://sciprofiles.com/profile/544371),[Xiangping Hu](https://sciprofiles.com/profile/488142) (https://sciprofiles.com/profile/488142) and [Hugo L. Hammer](https://sciprofiles.com/profile/1778889) (https://sciprofiles.com/profile/1778889)*Big Data Cogn. Comput.* **2021**, *5*(4), 55; <https://doi.org/10.3390/bdcc5040055> (https://doi.org/10.3390/bdcc5040055) - 15 Oct 2021

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Abstract A general issue in climate science is the handling of big data and running complex and computationally heavy simulations. In this paper, we explore the potential of using machine learning (ML) to spare computational time and optimize data usage. The paper analyzes the [...] **Read more.**

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 ((2504-2289/5/4/54/pdf?version=1634118313))**Effects of Neuro-Cognitive Load on Learning Transfer Using a Virtual Reality-Based Driving System** (/2504-2289/5/4/54)by [Usman Alhaji Abdurrahman](https://sciprofiles.com/profile/1716631) (https://sciprofiles.com/profile/1716631),[Shih-Ching Yeh](https://sciprofiles.com/profile/author/V1V2UG5oTFhvNDFOSEE1ajZJNENTN0pON0g4a3k2YVFNOGphY05uU2tVYz0=) (https://sciprofiles.com/profile/author/V1V2UG5oTFhvNDFOSEE1ajZJNENTN0pON0g4a3k2YVFNOGphY05uU2tVYz0=),[Yunying Wong](https://sciprofiles.com/profile/author/UDlYaUFITWU2K3NXOFBDRIFhQ2N0Qk96UkhES2lrRzFjemt4VDgrMHZaND0=) (https://sciprofiles.com/profile/author/UDlYaUFITWU2K3NXOFBDRIFhQ2N0Qk96UkhES2lrRzFjemt4VDgrMHZaND0=) and[Liang Wei](https://sciprofiles.com/profile/author/NFdKOHc3VTVhanFuQXpWOUJJKYzhQLzRIUkwzcHVUYTRCSEp4ZytMWTk5MD0=) (https://sciprofiles.com/profile/author/NFdKOHc3VTVhanFuQXpWOUJJKYzhQLzRIUkwzcHVUYTRCSEp4ZytMWTk5MD0=)*Big Data Cogn. Comput.* **2021**, *5*(4), 54; <https://doi.org/10.3390/bdcc5040054> (https://doi.org/10.3390/bdcc5040054) - 13 Oct 2021

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Abstract Understanding the ways different people perceive and apply acquired knowledge, especially when driving, is an important area of study. This study introduced a novel virtual reality (VR)-based driving system to determine the effects of neuro-cognitive load on learning transfer. In the experiment, easy [...] [Read more](#). (This article belongs to the Special Issue [Virtual Reality, Augmented Reality, and Human-Computer Interaction \(/journal/BDCC/special_issues/virt_reality_\)](#)) 🔍 ☰

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Bag of Features (BoF) Based Deep Learning Framework for Bleached Corals Detection (/2504-2289/5/4/53)

by [Sonain Jamil \(https://sciprofiles.com/profile/1853325\)](#), [MuhibUr Rahman \(https://sciprofiles.com/profile/307570\)](#) and [Amir Haider \(https://sciprofiles.com/profile/1159047\)](#)

Big Data Cogn. Comput. 2021, 5(4), 53; <https://doi.org/10.3390/bdcc5040053> (<https://doi.org/10.3390/bdcc5040053>) - 08 Oct 2021

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Abstract Coral reefs are the sub-aqueous calcium carbonate structures collected by the invertebrates known as corals. The charm and beauty of coral reefs attract tourists, and they play a vital role in preserving biodiversity, ceasing coastal erosion, and promoting business trade. However, they are [...] [Read more](#). (This article belongs to the Topic [Applied Computer Vision and Pattern Recognition \(/topics/Computer_Vision_Pattern_Recognition\)](#))

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Hardening the Security of Multi-Access Edge Computing through Bio-Inspired VM Introspection (/2504-2289/5/4/52)

by [Huseyn Huseynov \(https://sciprofiles.com/profile/1476446\)](#), [Tarek Saadawi \(https://sciprofiles.com/profile/1752013\)](#) and [Kenichi Kourai \(https://sciprofiles.com/profile/author/b3hJLzNmczRObnc3YUszU21GQkVnOWsrci9FZXdTSMlaMnIXd113UD15MD0=\)](#)

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Abstract The extreme bandwidth and performance of 5G mobile networks changes the way we develop and utilize digital services. Within a few years, 5G will not only touch technology and applications, but dramatically change the economy, our society and individual life. One of the [...] [Read more](#). (This article belongs to the Special Issue [Information Security and Cyber Intelligence \(/journal/BDCC/special_issues/secu_int\)](#))

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A Study on Singapore's Ageing Population in the Context of Eldercare Initiatives Using Machine Learning Algorithms (/2504-2289/5/4/51)

by [Easwaramoorthy Rangaswamy \(https://sciprofiles.com/profile/1832499\)](#), [Girija Periyasamy \(https://sciprofiles.com/profile/1832541\)](#) and [Nishad Nawaz \(https://sciprofiles.com/profile/1546866\)](#)

Big Data Cogn. Comput. 2021, 5(4), 51; <https://doi.org/10.3390/bdcc5040051> (<https://doi.org/10.3390/bdcc5040051>) - 29 Sep 2021

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Abstract Ageing has always directly impacted the healthcare systems and, more specifically, the eldercare costs, as initiatives related to eldercare need to be addressed beyond the regular healthcare costs. This study aims to examine the general issues of eldercare in the Singapore context, as [...] [Read more](#).




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Advances in Convolution Neural Networks Based Crowd Counting and Density Estimation (/2504-2289/5/4/50)

by  [Rafik Gouiaa](https://sciprofiles.com/profile/author/VHRIZiswT291UUVrb3ZOdnVMaGtuZFlyUDlySmxTUVNVRE1ZU3VSZGNWbz0=) (<https://sciprofiles.com/profile/author/VHRIZiswT291UUVrb3ZOdnVMaGtuZFlyUDlySmxTUVNVRE1ZU3VSZGNWbz0=>),  [Moulay A. Akhlofi](https://sciprofiles.com/profile/309135) (<https://sciprofiles.com/profile/309135>) and  [Mozhdeh Shahbazi](https://sciprofiles.com/profile/author/WUY0M2d5TE9hZ01ubHBVUFF5KzRjZWZTakk4clhyNGZOd1pCbXE0OFNJST0=) (<https://sciprofiles.com/profile/author/WUY0M2d5TE9hZ01ubHBVUFF5KzRjZWZTakk4clhyNGZOd1pCbXE0OFNJST0=>)

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Abstract Automatically estimating the number of people in unconstrained scenes is a crucial yet challenging task in different real-world applications, including video surveillance, public safety, urban planning, and traffic monitoring. In addition, methods developed to estimate the number of people can be adapted and [...] [Read more.](#) (This article belongs to the Special Issue [Machine Learning and Data Analysis for Image Processing](#) ([/journal/Bdcc/special_issues/image_detection](#)))

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ADD: Attention-Based DeepFake Detection Approach (/2504-2289/5/4/49)

by  [Aminollah Khormali](https://sciprofiles.com/profile/1079972) (<https://sciprofiles.com/profile/1079972>) and  [Jiann-Shiun Yuan](https://sciprofiles.com/profile/1562967) (<https://sciprofiles.com/profile/1562967>)

Big Data Cogn. Comput. **2021**, *5*(4), 49; <https://doi.org/10.3390/bdcc5040049> (<https://doi.org/10.3390/bdcc5040049>) - 27 Sep 2021


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Abstract Recent advancements of Generative Adversarial Networks (GANs) pose emerging yet serious privacy risks threatening digital media's integrity and trustworthiness, specifically digital video, through synthesizing hyper-realistic images and videos, i.e., DeepFakes. The need for ascertaining the trustworthiness of digital media calls for automatic yet [...] [Read more.](#)


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Big Data Contribution in Desktop and Mobile Devices Comparison, Regarding Airlines' Digital Brand Name Effect (/2504-2289/5/4/48)

by  [Damianos P. Sakas](https://sciprofiles.com/profile/author/bWhBMVZxWWtvbVhDb0dJOHN5RzEvZz09) (<https://sciprofiles.com/profile/author/bWhBMVZxWWtvbVhDb0dJOHN5RzEvZz09>) and

 [Nikolaos Th. Giannakopoulos](https://sciprofiles.com/profile/1673919) (<https://sciprofiles.com/profile/1673919>)

Big Data Cogn. Comput. **2021**, *5*(4), 48; <https://doi.org/10.3390/bdcc5040048> (<https://doi.org/10.3390/bdcc5040048>) - 26 Sep 2021

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Abstract Rising demand for optimized digital marketing strategies has led firms in a hunt to harvest every possible aspect indicating users' experience and preference. People visit, regularly through the day, numerous websites using both desktop and mobile devices. For businesses to acknowledge device's usage [...] [Read more.](#)


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Exploring How Phonotactic Knowledge Can Be Represented in Cognitive Networks (/2504-2289/5/4/47)

by  [Michael S. Vitevitch](https://sciprofiles.com/profile/452669) (<https://sciprofiles.com/profile/452669>),  [Leo Niehorster-Cook](https://sciprofiles.com/profile/1660101) (<https://sciprofiles.com/profile/1660101>) and

 [Sasha Niehorster-Cook](https://sciprofiles.com/profile/1782433) (<https://sciprofiles.com/profile/1782433>)

Big Data Cogn. Comput. **2021**, *5*(4), 47; <https://doi.org/10.3390/bdcc5040047> (<https://doi.org/10.3390/bdcc5040047>) - 23 Sep 2021

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Abstract In Linguistics and Psycholinguistics, phonotactics refers to the constraints on individual sounds in a given language that restrict how those sounds can be combined

form words in that language. Previous empirical work in Psycholinguistics demonstrated that phonotactic knowledge influenced how quickly and [...] [Read more.](#)
(This article belongs to the Special Issue [Knowledge Modelling and Learning through Cognitive Networks](#) ([/journal/BDCC/special_issues/knowledge_modelling](#)))

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[Uncovering Active Communities from Directed Graphs on Distributed Spark Frameworks, Case Study: Twitter Data](#) ([/2504-2289/5/4/46](#))

by [Veronica S. Moertini](#) (<https://sciprofiles.com/profile/1714179>) and

[Marishka T. Adithia](#) (<https://sciprofiles.com/profile/author/Ulc0THhYK3FYMFFHcUIWWXpsY0IrYTcyb0VpMkpsRFFZNEp6WkxhblfZWT0=>)

Big Data Cogn. Comput. **2021**, *5*(4), 46; <https://doi.org/10.3390/bdcc5040046> (<https://doi.org/10.3390/bdcc5040046>) - 22 Sep 2021

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Abstract Directed graphs can be prepared from big data containing peoples' interaction information. In these graphs the vertices represent people, while the directed edges denote the interactions among them. The number of interactions at certain intervals can be included as the edges' attribute. Thus, [...] [Read more.](#)

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
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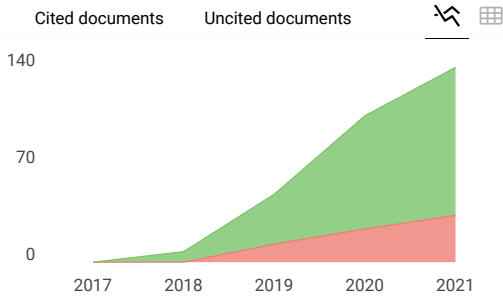
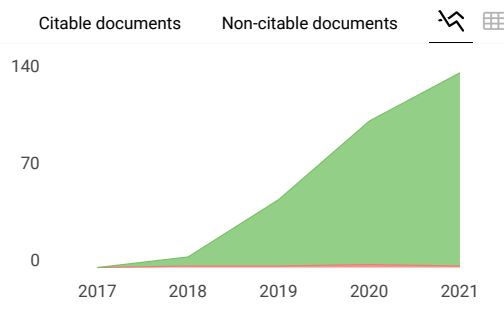
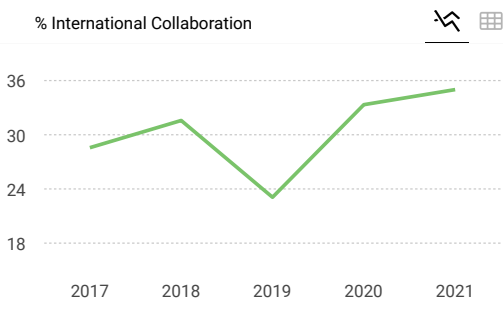
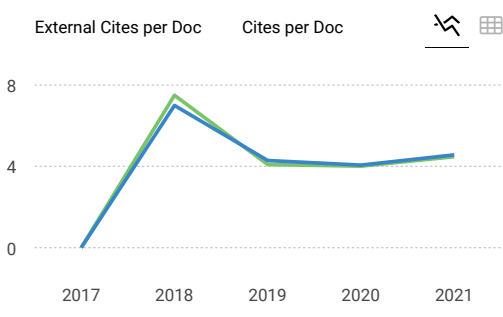
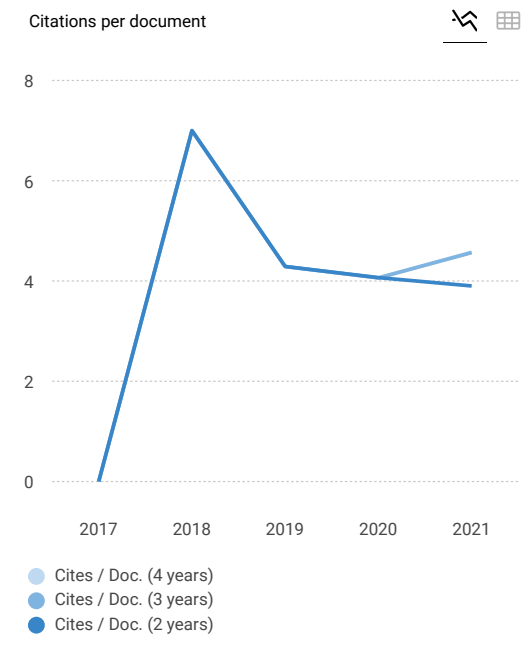
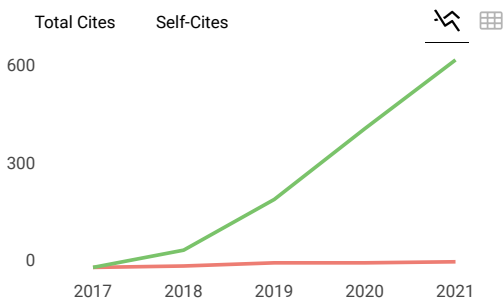
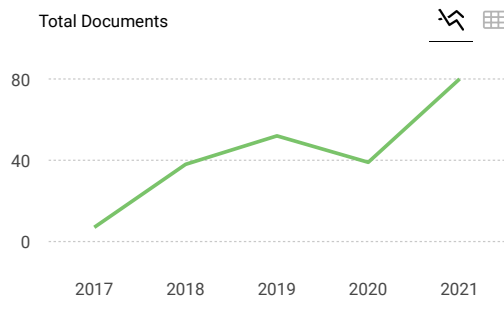
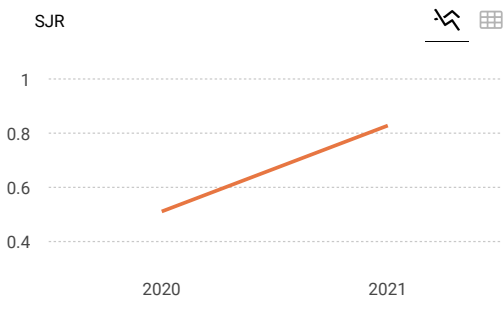
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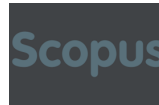
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