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Artificial intelligence within the interplay between natural and artificial Computation: advances in data science, trends and applications

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Abstract

Artificial intelligence and all its supporting tools, e.g. machine and deep learning in computational intelligence-based systems, are rebuilding our society (economy, education, life-style, etc.) and promising a new era for the social welfare state. In this paper we summarize recent advances in data science and artificial intelligence within the interplay between natural and artificial computation. A review of recent works published in the latter field and the state the art are summarized in a comprehensive and self-contained way to provide a baseline framework for the international community in artificial intelligence. Moreover, this paper aims to provide a complete analysis and some relevant discussions of the current trends and insights within several theoretical and application fields covered in the essay, from theoretical models in artificial intelligence and machine learning to the most prospective applications in robotics, neuroscience, brain computer interfaces, medicine and society, in general.

Keywords: Artificial intelligence (AI), machine learning, deep learning, reinforcement learning, evolutionary computation, ontologies, artificial neural networks (ANNs), big data, data fusion, robotics, neuroscience, human-machine interaction, virtual reality, emotion recognition, computational neuroethology, electroencephalography (EEG), mobile EEG, brain computer interface (BCI), connectivity, body pose and motion estimation, heart-rate variability, gait, speaking, gaming, neuroacoustical stimulation, instability phonation, Autism, dyslexia, Alzheimer, Parkinson, ischemia, glaucoma, AI for social well-being, education, home care, assistance.

1. Introduction

Artificial intelligence (AI) has become important in recent decades because of its vast real-world applications. Examples include medical diagnosis [1], face recognition [2], robotics [3], internet applications [4], data mining [5], industrial applications [6], and so on.

Interdisciplinary research is a hallmark of modern science [1]. Although different sub-fields have historically operated in segregation, researchers have since found that synthesis of different areas of science gives rise to more original and efficient solutions that are more applicable to the wider scientific community. A collaboration between physicians, data scientists, computer science researchers, and engineers is required to ensure that AI-based systems and their applications are properly trained, operated, and regulated. These systems will provide a dual perspective, both as a method of analysis and as a model of synthesis. As a method of analysis, various theories that are formulated on the operation of certain biological systems are validated via simulation through different models, without having to act directly on these systems. As a model of synthesis, they allow the construction of systems that will solve problems in manner similar to biological systems.

Accessibility to large datasets enables the application of complex data science (DS) algorithms and tools, e.g. deep learning (DL), to process huge amounts of bytes of unstructured information, allowing relevant feature extraction and recognizing high-level abstractions with increasing generalisability. In this sense, DS tools, such as machine learning (ML), have the potential to support several fields of research, such as biomedicine, neuroscience or robotics, by the automation or resolution of complex tasks in time series prediction, classification, regression, diagnostics, monitoring, and so on.

The current essay is a vision paper resulting from the discussions at the International Work-conference in the Interplay between Natural and Artificial Computation (IWINAC'19), which was held on June 3-7, 2019 in Almería, Spain. It covers several topics within a huge field of applications by a collection of works that are parcelled into eleven sections, from novel theories and methods in AI to the most recent applications of these technologies to society, robotics, medical imaging, and neuroscience.

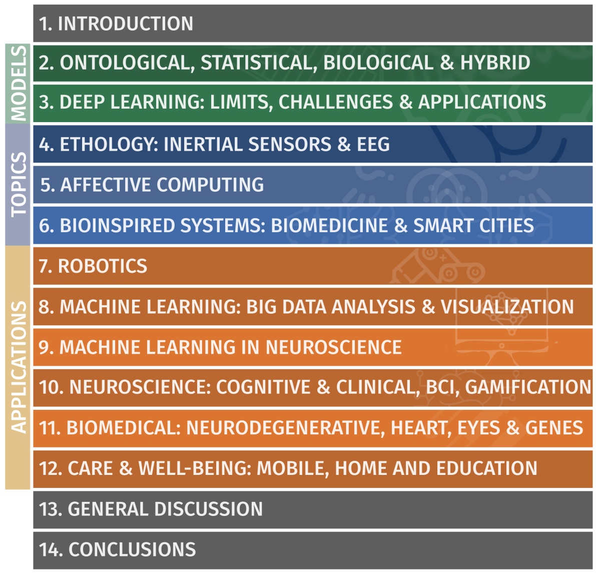

Figure 1: Organization of the article

The paper is structured as depicted in Figure 1. We start the essay by introducing two theoretical sections (2 and 3), which are related to computational models and architectures using several categorizations, and define the basis and fundamentals in DS and AI. They are able to provide prospective applications in several fields as shown in next sections. Then, we present specific topics in DS and AI, such as ethology, affective computing and bio-inspired systems (sections 4, 5 and 6), which are specially relevant for our aforementioned research forum. Finally, we introduce in depth the most relevant applications of these tools and techniques in robotics (section 7, data analysis (section 8), neuroscience (sections 9 and 10), care and well-being (section 12), and biomedicine (section 11), in general. Some discussions and trends are described in section 13 and conclusions are presented in section 14. A complete taxonomy of the paper can be found in figure 2.

1.1. A summary of the review

The opening section 2 entitled "Models: advancing in data science" refers to formal structures with operational semantics that are applicable to a particular domain, which allows us to reach valid conclusions in that domain based on data from specific cases. The clearest example is that of physical and

[1] https://www.nature.com/articles/d41586-019-03325-6

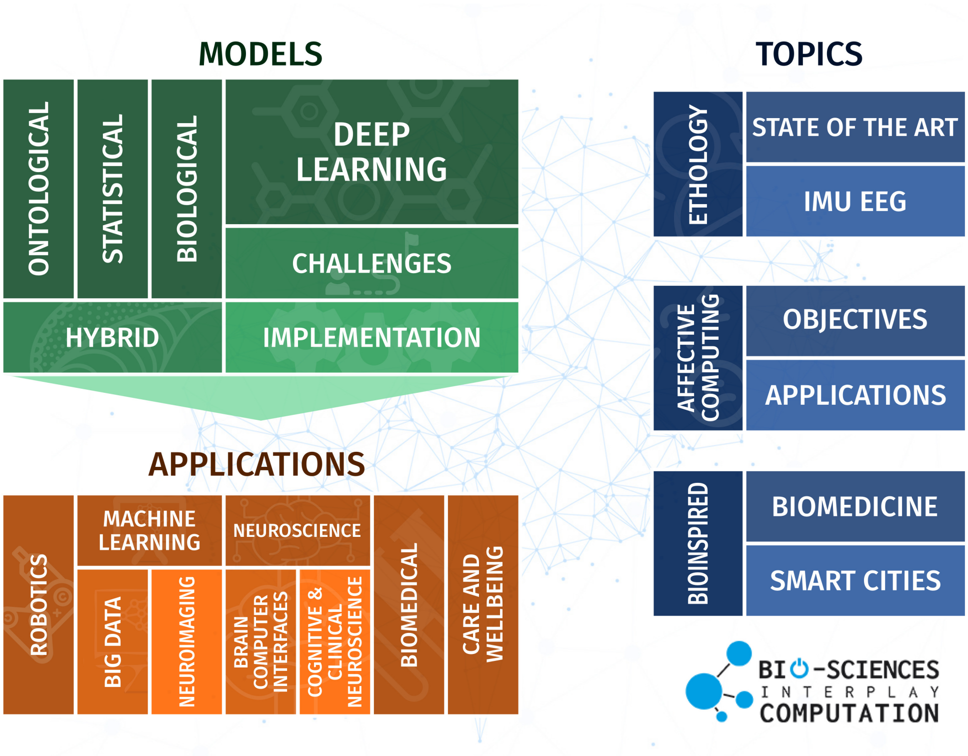

Figure 2: Taxonomy of the review paper

mathematical models, which supported by a theory, allow us to infer characteristics of the state of the system. In computing, models are stacked on top of each other, from the Turing machine to models that, by means of an obviously complex operation, are able to approximate any distribution function. Nowadays, the variety of models and objectives does not stop growing. They are used to represent and interpret all types of domains, which helps to understand the increasingly abundant data in the digital world and draw conclusions that were previously impossible to conceive.

Due to the current relevance of the topic, DL models [7] and applications in the areas covered in this paper are summarized in the separated section 3. DL comprises a series of AI methods which perform a learning task by extracting several layers of representations with successive levels of abstraction [8]. These representations are usually better suited for the end objective (for instance, classification) than the original features.

One source for devising new models and theories in this context is the mere observation of the behavior of biological systems. This is the strict definition of section 4, entitled "Ethology", a discipline whose classical domain has been animals in the wild, but it is also applied to animals in the laboratory, looking for advanced phenotype modeling. The increasing use of quantitative sensors and sophisticated computational resources in order to achieve precise quantitative modeling of behaviors has been termed Computational Ethology, where a host of applications are being developed, i.e. Neuroethology that aims to look for the correlation of behavior and neural activity, even for the identification of neural causal mechanisms. On the other hand, when computational science explores how technology can understand human affect; how interactions between humans and technologies can be impacted by affect; how systems can be designed to use affect to enhance capabilities; or how sensing and affective strategies can transform human and computer interaction [9], the field is named Affective Computing (AC) (section 5). AC relates to, arises from, or intentionally influences emotion [10].

These systems based on functional aspects of human beings or animals are beginning to be accepted as valid alternatives to conventional approaches in solving specific problems, as shown in section 6. In general, inspiration from nature, which has evolved over the centuries, will have solutions that must be taken into account for similar problems in order to optimize the available resources. Nonetheless, this is how bio-inspired systems emerged. In the study of bio-inspired systems converge physiology, medicine, systems modeling, microelectronics, computer science, etc. In this sense, the field of Robotics, summarized in section 7, is a good example of a bio-inspired system. This is mainly due to the embodiment provided by robots, which makes them much more similar to natural beings than the objects of study in other domains. As such, it is an area where just about any AI based approach can be used. Anything from general AI to very particular signal processing algorithms can be implemented and used on robotic platforms. Recent advances in such signal processing algorithms in ML can also be applied to other fields of research such as Big Data analysis, processing and visualization in Neuroscience and other applications (Sections 8 and 9).

The advent of the Big Data revolution has provided ML researchers and practitioners a huge amount of data of almost any imaginable kind. This has steered ML research towards those methodologies and algorithms which are able to manage large volumes of information within reasonable computational requirements. Moreover, algorithms that can distribute the computational load over a computer network are the most useful, since they can be executed in the cloud [11]. The motivations behind these changes are multiple, since ML techniques have become suitable for a wide range of application fields. However, Neuroscience is a representative example in which available data is usually high dimensional, a high number of samples is not always available, and databases are often unbalanced. In this situation, ML techniques provide new opportunities to develop specific methods to extract descriptors, allowing for the creation of complex models from high-dimensional data while preserving generalization capabilities. Indeed, these techniques, in combination with sophisticated brain activity scanning methods and instrumentation, as shown in section 10, allows for the translation of research output into interventions to make a difference in clinical practice [12, 13]. These medical applications explore diverse areas, such as neurodegenerative diseases, cardio-pathologies, glaucoma, strokes or even the genomic sequencing of DNA and RNA, among others, as shown in section 11.

The aforementioned synergy in AI has confirmed the possibilities of controlling simple mechanical or robotic systems using the electrophysiological activity of brain cortex captured through the skull and scalp or supporting physicians in the diagnosis of several diseases (Parkinson, Amyotrophic Lateral Sclerosis, Alzheimer) or conditions (Autism). In the last decades these findings opened the door to develop computer-aided diagnosis systems, non-invasive interfaces for the control of simple devices as a mouse cursor, or more sophisticated devices such as supportive limb prostheses or the navigation on virtual scenarios [14]. Moreover, a variety of AI applications for personal and professional services is shown in section 12, demonstrating how AI technology is addressing the needs of individuals and society as well. Large and mid-size enterprises are intensifying the use of ML and AI in their products, taking advantage of the opportunities these technologies present to perform advanced analysis on big data and to improve the performance of their products and services.

2. Models: advancing in data science

In AI a continuum from totally explicit to implicit models exists. The former are interpretable by an expert in the application domain, because he/she sees a direct reflection of his/her own knowledge, with a terminology and a causality that can be understood, close to the experience on this narrow scope of analysis. The most obvious example is perhaps ontologies, since they are raised with that objective; they are consensual and formal models that allow for the representation of the concepts and relationships of a domain. They have been very useful to extract and share knowledge or to integrate data sources of different origins [15].

In contrast, non-explicit models are generic models, applicable to a wide range of problems whose parameters must be adapted to a particular domain. We say that models learn from data, which translates into adjusting their internal parameters to respond prospectively, according to the patterns and recurrences found in the dataset. They are black box models (some more than others) in the sense that the explanation of why they infer what they infer is not immediate, since knowledge derives directly from the data, not from the conceptualization of an expert. For this reason, it is necessary to find additional mechanisms that explain the reasoning behind how conclusions have been reached, to achieve systems that are reliable and, therefore, easier to deploy in sensitive areas, such as health or security, in which machines interact with humans [16, 17]. It is possible to interpret the implicit models through changes in the representation system that make them more transparent, although possibly not fully explainable. This explanation is already a recognized right for the European Union[2].

2.1. A new era for Artificial Intelligence

The commotion raised by the DL models has brought great prominence to this problem (see following section 3 for more details). Using DL we are able to approximate any function as long as we have a dataset large enough so that its distribution function is close to the real one. They are complex models, with a strong and costly operation, that find their best territory in learning problems from large amounts of data, and that were previously limited by extreme computing costs and availability of digitized data. This has changed in the last decade because they have benefited from the continuous improvement in technology and the huge amounts of digitized data (or having obtained them automatically, if they were not). But despite the success, this paradigm is not problem-free [18], and, in addition to the difficulties of model explainability [19, 20], there is further room for improvement, for example, in the effectiveness and efficiency of learning mechanisms and applicability to smaller datasets.

DL is giving such good results that the applicability to not-so-large data sets is a first-level research objective. However, obtaining representative datasets of a given problem is not always easy or economical. The concept of transfer learning has certainly helped in this regard. It benefits from the initialization of the system over other datasets with huge amounts of data, normally obtained through the internet, to overcome its lack in the application domain. On the other hand, the concept of reinforcement learning brings a completely logical proposal: instead of having to generate *a priori* datasets, it is proposed that the model itself collects data from the environment in order to optimize a certain reinforcement function (reinforcement that also derives from the response of the environment to the exit of the system) [21].

2.2. Ontological, statistical, hybrid and biological models

In relation to the problems raised above, we have a clear example of explicit models in ontologies. In [22], the authors review the different approaches carried out with the purpose of solving interoperability and standardization problems in domains [15] related to the study of mild cognitive impairment (MCI) and other neurodegenerative diseases. The capacity of ontologies to address these problems, together with the facility for storage, retrieval and inference of information, makes them a must-have model in the studies of the diagnosis of MCI.

The extraction of knowledge from time series is a problem studied in data mining. In [23] they do so by building an explicit model, a set of rules that are perfectly understandable to the expert, but without resorting to him or "ad-hoc" solutions. The proposed method creates timelines by abstraction from the time series, and from here to temporary rules using a known algorithm called APRIORI [24].

In [25] a rule-extraction technique applied to convolutional neural networks (CNN) is presented. A special transparent model located in the dense layers generates the rules. The antecedents of the extracted rules represent responses of convolutional filters that make it possible to determine for each rule the covered samples. With this method, it is possible to visualize the centroid of each rule, which produces an overview of how the network works. As an example, fig.3 illustrates a number of generated centroids for the MNIST classification problem, with each centroid covering hundreds to thousands training samples. It is worth noting the different patterns and the varying orientations of the class "one" digit.

An example of research to complement certain models and trying to solve some of their problems can be found in [26]. While support vector machines (SVM) are the most successful models for supervised learning problems, it is true that they suffer from scalability problems with large amounts of data. Thus, the authors propose Deep SVM models that combine the highly non-linear feature processing of Deep Neural Networks (DNNs) with SVM loss functions. As the authors show, these models achieve results similar to standard SVM, but on large datasets. However, these models are required

[2]The EU general data protection regulation 2016/679 (GDPR) https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R0679

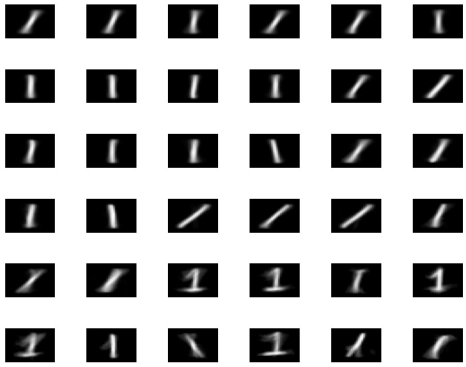

Figure 3: Centroids generated from symbolic rules on the MNIST classification problem[25].

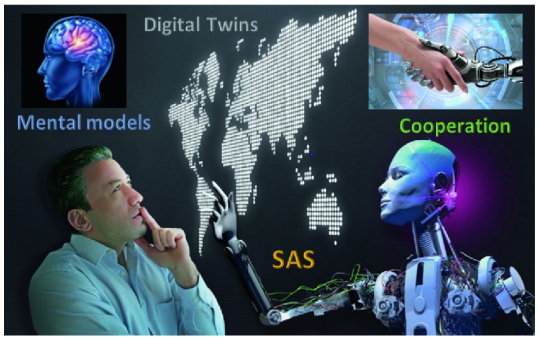

Figure 4: SAS human-machine cognitive cooperation[31].

to be further analyzed in imbalanced datasets as shown in [27]. The work shows the conditions under which a SVM failure occurs, both theoretically and experimentally, and show that it can be relevant even in cases of very weakly imbalanced data. Moreover, this work depicts a guideline to avoid the SVM failure.

Moreover, in [28], a combination of two models is presented to construct a two-stage method for example-dependent cost binary classification problems. The first stage obtains, by training a Multi-Layer Perceptron (MLP) with a Bregman divergence [29] as surrogate cost, consistent estimates of the posterior probabilities that, in the second stage, will be used by a Bayesian decision rule to solve the classification problem.

Continuing with this line of hybridization or combination of models, [30] proposes to develop new models to combine the performance of ensembles with the transparency and interpretability of choice models. The authors explore the possibilities of blind or uninformed methods focusing on two aspects of the ensemble building process: the data sampling strategy and the aggregation technique. The results obtained indicate the best performance of the bagging methods to build optimal choice-based ensembles.

Much research has been carried out to emulate human cognitive behaviors, but mainly with parcelled models for different capabilities. The authors of [31] look for symbiosis with humans through a framework of deep man-machine cooperation. They seek cognitive agents that should build goal-oriented dynamic holistic models of the involved task to support efficient domain understanding and general learning, rather than merely solving pattern-recognition problems. Thus, they present a cognitive framework for consciousness, that is mainly based on a network of associate cognitive digital twins, to support cognitive activities of symbiotic autonomous systems (SAS) (fig.4).

Nature has always been an inspiration for creating artificial models that emulate or improve human abilities. In [32] the author studies a property of biological neural networks (BNNs), computational robustness, which is missed in the artificial NN (ANN), and that is a property that is increasingly seen as a key to evolutionary drift. The author tests the relationship between computational properties in ANN and the neuronal codes through in silico experiments to reach two conclusions: i) There is a relationship between the number of epochs needed to train a feed-forward neural network using back-propagation and the neural code of the neural network, and ii) a relationship exists between the computational robustness and the neural code of a feed-forward neural network.

3. Deep Learning

Since DL models are implemented as ANNs where inputs and outputs are modifiable for each problem, they can adapt to special problems with non-standard traits or other obstacles for common learners. However, this also means that, in order to be trained, numerous parameters and hyperparameters need to be optimized, which entails some challenges that are still undergoing intense research. Figure 5 depicts some architectures that may be used to build DL models, specifically a convolutional ANN and an autoencoder.

Due to the outstanding performance that DL methods obtained in image processing tasks, many of the applications currently in development involve the treatment of images. Notwithstanding, DL models can be notably useful in other fields as automatic regressors or feature learners in addition to classifiers. The following sections review several developments and ongoing works in the DL field, both in the theoretical aspects of DL models and in different application fields.

3.1. DL methods: limits and challenges

From a theoretical perspective, the ongoing developments on ANNs and DL are tackling open problems in the field, as well as advancing in treatment of learning problems which present special difficulties. Among the first issues we find the interpretability of these models and the need for strategies to build them and to design convenient objective functions. Among the special difficulties, there are many complexities that can prevent traditional learners from finding good solutions to specific problems, and some of the following works put those in the spotlight.

Interpretability is nowadays one of the main focuses in this area [33, 34], since ANNs have traditionally been considered black-box models. Along these lines, there are models that extract propositional rules from ANNs, but are commonly limited to simple MLPs. The work in [25] further develops this approach by proposing a model for extraction of propositional rules from a CNN. This work achieves this by approximating the fully connected layers of the CNN architecture with a Discretized Interpretable MLP after training. This structure performs a discretization of its inputs via a staircase activation function, while retaining the learned weights in the CNN. The rules that are extracted have in their antecedents the responses of the filters in the last convolutional layer and cover several examples that can be summarized in a centroid. In their experiment, the authors extract a set of 1105 rules for MNIST classification, achieving an accuracy just slightly inferior to the CNN itself. This set may contain too many rules to be considered interpretable yet, but it is a simpler model than the CNN.

Autoencoders (AE) are neural network-based tools that perform feature learning [35]. These are usually applied to unsupervised learning problems, since they generally do not need any label information from the training patterns. Instead, they learn a new feature space where these can be projected onto and reconstructed from, similarly to manifold learning algorithms. However, there is no straightforward procedure to design the architecture of an AE, including the number of layers and the amount of neurons in each layer. There are already some proposals for automatically finding neural network architectures, but none centered on autoencoders. In [36], an evolutionary approach for architecture search is proposed and tested against an exhaustive grid search. The search methods based on evolutive algorithms present significantly superior performance than the exhaustive version.

Defining an appropriate objective function for a problem can greatly affect the model learned by an ANN [37]. One of the components of this function may be the coding given to the possible responses, usually corresponding to classes in a classification problem. A small experiment in [32] suggests that some codes may be more beneficial than others when the ANN faces potential damages (e.g. deleted neurons).

A high number of instances can decrease the performance of a traditional learner, especially in computation time, where some methods may be incapable of treating datasets with several hundred thousand instances. Support vector-based methods, which implicitly work with a transformation of the original feature space onto a higher-dimensional space, are especially hindered by the number of training patterns, due to the linear increase of the amount of support vectors. Although some proposals attempt to overcome this obstacle, in many cases they still struggle with large datasets. The developments in [26] describe deep ANN models for both classification and regression which leverage the loss functions of support vector machines and support vector regression models, respectively. The results show that the performance is very similar to that of the traditional models, but the training time required to learn an ANN-based model is much shorter.

Another obstacle in learning problems arises when the cost of an erroneous prediction depends on the predicted pattern itself. This is known as an example-dependent cost [38]. This circumstance can join other well known difficulties for classification tasks, such as class imbalance [39]. A method which adequately treats such a problem should take into account the per-instance cost as well as the predominance of some classes over the rest. The work in [28] develops a novel method which couples a

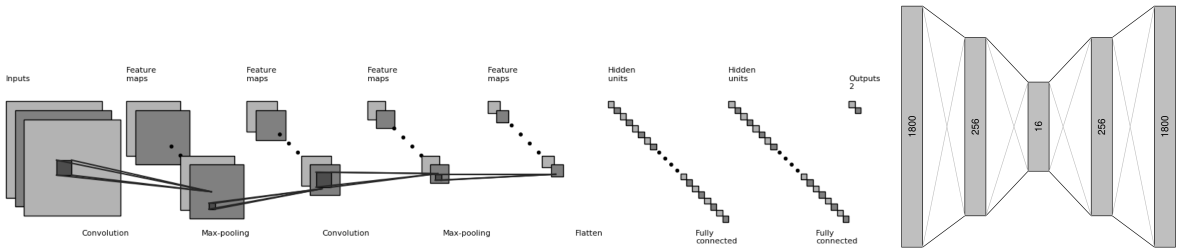

Figure 5: Illustrations of architectures of two possible ANNs: on the left, a convolutional ANN; on the right, an autoencoder.

statistical procedure with a multilayer perceptron classifier, allowing to rebalance the importance of each class by weighting them during the training phase as well as to provide a class decision based on a computation which takes example-dependent costs into account.

Some problems are more complex due to the structure of their inputs or outputs, and are commonly known as nonstandard learning problems [40]. One of them is ordinal classification, where there is an order among output labels. The approach in [41] tackles ordinal classification from the perspective of a more traditional model, reproduced by means of an ANN. More specifically, it implements a Proportional Odds Model, a statistical technique which predicts a value in a 1-dimensional space for each pattern. The resulting ANN has an output layer which extracts class probabilities from a single-variable projection computed in the previous hidden layer. These are then evaluated by means of the continuous version of the Quadratic Weighted Kappa loss function. The optimizer uses this as the objective function which the network has to minimize.

3.2. Building DL Applications

Applications of DL models are very diverse. A large part of them focus on image treatment, since they supposed a breakthrough in large image classification problems in the recent years [42]. Nevertheless, DL models are also employed in scenarios where agents such as robots must interact with their environment and react to changing conditions, as well as other purposes within the data science field like semantic hashing or anomaly detection. Throughout this section, several examples of these kinds of applications are gathered and reviewed. Some of the results are illustrated in Figure 6, where the outputs of different DL models dedicated to specific applications are represented.

Image classification applications are very commonly found within the DL field, due to the potential of convolutional ANNs [46] to learn high-level features from image data using less trainable parameters than other kinds of networks. In this context, [47] proposes a CNN-based classifier which is able to identify the level of quality of an olive oil sample: extra virgin, virgin or *lampante*. It is composed of three convolutional blocks and four fully connected layers which compute the prediction. The resulting model achieves better accuracy than previous methods over the same dataset, while eliminating preprocessing steps at the same time.

The work in [48] also approaches an image classification problem, in this case, waste classification into glass, paper, cardboard, plastic, metal and general trash. This is usually tackled from a computer vision perspective, in three phases: segmentation, feature extraction and classification. The objective is to reduce this process using a CNN which automatically performs the necessary steps. A range of well known CNNs are tested and compared for the same dataset, TrashNet. These include VGG-16, VGG-19, Inception, ResNet and Inception-ResNet. The ResNet model obtained the best accuracy rate, surpassing other experiments from the state of the art.

One problem related to image classification is image segmentation, in which the model has to detect and delimitate regions in images. In [44], this circumstance arises in neurology, specifically in automatic segmentation of white matter intensities in magnetic resonance images. Instead of a standard CNN classifier as in the previous problems, segmentation can be carried out by a CNN, which means that the network does not include any dense layers, and instead it has a bidimensional output produced by convolution or deconvolution operations. The work revolves around the preprocessing techniques that can be applied to images before feeding them

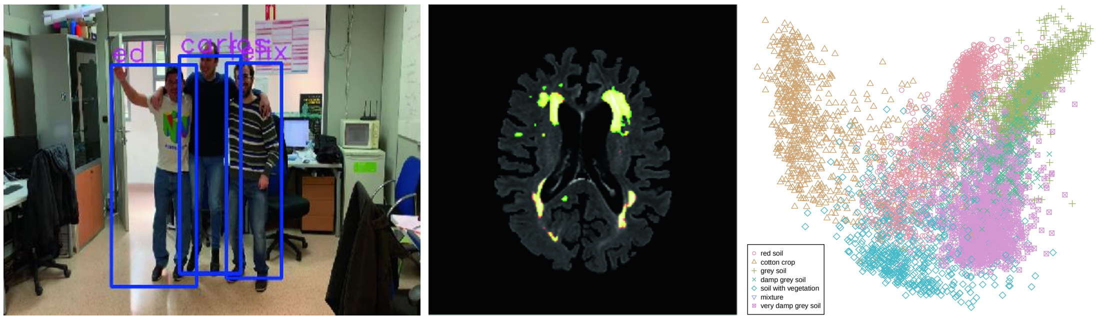

Figure 6: Outputs from DL models for different application domains, from left to right: person detection and identification [43], white matter hyperintensity segmentation [44], 2-dimensional embedding of satellite images [45].

to the CNN. The experiment suggests that enhancing the contrast, removing the skull and standardizing the features benefits the learning process.

Many uses of DL systems involve robots in social situations. These agents need to be sufficiently autonomous and, thus, act according to their environment and adequately interact with humans. Assistant robots for elder people and other communities are the main focus in [43], where a person identification memory system is developed by combining an object detector based on YOLO v3 [49] with a nearest neighbor clustering. This system is capable of identifying people present in previous frames and of incorporating new unknown individuals to its memory.

When robots are involved in child tutoring, they must be able to detect their mood and basic emotions to react accordingly. In [50], a facial expression recognition model is built and integrated into a complete system for the development of this kind of robots. The model is able to distinguish six types of emotions: anger, fear, joy, sadness, disgust and surprise, as well as an additional neutral state. The model was validated with actual images of primary school children.

4. Ethology

Ethology is the discipline of the observation of the behaviour. Its classical domain has been animals in the wild, but it is also applied to animals in the laboratory, looking for advanced phenotype modelling. The increasing use of quantitative sensors and sophisticated computational resources in order to achieve precise quantitative modelling of behaviours has been termed Computational Ethology, where a host of applications are being developed [51]. Neuroethology aims to look for the correlation of behaviour and neural activity, even for the identification of neural causal mechanisms [52, 53].

The integration of neural sensor readings (i.e. inserting electrodes in the brain) and motion capture devices allows the quantitative modelling in some restricted experimental environments [54]. These experimental conditions are quite difficult to be applied to humans, for technical, ethical and ecological validity issues [55]. Thus Human Computational Neuroethology (CNE) poses a new panorama of sensing and computational challenges [56]. There is a rich literature on human motion modeling for a variety of applications, ranging from medicine, sports, and artistic rendering. However, these approaches are usually rather restrictive, limiting the ecological validity of the experiments. Thus, new sensors and algorithms should be developed in order to achieve high motion precision in natural settings. On the other hand, the advent of new wireless connected electroencephalography (EEG) devices allows monitoring neural activity while the subject is in motion [57, 58]. The high sensitivity of EEG to motion artifacts and electromagnetic fields impedes the detection of low magnitude and noisy effects, such as those required in brain-computer interfaces [59].

4.1. State-of the art

Traditionally, validation of neuroethological models has been carried out by direct manipulation of the neural systems, such as producing alterations in the neural circuits by genetic or chemical means, and observation of the ensuing behavior. However, these methods are not of application to humans for self-evident ethical reasons. Even the invasive methods that insert electrodes in the brain tissue have to be severely limited to well justified cases. One approach to the validation of neuroethological models consists in the confirmation of improved activity detection when using the fused information. This is a line of research where several authors have achieved some success and will be extending the experimental evidence base. The research goals in this context has to tackle with several aspects, such as face motion recognition, body motion recognition, and EEG signal processing.

Most of the work in this area concerns animal computational ethology, which has been proposed as discipline on its own [60]. Regarding human behavior modeling, there is a host of computer vision based approaches as well as inertial measurement unit (IMU) based modeling (see figures 7 and 8) among them the new DL architectures are foremost [61]. Most of these approaches are in fact related to robotics interaction [62] instead of modeling human cognition and related fields of interest for CNE. There are some timid attempts to use wireless EEG in clinical trials [63] but there is not much advance, except in very specific well known diseases, such as epilepsy. There are instances miscellany experiences, such as the monitoring of wireless EEG signal while wandering in an art museum [64].

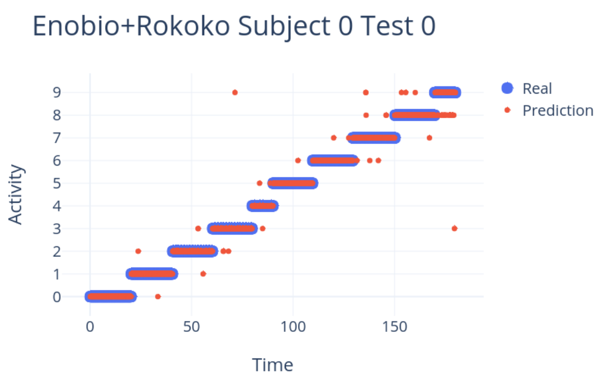

Figure 7: An example of ethogram estimated using data fusion of IMU body motion estimation and wireless EEG recording.

4.2. On the use of inertial sensor units and electroencephalography

In general, methods at this point in time consists in the synchronized collection of body motion and EEG readings while the subject is performing simple tasks. In this regard, image based eye detection, inertial motion units, and several wireless EEG recording devices are considered for the analysis. The system performance evaluation unit is the

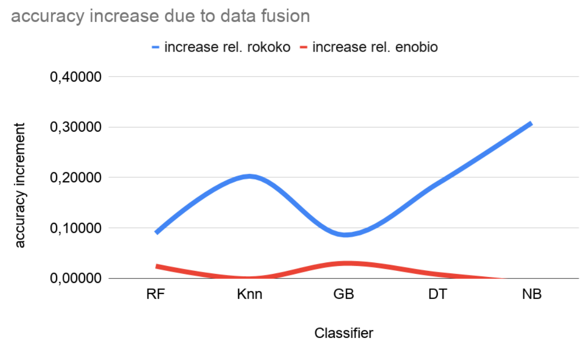

Figure 8: Summary accuracy increase over a cohort achieved using data fusion of IMU body motion estimation and wireless EEG recording in a cross-validation experiment.

ethogram, i.e. a time series of the subject activities carried out and detected, hence the goal is to achieve perfect ethogram recognition, but we also carry out conventional cross-validation experiments in order to evaluate the ML approaches prior to ethogram estimation. Figure 7 shows a recent experimental result of this kind of neuroethogram estimation when we fuse EEG and IMU motion estimation. Figure 8 shows the increase in accuracy in 10-fold cross-validation achieved when using the joint data sources versus the isolated data sources.

A short review of CNE was provided [65], where the main focus was on human motion analysis and some related neural activity modeling research works, mostly in the animal domain, giving hints how these experiments can be extended to the human domain. Another related contribution [66] proposed DL techniques, specifically Long Short Term Memory (LSTM) for gait movement modeling and prediction, which could be combined in the future with neural activity modeling. Also the recognition of cognitive activities through eye tracking [67] could be fused with neural activity recognition for a more detailed modeling, and even causality prediction. Finally, an experimental example is provided where the fusion of neural and motion information effectively achieves improved activity recognition performance and ethogram estimation. This latter work is the most complete instance of the desired experimental and analysis setting up to date.

5. Affective Computing

AC is a growing interdisciplinary area, participating from areas as different as psychology, physiology, engineering, sociology, mathematics, computer science, education, and linguistics. The broad diversity of disciplines pertinent to affective computing is a mirroring of the difficulty of describing, understanding, and mimicking feelings.

During the last two decades, important advances in sensing, tracking, analyzing, and animating human communication have produced increasing attraction in affective computing by human-machine interaction (HMI) researchers [68]. This trend has also reached the human-robot interaction (HRI) community. In fact, the astonishing advancement of (personal and service) robotics has led to an increased demand for social robots that interact socially with humans and other robots [69].

For AC, and also related to HMI/HRI, virtual reality (VR) has demonstrated an increasing interest, probably because humans engage humans better than robots. Moreover, VR eases the simulation and assessment of spatial environments under supervised lab conditions [70]. Virtual characters generate affect that give rise to a more affine interaction with humans [71].

5.1. Main objectives nowadays

In general terms, the objective of investigation in affect recognition (a piece of affective computing) is to detect the emotional state of a person based on observables [72]. For instance, affective speech is conveyed through semantics and speech prosody. Probably facial expressions and body gestures are the most obvious and significant channels for expressing affect, as most human communication is non-verbal [73]. More recently, apart from propositions based on audio and vision, solutions relying on wearable sensors have received greater attention. Wearables provide long-term affect recognition supplying with insights into physiological aspects such as respiration, skin color, temperature, heartbeat, blood pressure, and pupil dilation [74]. Physiological signals are considered as a specific information channel for affective reactions. Specifically, an outstanding number of approaches are offering high accuracy of stress detection using non-intrusive physiological sensors.

AC has also encouraged the advent of novel applications in entertainment, education, marketing and health care. Perhaps one of the most significant research domain of affective computing is focused towards discovering the relation between emotions and human health, both mental and physical [73]. Research in AC has already provided significant benefits (e.g. Williams syndrome, Asperger syndrome and Parkinson disease -PD-). Affective computing can also be used for personalization such as adjusting light, type of music, and room temperature by detecting a person's emotional state to strengthen people's health and well-being [75].

5.2. Human-machine interaction and health-care applications

The works included under this area cover several aspects related to AC. These topics can be described in regards to three main aspects, namely affective computing for interaction among humans and machines, technologies used in AC, and affective-based health-care applications (see Fig. 9).

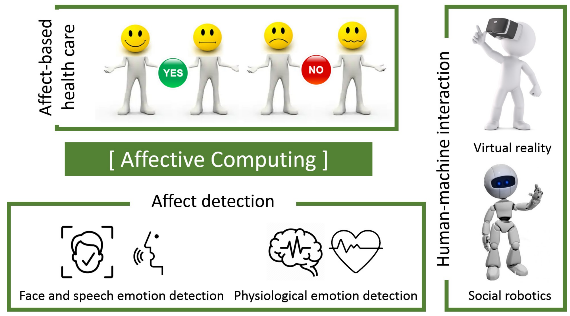

Figure 9: The three main aspects involved in the special session on affective computing.

Considering the health care applications tackled, the application field faced (i) elder people with PD, exploring new paradigms of interaction [76], (ii) patients with deficits in facial affect recognition, designing therapies based on human avatars [77], (iii) people with disabilities in general, identifying the brain areas involved in processing emotions [78], (iv) people with visual and intellectual disabilities, reporting the effectiveness of using a game or a conversation on achieving a higher self-disclosure [79], (v) dependent people living at home, using a flying robot the monitor facial emotions [80] and a wearable to detect stress [81], and, (vi) people performing physical rehabilitation exercises, monitored from two carts equipped with an RGB-D camera each on a motorized circular rail [82].

HRI was at the core of [83] that introduces a real-time emotion recognition system using a YOLO-based facial detection system and an ensemble convolutional neural network. Another work benefited the field of HRI by facing a broadened understanding of brain emotional encoding in order to improve the capabilities of robots to fully engage with the user's emotional reactions [84]. Another article introduced a framework for assisting dependent people at home through an autonomous unmanned flying robot that captures images of the dependent person's face [80]. The outcomes of another paper will help to improve HRI for promoting self-disclosure as the first step in a research project that aims to alleviate worrying behavior in the user group [79]. In the interaction domain, a last paper introduced the design process of facial expressions on virtual humans to play basic emotions, grounded on the Facial Action Coding System [77].

The papers have detected affect from facial cues by robots working in real-world scenarios [83] and speech in order to elicit stress through a set of online interviews, as well as to establish a standard speech corpus to assess emotions across multiple languages [85]. Hence, a number of papers introduced solutions based on the acquisition and processing of physiological signals. A couple of papers used electrodermal activity (EDA) and heart rate variability (HRV) acquired from a wristband. One of the papers introduced a system composed of hardware, control software, signal processing and classification for the deployment of a wearable with a high ability to discriminate among seven emotional states (neutral, affection, amusement, anger, disgust, fear and sadness) [86]. Another paper described the acquisition of EDA signals and their storage and processing for stress detection. The classification was undergone by using several support vector machines [81].

Other approaches addressed the use of EEG signals in this context. As an example, a study of cortical asymmetries based on the spectral power and differential entropy of the EEG signal of subjects is carried out [87]. Subjects were stimulated with videos of positive and negative emotional content in order to understand the neurophysiology of emotions, the neuronal structures involved in the processing of emotional information and the circuits by which they act. Another work proposed a temporal analysis approach for the discrimination of two states (high and low) of valence and arousal emotional dimensions, with the additional benefit of identifying the brain areas involved in processing emotions [78]. In addition, [84] took advantage of the lateralization produced in brain oscillations during emotional stimuli and the use of meaningful features related to intrinsic EEG patterns. Finally, a solution based on a brain-computer interface (BCI) able to control events is presented [76]. This mobile-BCI application in turn triggers actions that facilitate mental interactions.

6. Bioinspired Systems

Bio-inspired computing methods take inspiration from nature to develop, in many cases, optimization and search algorithms or metaheuristics, typically in order to tackle the search of optimal solutions of complex problems in science and engineering, which usually imply a high dimensionality of the search space.

Apart from the traditional evolutionary computation methods, artificial immune systems, ant algorithms or particle swarm optimization, the novel bioinspired computing approaches are intended to focus on new bio-inspired solutions, such as swarm algorithm solutions based on bee colonies, algorithms based on firefly insect behavior, artificial algae algorithm and many more, together with their combination with local search strategies or other metaheuristics. Topics areas in this field include:

- Bio-inspired approaches based on animal behavior (Cuckoo search, Cat swarm, Artificial Bee Colony, Bat algorithm, Wolf search, etc.).
- Bio-inspired approaches based on plant behavior (artificial algae algorithm, flower pollination algorithm, PIBO, etc.).
- Bio-inspired approaches based on bacteria like BFO.
- New approaches in evolutionary computing methods.
- Combination of bio-inspired approaches with local search: Lamarckian strategies, Baldwinian strategies, memetic algorithms.
- Combination of the bio-inspired approaches with artificial life models like cellular automata or Lindenmayer systems.
- Applications with bio-inspired approaches.

6.1. Solutions in biomedicine

The inference problem of protein structure prediction can be tackled with a hybrid combination between differential evolution and a local refinement of protein structures provided by fragment replacements [88]. In this case, the coarse-grained protein conformation representation of the Rosetta environment was used. Given the deceptiveness of the Rosetta energy model, an evolutionary computing niching method, crowding, was incorporated in the evolutionary algorithm with the aim to obtain optimized solutions that at the same time provide a set of diverse protein folds. Thus, the probability to obtain optimized conformations close to the native structure is increased.

Another bio-inspired approximation is called bacterial antibiotic resistance algorithm [89] in which a bacteria colony represents a set of candidate solutions subjected to the presence of an antibiotic as a pressure factor for separating good and wrong answers. In these terms, the classification allows having two groups: resistant and non-resistant bacteria. Then, by using genetic variation mechanisms (conjugation, transformation, and mutation), non-resistant bacteria is expected to improve their defense capability to enhance their probability of survival.

Finally, the Koniocortex Like Network (KLN) [90] is a novel Bioinspired Artificial Neural Network that models relevant biological properties of neurons as Synaptic Directionality, Long Term Potenciation, Long Term Depression, Metaplasticity and Intrinsic plasticity, together with natural normalization of sensory inputs and Winner-Take-All competitive learning. As a result, KLN performs a Deeper Learning on Datasets showing several high order properties of biological brains as: associative memory, scalability and even continuous learning. KLN learning is originally unsupervised and its architecture is inspired in the koniocortex, the first cortical layer receiving sensory inputs where map reorganization and feature extraction have been identified, as is the case of the visual cortex. This new model has shown big potential on synthetic inputs and research is now on application performance in complex problems involving real data in comparison with state-of-art supervised and unsupervised techniques. The early detection of cardiovascular disease is an interesting domain addressed in [90] with KLN.

6.2. Solutions in smart cities

Smart cities result from the wide adoption of information and communication technologies aimed at addressing challenges arising from overpopulation and resources shortage. Despite their important and fundamental contributions, ICT alone can hardly cope with all the challenges posed by growing demands of overpopulated cities. Hence, novel approaches based on innovative paradigms are needed. The concept of Cognitive City founded on Siemens' Connectivism and understood as the evolution of current smart cities augmented with artificial intelligence, internet of things, and ubiquitous computing. The concept of cognitive city as a complex system of systems resembling complex adaptive systems with natural resilient capabilities is another approximation [91]. On-line scheduling is another domain. This problem addressed in [92] arose from a charging station where the charging periods for large fleets of electric vehicles (EV) must be scheduled under limited power and other technological constraints. The control system of the charging station requires solving many instances of this problem on-line. The characteristics of these instances being strongly dependent on the load and restrictions of the charging station at a given time. The goal was to evolve small ensembles of priority rules such that for any instance of the problem at least one of the rules in the ensemble has high chance to produce a good solution. To do that, Genetic Algorithm (GA) that evolves ensembles of rules from a large set of rules previously calculated by a Genetic Program (GP) were used in [92].

Bio-inspired methods are often applied to structure calculation in civil engineering. One example of this was proposed in [93]. In this case, the authors consider repairing bridges that cross watercourses. It is a situation that must be resolved in a timely manner to avoid the collapse of its structure. Its repair can mean a high cost, as well as road and environmental alteration. An effective solution, which minimizes this impact, is the installation of a superstructure in the form of an arch that covers the entire length of the bridge. The structure is anchored to the deck of the bridge by means of hooks, and so it allows the arch to support the bridge. This structure must keep the original properties of the bridge, so the magnitude of tension of the hangers and the order in which they are applied is essential for not to cause damage to the bridge. In [93] the authors use moth search algorithm to calculate these tensions and the order in which they are applied.

Scheduling problems arise in an ever-increasing number of application domains. Although efficient algorithms exist for a variety of such problems, sometimes it is necessary to satisfy hard constraints that make the problem unfeasible. In this situation, identifying possible ways of repairing infeasibility represents a task of utmost interest. The authors in [94] considered this scenario in the context of job shop scheduling with a hard makespan constraint and addressed the problem of finding the largest possible subset of the jobs that can be scheduled within such constraint. A genetic algorithm that looks for solutions in the search space defined by an efficient solution builder was proposed [94].

7. Robotics

AI research in the field of robotics can sometimes become very eclectic with extremely different approaches coexisting in order to allow robotic systems to do their thing. This eclecticism can be organized in different ways, but two of them are more prominent. On the one hand, and focusing on robotic skill acquisition, it can be organized into, at least, three categories in terms of how the robot acquires its competences. That is, in the lower level one could find more classical approaches, where the robot is provided with the operational skills it needs in terms of programs, or ANNs, that perform the desired tasks [95].

A higher level would encompass learning approaches, where the robots are able to learn skills in their domain, that is, they can learn **how** to perform the task they are externally commanded to carry out [96, 97, 98]. Finally, in the highest or cognitive level, one could even resort to more autonomous approaches involving motivational systems within cognitive architectures [99, 100] that seek to allow the robot to decide **what** tasks it needs to perform and then learn the appropriate skills. In this level the problem the robot would face would be that of lifelong open-ended learning.

From another, more traditional, point of view, research in robotics is often organized with regard to categories of skills desired from the robot. In this categorization we can go from basic low level skills, such as trajectory generation issues, to the acquisition of particular interaction skills or to the analysis of how to achieve particular effects on the domain, including effects on humans, through interaction with the robots. These last effects include eliciting emotions or providing education to humans.

7.1. Physical interaction with humans

One of the main goals of robotics is to assist people with disabilities [82]. In this sense, a robotic system consisting in a motorized circular rail that generates the motion of two carts with an RGB-D camera (depth sensor) can track a person's physical rehabilitation exercises from two points of view and his/her emotional state from one of these viewpoints. Moreover, the problem of trajectory generation and planning aimed at assisting dependent people at home, can also be tackled with a quadrotor that includes a vision system [80]. The solution includes a trajectory planning algorithm that allows the UAV (unmanned aerial vehicle) to position itself in order to capture images of the dependent person's face. These images are later processed by a base station to evaluate the person's emotional state, together with his/her behavior, thus determining the assistance needed in each situation.

7.2. Emotional interaction

Going up into the interaction realm, one of the next barriers in robotics is to provide sociable robots with the ability to fully engage in emotional interactions with users. In this line, in [83] authors propose a real-time emotion recognition system using a YOLO-based facial detection system and an ensemble CNN. The field of human-robot interactions (HRI) will benefit from a broadened understanding of brain emotional encoding and thus, improve the capabilities of robots to fully engage with the user's emotional reactions. In [84] authors propose a methodology for real-time emotion estimation aimed for its use in the field of HRI. On the other hand, and in the same line of endowing social robots with natural interaction abilities, [101] addresses the development of robotic dialogue skills.

This use of robotic systems to try to elicit human reactions can be one step further and into more psychological, emotional domains. An example is the work in [79], where the authors present the results of a pilot test on the effectiveness of using a robotic game or a conversation on achieving a higher self-disclosure in people with visual and intellectual disabilities. They implemented an interaction process with a Nao Robot through games or conversation and their results indicate that during the game-based interaction the participants used much longer self-disclosing sentences in comparison with the to be conversation-based interaction.

Finally, and reaching the higher level cognitive realm, [102] studies motivation in autonomous robots. The latter work focuses on the basic structure that is necessary for bootstrapping the initial stages of multiple skill learning within the motivational engine of the MDB (multilevel Darwinist brain) cognitive architecture (see Fig. 10). Taking inspiration from a series of computational models of the use of motivations in infants, they propose an approach that leverages two types of cognitive motivations: exploratory and proficiency based. They postulate that these make up the minimum set of motivational components required to initiate the unrewarded learning of a skill toolbox that may later be used in order to achieve operational goals.

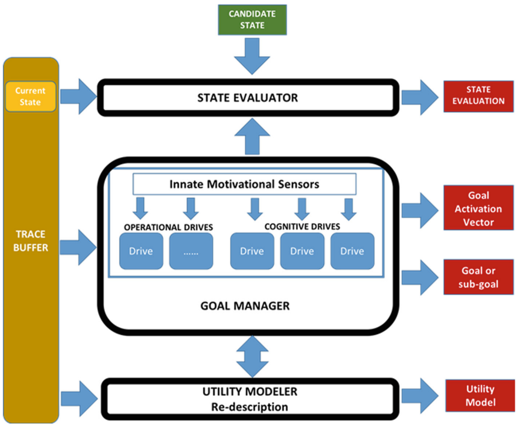

Figure 10: Motivational engine diagram of the MDB cognitive architecture [102].

7.3. Education and social robots

Robotics have proved to be a very attractive tool for student specially in STEM areas that involve active exploration. Nevertheless, learning activities with robotics kits are usually isolated from official curriculum and no evaluation about the learning outcomes of students are provided. The work in [103] presents IDEE, an integrated learning environment which uses robotics as a learning tool for a physics laboratory (see Fig. 11). Students in IDEE have to achieve certain learning goals or skills when solving physics problems. On the basis of students' skills, IDEE shows certain hints to help students and teachers, in supporting the students' learning process.

Another example of the use of robots in education is the work in [50] that develops a tool to support education through social interaction. Authors use in their research, facial recognition of emotional expressions, aimed at improving ARTIE, an integrated environment for the development of affective

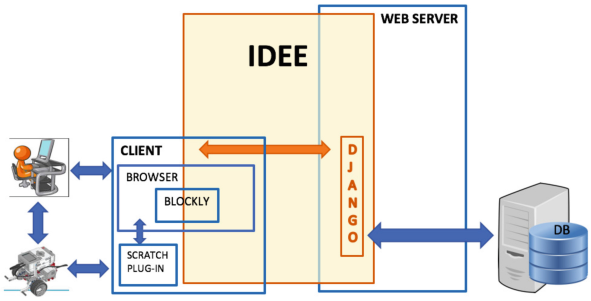

Figure 11: General architecture of IDEE integrated learning environment [103].

robot tutors. A Full CNN model has been trained with the Fer2013 dataset, and then validated with another dataset containing facial images of primary school children, which has been compiled during computing lab sessions.

Social Robots is other emergent area in robotics, not only in education but also in several areas of interaction with humans. [43] uses the combination of CNN and statistical classifiers to create a long-term semantic memory that is capable of learning online. To validate this hypothesis, the authors have implemented a long-term semantic memory in a social robot. The robot initially only recognizes people, but, after interacting with different people, it is able to distinguish them from each other. The advantage of their approach is that the process of long-term memorization is done autonomously without the need for offline processing. When a Social Robot is deployed in a service environment it has to manage a highly dynamic scenarios that provide a set of unknown circumstances: objects in different places and humans walking around. These conditions are challenging for an autonomous robot that needs to accomplish assistive tasks. [104] proposes the use of a probabilistic Context Awareness System that provides a set of belief states of the environment to a symbolic planner enabling PDDL (Planning Domain Definition Language) metrics. The Context Awareness System is composed by a DL classifier to process audio input from the environment, and an inference probabilistic module for generating symbolic knowledge. This approach delivers a method to generate correct plans efficiently.

7.4. Industrial Robotics

Industrial Robotics is, obviously, an important part of robotics research, as we can see in the following contributions. Despite that the work in [105] is not a robotic specific contribution, navigation is still an open problem in robotics. In their paper, the authors propose a method able to provide a robust user heading as a result of detecting the relative position of the mobile phone with respect to the user, together with a heuristic computation of the heading from different Euler representations. They also have performed an experimental validation of their proposal comparing it with the Android default compass. The results confirm the good performance of this method.

Drones are also an emergent area in robotics. In [106] a Qdash-learning control strategy is proposed for a system consisting of a UAV lifting a damped pendulum from the ground. This dynamic system is highly nonlinear and thereafter, it represents a challenging task to get a smooth and precise behavior. Aerial transportation of a pendulum in a stable way is a step forward in the state of the art, which permits to study the delivery of different deformable linear objects.

The deployment of Industry 4.0 will achieve great aims regarding production rate, control, data analysis, cost, energy consumption and flexibility. However, robots, machinery and knowledge needed could lead to a social problem for those operators who are not prepared to face such big technology challenges. To preserve this emerging paradigm's balance, researchers and developers must consider using intelligent human-machine interaction capabilities before building novel industry deployments. [107] introduces a smart gesture control system that facilitates movements of a robotic arm with the aid of two wearable devices (see Fig. 12). By using this kind of control system, any worker should fit into the new paradigm where some precise, hazardous or heavy tasks incorporate robots. Furthermore, their proposal is suited to industry scenarios, since it fulfills fundamental requirements regarding success rate and real-time control as well as high flexibility and scalability, which are key factors in Industry 4.0.

Another industrial use of robotics that have achieved some importance in recent years is agriculture. In [108] the design and verification of the GREENPATROL localization subsystem is described. GREENPATROL is an autonomous robot system intended to operate in light indoor environments, such as greenhouses, detecting and treating pests in high-value crops such as tomato and pepper. Their proposed localization subsystem (see Fig. 13) consists of two differentiate parts: (1) an absolute localization module which uses precise positioning GNSS (global navigation satellite system) techniques in combination with the robot proprioceptive sensors (i.e. IMU and odometry) with an estimated position error, and (2) a relative localization module that takes the absolute solution as input and combines it with the robot range readings to generate a model of the environment and to estimate the robot position and heading inside it.

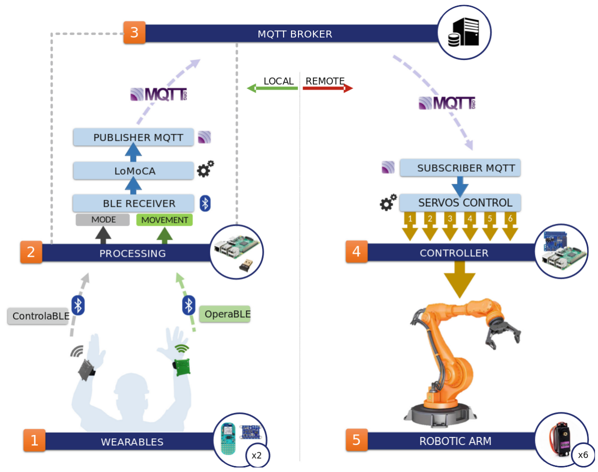

Figure 12: Architecture of gesture control system [107].

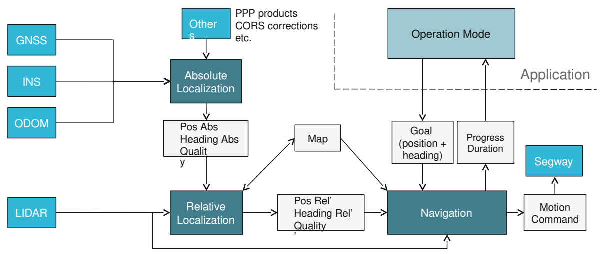

Figure 13: GREENPATROL software architecture diagram [108].

Finally, transportation and logistics, an important area of world economics, is represented by the work in [109]. In their research, authors attempt to build a user interface for controlling a group of omnidirectional robots to realize the transportation of convex shape edge objects. Their method establishes a manual guidance to the robots initial positions, initializes the collective grasping/lifting process and finally, provides the user with a high level control over the velocity of the load during transportation to the required destination. The hardware and software structure of the system are described and simulation is performed to convey the data from the robots sensors.

8. Machine learning applied to big data analysis, processing and visualization

One of the best known applications of ML techniques to Big Data is the analysis of the information coming from social networks [110]. The general public has found with surprise that some human behavior tendencies can be predicted from human activity in those social networks. Other applications of ML which have a paramount social relevance include health care enhancement by exploitation of clinical data [111]. In this way, doctors and other health professionals can benefit from predictors generated by supervised learning algorithms [112].

Among the myriad of methodologies which comprise ML, DL of ANN architectures stands as one of the most successful. The capability of deep networks to analyze large volumes of high dimensional data has led to extraordinary results in image processing, computer vision, natural language processing, speech recognition and remote sensing [113, 114]. The key to these achievements is the automated feature learning which deep networks exhibit. This liberates the practitioner from the need to produce a set of hand made features [8]. Therefore, the work to be completed by the human is reduced. Moreover, significant features are discovered by the machine that humans may never be able to find out. In other words, deep networks can reach solutions to pattern recognition tasks that humans would never come up with.

Visual data analysis is often carried out with the help of a particular kind of deep networks, namely CNN. They comprise convolutional layers which adaptively learn convolution filters that recognize significant features of images and videos. This way visual information can be understood by the machine [115]. The initial neural layers in the architecture learn low level features like edges, while subsequent layers discover high level features and concepts, so that representations of objects parts and object types can be learned from visual data sets. CNN are instrumental in medical image analysis [116, 117], among other visual understanding applications.

8.1. Processing large datasets

The automated processing of large volumes of georeferenced positional data is instrumental in the analysis of complex human behavior. This is illustrated in [118], where a Geographic Information System (GIS) is employed as a framework to run realistic simulations of urban environments of the city of Quito (Ecuador). The simulations model the social and public health consequences of the abandonment of dogs. The authors propose a set of simulation specifications and features. Then the simulation results are analyzed and validated, including the interactions among the relevant agents and the effects of those interactions. It is concluded that a higher level of social awareness about this problem is required to solve it by attaining a balance among the interests of the intervening agents.

Large image content repositories are being used in many fields which has created an ongoing demand of image retrieval systems. The procedure of automatically retrieving images by the extraction of their low-level visual features (color, texture, shape properties...) is called Content Based Image Retrieval (CBIR). A CNN for feature extraction to address the CBIR issue has been presented in [119]. The proposal is based on computing the class probability vector of an image and employ it as a vector of representative features. After that, a suitable distance measure is used to compute the dissimilarity among the test image and the images stored in the image database from which similar images are to be retrieved.

Moreover, the use of high quality medical images in large datasets is essential for the diagnosis of diseases. One important image modality is magnetic resonance (MR), whose resolution in the acquisition depends on several technical and human aspects. Super-resolution is a technique to enhance the resolution of MR images using the information of the image itself or the learned features of large image datasets, as DL based methods do. Most of these CNNs are based on the minimization of the residuals using the squared Euclidean cost function. [120] proposed a novel optimization algorithm for CNNs based on the p-norm, where p is the exponent of the norm, which can reduce the effect of outliers and improve the convergence of the network. The use of values $p < 2$ reduces the influence of extreme values of the residual error, i.e. badly measured training samples, and both the loss function and the final generated high-resolution image yield better outcomes than the usual squared Euclidean norm.

8.2. *Video surveillance systems*

An important issue in the video surveillance systems is the background modeling and foreground detection. The performance of many proposals which address that problem is strongly correlated to the level of noise present in the video. However, the segmentation method proposed in [121] can reduce the effect of a heavy Gaussian noise satisfactorily. Each video frame is organized into several shifted patches (tilings) and a set of significant features is extracted from each patch. A trained stacked denoising autoencoder, which is an unsupervised DL NN, is employed for unsupervised feature extraction due to its ability to provide relevant visual features.

The detection of anomalous objects is another fundamental task in video surveillance. Many DL approaches have been developed requiring high power consumption due to the use of GPU-accelerated techniques. The DL based detection system proposed in [122] is implemented in microcontrollers achieving a low cost surveillance system for panoramic cameras. Instead of an exhaustive scan of the full image, the decision about which window of the image is analyzed at each time instant is based on a probabilistic mixture of a uniform and a Gaussian probability distributions. Thus, the uniform component represents the uninformed fully random selection and the Gaussian helps to generate the next window close to where an anomalous object was previously detected. A trained CNN was implemented in a Raspberry Pi through the Microsoft Cognitive Toolkit, providing a high performance detection system for security tasks.

9. Machine Learning in Neuroscience

Currently, data acquired in biomedical studies has singular characteristics that difficulties the processing in exploratory or discriminative analysis. Moreover, classical statistical methods not always offer the necessary tools to cope with these difficulties in the search, for instance, of specific disease or disorder patterns. In addition, the hybridization of different ML methods can help to address specific difficulties or to improve the models provided by classical algorithms. On the other hand, DL-based methods are gaining popularity in the last years due to the good results provided especially in the field of image processing, where classical alternatives have been overcame.

Machine learning in neuroscience covers different aspects, regarding several bio-signal modalities and techniques applied to exploratory and discriminative analysis. As an example, the application of ML methods to neuroimaging processing have allowed to improve the diagnosis accuracy of the PD using 3D DatSCAN-SPECT images. Its diagnosis usually relies on visual analysis of Single Photon Emission Computed Tomography (SPECT) images acquired using $^{123}I-ioflupane$ radiotracer to detect a deficit of dopamine transporters at the striatum. This way, PD can be differentially diagnosed by detecting a dopaminergic deficit in PD patients with respect to Controls (CN) or other diseases presenting similar symptoms. Several Computer-Aided Diagnosis (CAD) tools based on statistical techniques have been developed [123, 124]. Moreover, the use of deep neural networks in the last years for image processing and classification has provided a new opportunity to improve previous CAD systems based on statistical learning techniques [125, 126, 127]. In addition, ML and DL methods can be boosted by training them with specific features.

DL techniques, can be also used for Functional Magnetic Resonance Imaging (fMRI) processing to compute complex models of functional connectivity. Moreover, DL allows to extract representative features in other brain disorders that are traditionally very difficult to diagnose such as the Autistic condition. Functional connectivity can be estimated by measurement of correlation between time-series of blood oxygenation level dependent (BOLD) endogenous contrast estimated from brain regions whilst in resting wakefulness has been demonstrated as a reproducible measurement on an individual basis [128]. Additionally, the use of DL architectures to reveal patterns requires the use of specific techniques to inspect how the DL *black box* is working and the features it is learning from the input data.

The use of ML techniques has revolutionized data processing providing new and powerful tools to exploit the data in search of complex patterns, which has been proved to be effective even with noisy [129], incomplete [130] or unbalanced data [131]. However, studies that explore these techniques to reveal their limitations and the conditions in which they are effective, provide very interesting information for the data processing scientific community.

9.1. *Processing Neuroimaging studies*

Preprocessing methods in neuroimaging result very important to the performance of classification and feature extraction algorithms, as well as for visual inspection of the images. Thus, [132] presents a comparison between affine and non-affine methods for spatial normalization of $I^{[123]}$-FP-CIT images which fundamental to match equivalent areas of the brain from different subjects.

PD diagnosis using neuroimaging is addressed in [1], which presents a method to classify DatSCAN images using a CNN) trained with the isosurfaces computed from the images as shown in Fig. 14. The extracted isosurfaces provide descriptive features to model the striatum shape. Moreover, isosurface images have been used as input of the CNN outperforming the classification performance provided by DatSCAN images and allowing the computation of regions of interest by means of the CNN saliency and activation maps.

DL techniques are also used in [133] with application to autism disorder diagnosis. In this work, authors compute the functional connectivity as the correlation between time-series of BOLD for different brain regions. Subsequently, the correlation matrices are used as input samples on the CNN shown in Fig.15. The saliency maps obtained provide very interesting and useful information regarding the differences between typically developing controls and Autism.

Finally, [134] presents a method for automatic analysis of behavioral variables of laboratory rats to describe their activity, based on ML and image analysis techniques. This work present a set of experiments to investigate whether rat strain influences the behavioral and physiologic measures typically used to assess stress responses.

9.2. Multivariate pattern analysis in EEG signal processing

Classical EEG signal processing techniques along with multivariate pattern analysis is used in [135] to decode conflict-related neural processes associated with congruent or incongruent events in a time-frequency resolved way and determined how different frequency bands contribute to the overall decoding accuracy by means of a linear SVM.

Novel advances related to EEG processing include [136], where correlation between EEG spectrum in the typical EEG bands (Delta, Theta, Alpha, Beta and Gamma), are used to infer functional connectivity patterns that reveals differences between controls and dyslexic subjects. Unlike classical experiments in this area, non-interactive auditory stimuli have been used in this work. Example of connectivity matrices obtained with the proposed method are shown in 18. In the framework of the same research, [137] provides an exploratory analysis on the differences between EEG channels in each band, by means of the spectral coherence. This reveals the most relevant channels according to the difference in the frequency response as shown in Fig. 16 and Fig. 17. Moreover, this work proposes the use spectral descriptors for each EEG band along with a one-class SVM to classify subjects into controls and dyslexic.

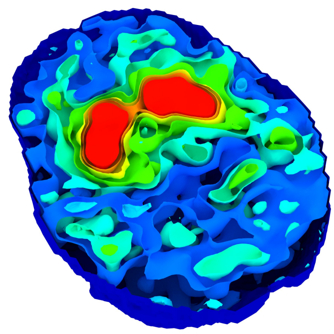

Figure 14: Isosurfaces computed from PPMI DatSCAN image, corresponding to a normal/control subject.

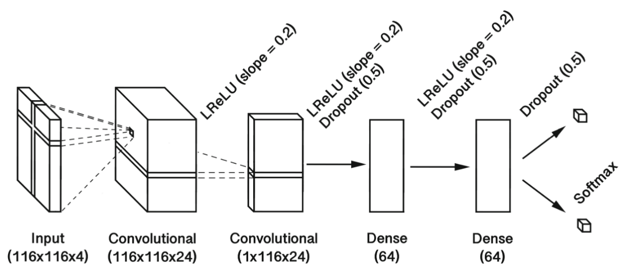

Figure 15: Neural Network used in [133], based on BRainNetCNN.

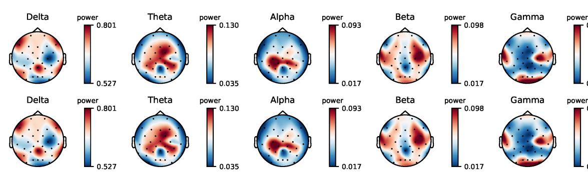

Figure 16: Average activation patterns computed for 2 Hz stimulus by different bands for Controls and Dyslexic subjects.

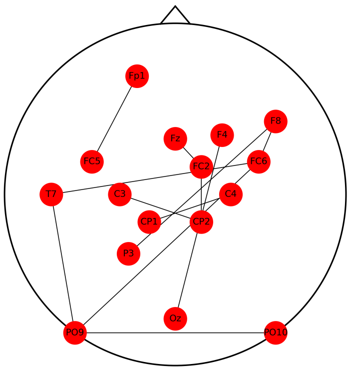

Figure 17: Most relevant relationships between EEG channels for Theta band, according to the features selected by the ℓ_1-SVM.

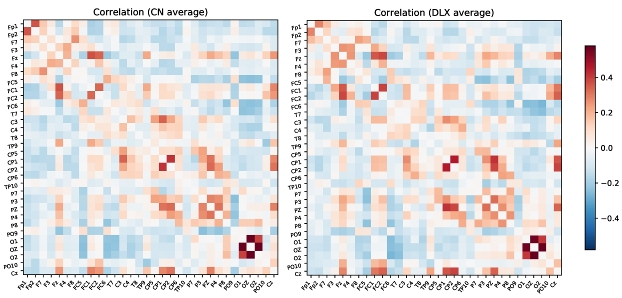

Figure 18: Mean connectivity matrices per group and feature under the same scale

10. Neuroscience Applications

The knowledge accumulated on the cortical EEG activity has been intensively used in the design of BCI, a one-way path to the moment, although the reverse way (from outer world to brain) has become also an important target for present and future research. Other fields of research are the development of reduced electrode count dry EEG interfaces not requiring from conductance enhancing substances to be used in rehabilitation or substitutive biomechanical structures for artificial ankles, knees, hips, wrists, elbows or shoulder joints. On the one hand, the availability of BCIs have facilitated the growth of corroborated studies in which brain cognitive and/or sensory-motor activity is augmented by EEG records to base causative relationships which may be on the background of cognitive and neuromotor human activity. In this way studies on endocrinal control of heart function, elevated blood pressure, chronic stress, depression and other psychophysical diseases affecting well-being and underlying diseases are being investigated [138]. On the other hand the intensive research conducted during the past decade has produced outstanding results in detecting the elementary neural processes behind fundamental human activity in cognitive processes as learning, decision-making, aging and neurodegeneration, among the most relevant ones [139].

10.1. Brain-computer Interfaces

Simple BCI based on an EEG can detect alpha and beta EEG bands on Fp2 and O2 electrodes known to be associated with open (oE) or closed (cE) eye states [4, 140]. The detection is based on the ratio between the average power of alpha and beta bands, which is compared with a threshold obtained from averaging both maximum cE and minimum oE ratios [141]. The results show estimations of this threshold applying different time windows for different subjects for off-line experiments. Online ones consisting in sessions of 277 s long show good performance scores in detecting the oE and cE conditions. The authors propose using this simple BCI in domotic applications where the wide-awakeness state of a subject is to be monitored, as in patients with impaired mobility.

Motor imagery tasks-based BCI system finds applications for disabled people to communicate with surrounding [142]. The methodology used is based on two types of EEG features: on the one hand event-related synchronization-desynchronization is used based on relative power spectra scattering over a given period of time; on the other hand functional connectivity estimation was used to evaluate a weighted phase locking index from continuous wavelet transform coefficients between each two channels present in the EEG. The results were presented in terms of plots by frequency bands in time and channel when conducting each motor imagery task on the scalp map.

A BCI application based on the BCI2000 system in [143] focuses its attention on assessing differences in activation of both hemispheres in stroke survivors during a motor task usually employed for BCI control. To perform this undertaking, it is necessary to increase the knowledge about EEG changes in ipsilateral and contralateral limb movements during motor control. The study sample consisted of stroke male patients and healthy male participants and the experimentation was carried out in a single session which was divided into two subtasks. The authors reported that in the affected hemisphere of stroke patients, there is a significant Event-Related Desynchronization (ERD) in alpha and beta bands more marked when the using contralateral (affected) hand than using the ipsilateral (non-affected) hand. However, the time-frequency analysis of EEG shown the presence of a significant ERD in alpha and beta bands, clearly more marked than in the affected hemisphere, without differences between hands in the unaffected hemisphere of stroke patients. Therefore, it is possible to control the BCI system with signals obtained from both hemispheres, appearing significant differences between them and implying different physiological mechanisms that might be relevant for BCI implementation.

10.2. Gamification

Beyond BCI, gamification and usability techniques were considered to empower the improvement of communication between player/user and Aided Communication Devices [144]. This work focuses its attention on the use of different devices to assess the hand-wrist movement on a normative population. This approach is based on designing and development a first-person racing video game. The From this novel methodology, biomechanical indicators were gathered. Non-parametric statistical methods were used to evaluate and distinguish the three different aging clusters (young, mid-age and elder people). The study involved thirteen volunteers divided into two groups (control group - nine individuals, and contrast group - four individuals). The first group used a lightweight device (smartphone), while the second group used a heavier device (tablet). The outcomes achieved were presented on a set of tables and graphical plots. The key reportings are that the third group (elder players) obtained the highest difference with respect to the two other groups, independently the device used. However, the device weight should be taken into account to carry out this kind of activities. The following step is testing this methodology with people diagnosed with PD.

One of the most important issues in this topic is the connection between spatial and numerical cognition as the basis of mathematical cognition and academic achievement. A twofold strategy to improve numerical skills through spatial cognition is proposed in [145] on game-based learning and technology enhanced learning: Velocicards and Flatlandia creatures. The basis for the study is the approximate number system ability in humans, a cognitive system that supports the estimation of set cardinality without resourcing to numbering or using symbols, strongly linked to spatial cognition abilities, and active since very early in life. The existence of a strong connection between spatial and numerical cognition and the number interval position effect can be exploited in predicting school achievement and success as in the development of writing and calculation skills. It proposes a game-based learning framework designing an educational approach which promotes spatial and numerical skills by Velocicards, an application to strengthen numerical abilities, by selecting cards with different codes favoring the transition between analogical representations and symbolic ones, helped with collection of statistics. Within the same framework, Flatlandia creatures are building blocks of different geometric features, helping to create links between the physical and digital worlds stimulating mental representation of spatial elements. See related work in [146, 147].

10.3. Cognitive Neuroscience

Investigations on the capacity of perception, reasoning and action in spatial coordinates in the identification of visual and spatial relationships among objects, to enable subjects to interact with the surrounding world, is crucial in Cognitive Neuroscience (CN). This understanding will allow the correction of spatial cognition problems by assessing visuospatial abilities, as target identification, object perception and multidimensional spatial relationship understanding, with specific focusing in the visual system. The platform ETAN [148] for the assessment of visuospatial abilities by means of technology enhancement is introduced, allowing the immediate physical interaction with external world stimuli by arms and hands using small disks detectable by a video camera tracing the tokens on a specific desk. Three types of arrangements were simulated: normal, unilateral spatial neglect, and other unspecific anomalous arrangements. SVM is used to classify and discriminate normal from abnormal dispositions.

A new interesting psychophisical property of the number interval bisection task is the number interval position effect (NIPE). In [149] a quite cognitive character to explore the NIPE in children and adults is studied. This effect manifests in the task of number interval bisections where human participants show a systematic error bias, which is linked to the position occupied by the number interval within a ten. To study this numerical cognition effect simple arithmetic questions are proposed to human participants demanding an immediate response, as identifying the natural number that divides equally a numerical series delimited by two natural numbers (bisection task). An artificial model is proposed to explain the effect, based in neuronal principles, implying that basic numbers are encoded in an a-modal way by distinct neural groups, and that neural elaboration relies on energy transfer between neural groups through networks provided with a probabilistic winner-takes-all strategy [147].

Moreover, CN systems and tools for modeling and measuring creativity is a prospective topic for the analysis of creative association [150]. The basis of the research is the Remote Associates Test (RAT) as a measure of the associative factor in creativity, summarized in the CreaCogs framework, proposing processes to solve associative related tasks, creative use and object inference. In addition, a visual adaptation of the RAT to integrate visual and linguistic performance was proposed following the methodology described in [150], and two separate studies were also conducted to evaluate it. Correlation studies show how these cognitive computation methods present a statistical association between the construction of visual and linguistic tests to gain cross-modal strength.

Finally, other studies in CN analyse the influence of the physiological signals regarding cognitive states via the autonomous nervous system [151] . In the latter work, the methodology is based on the estimation of the low and high frequency bands over the interpolated pulse-to-pulse intervals, using a smart wristband Empatica E4. Kruskal-Wallis ANOVA, feature ranking and a multilayer perceptron were used to assess within and between group comparisons (controls, slow, normal and fast breathing). In this way, low and high frequency features of the breathing phase are suitable for classification, although the cognitive parameters failed in producing statistical significance even though results suggest a statistical relationship between HRV and cognitive parameters during slow and normal breathing. It can also be inferred that slow breathing induces a relaxation state that slows down the reactivity and enhances efficiency, producing the clearest changes in the autonomous nervous system state, suggesting that breath control could influence the efficiency of certain cognitive tasks.

10.4. Clinical Neuroscience

A central paradigm in modern neuroscience is that anatomical and functional connections between brain regions are organized in a way such that information processing is near optimal [152]. As an example, functional connectivity, which is defined as the temporal dependency of neuronal activation patterns of anatomically separated brain regions, reflects statistical dependencies between distinct and distant regions of information processing neuronal populations [152].

To assess connectivity, several experimental frameworks, such as the estimation of transcraneal direct current stimulation effects on the mobility of distal limbs active in gait[153], are demonstrated to be valid. The latter technique is based on stimulating subjects with low levels of direct current between an anode-cathode fixture on the scalp, estimating the connectivity among the stimulation areas and the supplementary motor area, the primary motor cortex, the primary somatosensory cortex and the premotor area from EEG signals measured on the electrodes associated with these mentioned areas is being described. The study involved eight subjects, four of them labeled as ‘active’ ones and four of them taken as ‘neuter’ (controls). The connectivity study was based on partial directed coherence on the theta, alpha and beta bands [154], manifesting a differential behavior of active vs neuter subsets in the stronger aligned connectivity, shown on electrodes C4 and Cz. Possible clinical applications of this stimulation technique are in impaired distal limb rehabilitation, as in gait. In the Fig.19, it is depicted an example of the composition of the EEG signal form different frequencies.

Another clinical application is supporting the practice of anesthesia in peripheral nerves, e.g. based on the visualization and processing of nerve paths in ultrasound imagery [156]. This tool allows the application of different image processes for the enhancement of the representations. These include diverse image filtering methods, as average, Gaussian or Bayesian, and what they call a Super-Resolution tool, performing an increase in the resolution by a user-adjustable factor. The authors present several methodologies to implement HAPAN. The system efficiency is measured by

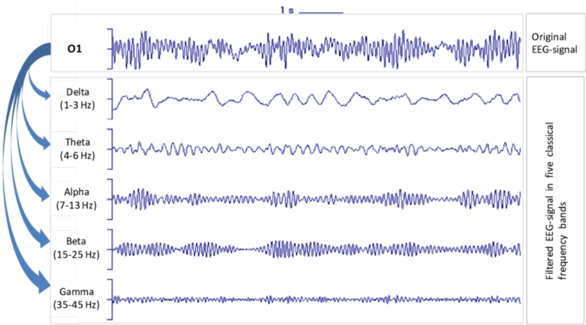

Figure 19: Composition of the EEG signal from different frequencies (oscillatory activities). Five classical physiological bands are shown for the same raw EEG signal: delta (1-3 Hz); theta (46 Hz); alpha (7-13 Hz); beta (15-25 Hz); and gamma (35-45 Hz). These basic EEG bands are assumed to reflect different functional processes in the brain [155].

the average execution time of the algorithm and similarity coefficients [156].

Finally, connectivity is also involved in the development and implementation of computational models of different types of visual neurons [157] . The goal is to design a tool enabling the interface of the models with a visual neural prosthesis and creating natural electrical stimulation patterns, specifically targeted to the Utah cortical visual stimulation arrays. In this sense, we need to design and integrate models of neural function, psychophysics, signal processing and neural encoding, for their application in a working pipeline, leading to advance the development of cortical visual prostheses. Vision models were based on retinal processing models; stimulation and control API's, communication with the Neural Compute Stick from Intel, and helper functions as filters on electrode mapping compose the software framework. The stimulation control capability of the system has been tested using ganglion cell firing responses to different light patterns deployed on a neurostimulator control simulator, on its turn, the retina model has been defined normalizing the ganglion cell model weights on a DL model.

11. Biomedical Applications

Nowadays, biomedical applications are trending topics in contemporary research. New devices, approaches, techniques or toolkits are some advances in this research area. The main feature of this field is the degree of interdisciplinary between diverse professionals. For instance, the application of medical principles joins to design and develop of new approaches or tools that require the conjunction of engineers, physicians, mathematicians and speech therapists, among others. Bioinformatics, biomechanics, biomaterials, medical devices, rehabilitation engineering are only some of the different fields that belong to biomedical applications. These applications allow advancing in health care treatment, including monitoring, diagnosis or even therapy [158]. When discussing biomedical applications the areas involved are numerous and diverse. One of the biomedical areas that has received considerable attention over the last decade is neurodegenerative disorders, such as PD or AD. Indeed, the number of patients with PD is expected to double in twenty years and will triple around 2050 [159]. In the Fig. 20 is depicted the prevalence as the percentage of the population that is affected by the disease. Shading indicates 95% uncertainty intervals.

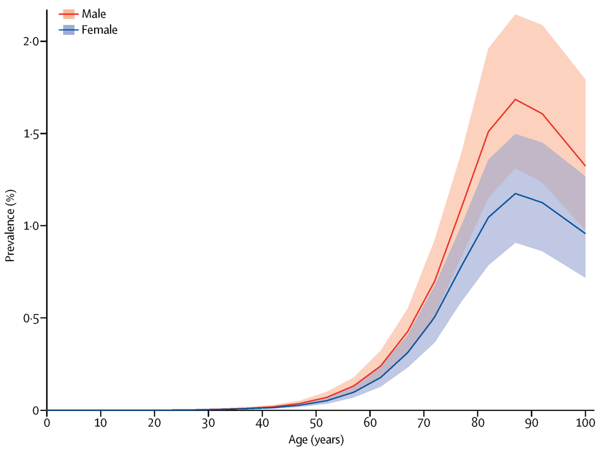

Figure 20: Prevalence is expressed as the percentage of the population that is affected by the disease. Shading indicates 95% uncertainty intervals [159].

On the other hand, our current life style is frantic and stressless. For this reason, heart attacks, and strokes are very common health threats too. Since 2006 yearly, the American Heart Association (AHA) brings together the most up-to-date statistics related to heart disease, stroke, and other cardiovascular and metabolic diseases and presents them in its Heart Disease and Stroke Statistical Update in conjunction with the Centers for Disease Control and Prevention, the National Institutes of Health, and other government agencies due to the relevance of this kind of health problems in USA and over the world [160].

11.1. Neurodegenerative disorders

Patient's neuromotor functionality in relation to PD is assessed by the use of neuroacoustical stimulation with binaural beats and its observable effect on phonation [161]. The main approach is based on stimulating with two kinds of signals, active or non-active. A set of acoustic features were extracted such as jitter, shimmer, biomechanical unbalance, and tremor in different bands. A cohort of 14 volunteer speakers in stages 1 and 2 of the Hoehn & Yahr Scale [162] were recruited. Each patient was submitted to two neuroacoustical stimulations (pre and post-stimulus) with a minimum separation of seven days. Results from a single male speaker showed statistical relevance. Four speech recordings were used and the segments of the vowel [a:] were analyzed. It seems that a clear positive effect was produced by neuroacoustical stimulation in the phonation neuromotor stability of the PD patients.

On the other hand, information theory fundamentals and common statistical tools can be applied to differentiate and score PD speech on phonation and articulation estimates [163]. To this purpose, a speech corpus is divided into three groups of individuals: the first group consists of PD patients, the second group is composed of age-paired healthy controls, and the last group is integrated by mid-age normative subjects. A sustained vowel [a:] was used to assess the capability phonation stability between PD patients and age-paired healthy controls within the same age range, concerning a normative reference set considered the golden standard regarding maintained phonation. Vowel utterances by 8 males and 8 females from the three groups were extracted and used in the analysis. Based on the mutual information between two given probability density functions, they were able to distinguish PD, aging healthy controls (HC) and normative subjects. Anyway, further validation including the effects of laryngeal pathology cases, which is known to strongly alter the phonation profile is required in future research.

11.2. Heart, eyes and genomics

One of the major clinical contexts in which algorithms for biomedical signal processing are designed, is diagnosis. As an example, the use of continuous wavelet transforms on the Electrocardiography (ECG) signal is evaluated in differentiating the heart rate produced by non-ischemic events from ischemic episodes [164] . Randomly chosen patient records from an open-source database (Long Term ST Database) were used in the study. From these data, a set of episodes were selected to carry on the evaluation. The duration of each record ranged from 48 to 4710 seconds, with 52 ischemic and 25 non-ischemic related episodes. This technique provided frequency as well as time information. The result scores were 86.64% in sensitivity and positive predictability, respectively.

Another study in signal processing and diagnostics [165] proposes a method to automatically locate and segment the optic disk and the excavation in retinal fundus images to determine normal from glaucoma-affected eyes in the clinical evaluation. The approach is based on a fast and efficient morphological image analysis and a frequency-based implementation of active contours. The fundus images were acquired by means of a Topcon TRC-NW400 non-mydriatic retinal camera. The main advance in [165] was the use of an efficient frequency-based implementation of parametric active contours, which are time-varying curves widely used in image processing for describing boundaries of objects. Usual applications are segmentation and tracking of structures of interest within the image. Two main traits, ISNT and CDR, were considered. The first one explains the regular morphological shape of disc rim thickness eye, and the second one is cup-to-disk ratio which is used in ophthalmology as a measurement to assess the evolution of glaucoma. The results automatically obtained were compared with the values of CDR provided by two expert ophthalmologists and found to be analogous.

Finally, in the field of genomics [166] focuses on describing research on a tool for the guided and safe composition of pipelines to treat a specific kind of sequence in RNA-proteins. Specifically, Photo-Activable-Ribonucleoside-enhanced-CLIP (PAR-CLIP) was proposed to achieve a single-nucleotide resolution. A critical step called, peak calling, is used in the analysis of PAR-CLIP sequences. This study dives into general data processing and several algorithms of peak calling used in PAR-CLIP sequences that helps to put together the heterogeneous pieces of the puzzle. In this sense, the research work presents BIOTHINGS, a tool that enables the seamless construction of PAR-CLIP sequence treatment pipelines.

12. Care and well-being Applications

This area of research represents a variety of AI applications for personal and professional services, demonstrating how artificial intelligence technology is addressing the needs of individuals and society. Large and mid-size enterprises are intensifying the use of ML and AI in their products, taking advantage of the opportunities these technologies present to perform advanced analysis on big data sets and to improve the performance of their products and services.

The topics are grouped under three themes: *AI in mobile devices, AI at home, and AI in education.* Fig. 21 shows an overview of these topics. A "mobile device" is a generic term used to refer to a wide range of devices that allow people to access data and information from anywhere at any time. These devices include laptops, smartphones, tablets, wearables, etc. Most of us carry mobile devices, and thanks to better sensors and network connectivity, these devices are being used for an increasingly wide range of applications. We will highlight three fields of application in this section: efficient scheduling for mobile computing, pedestrian absolute positioning, known as "dead reckoning" for indoor localization, and gesture control with wearable devices for human-machine interaction.

Due to the increase in demand for ubiquitous computing and the fact that most user requests have time constraints, real-time scheduling mechanisms must be employed. Usually, scheduling algorithms are divided into two types: input task schedulers (scheduling the requests received from users or sensors) and output task schedulers (scheduling the results or services obtained through the execution of input tasks). In this domain of complex real-time systems, AI appears to be an effective approach to coping with real-time decision making [167, 168]. Several AI techniques have been proposed to guarantee that time and resource requirements are met. Some of these techniques [169, 170] are expected to be the backbone upon which complex real-time systems can be built. An architectural model that includes a high-level AI planner, a low-level real-time scheduler, and an appropriate interface between the two [168, 171] appears to be suitable if we want to achieve real-time predictability and to cope with increasingly complex problem solving.

The ability to track people and equipment indoors has applications in many areas, such as hospital tracking of patients, visitors or employees, or for retail stores to customize displays, collect shopping patterns, assist customers in finding products, etc. One of the solutions explored in the past is the double integration of the observed acceleration of the smartphone. However, double integration rapidly accumulates errors from the high-noise accelerometers. Some works [172, 173] focus on correcting the measurements in order to reduce the accumulated error, but these approaches make several assumptions, such as that subjects always walk on a flat floor. Most existing approaches for heading estimation [174, 175] using PDR assume that the misalignment between a device's forward direction and the user's heading remains constant. This does not work when the phone is in a pocket, though, since the yaw angle will change dynamically even when the pedestrian is walking straight ahead. In the case of the magnetometer, the magnetic field is strongly perturbed by surrounding artificial fields [176].

12.1. AI in mobile devices

In the case of AI for mobile devices and mobile computing, scheduling is one of the classic problems in real-time systems. The work presented in [177] focuses on the evaluation of an AI planner in mobile broadcasting. The real-time scenario chosen for this evaluation is based on the Adaptive Hybrid Broadcast (AHB) model [178, 179].

The multi-level scheduler is divided into: i) High-level scheduler (HLS): responsible for determining the requests to be serviced from among all requests received and the specific data units to be transmitted for each request and ii) Low-level scheduler (LLS): responsible for generating a schedule of all the data units that are going to be broadcast. The results show that the incorporation of AI in the real-time scheduler improves its performance, adaptiveness and responsiveness. Next steps in this area include ML techniques to further improve the performance of the HLS.

In the context of heading estimation in walking recognition [105] proposes a novel method which

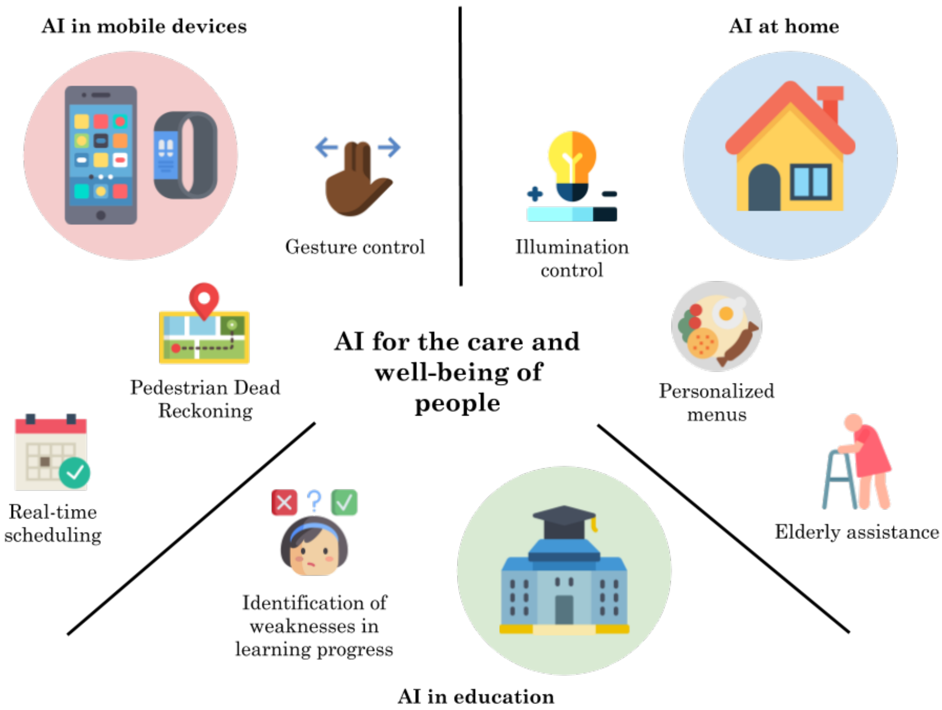

Figure 21: Overview of the topics covered in *Care and Well-being Applications*

combines the processing of inertial data with ML techniques and quaternion algebra to give an accurate estimation of the user's heading. A robust user heading estimation is obtained whether the smartphone is carried in the hand or pocket without making any assumptions or using more information than that coming from the inertial sensors of the device. First, using the 9-dimensional data from the 3 inertial sensors (accelerometer, gyroscope and magnetometer), a quaternion is estimated, which represents the attitude of the phone in the inertial-Earth reference system (independent of the device pose) applying Madgwick's method [180]. Second, the relative position of the device with respect to the user (hand, pocket, other) is computed, using a SVM that is trained using features extracted from the IMU. The best Euler angles are selected from the quaternion, which represent the attitude of the phone and make some corrections to the angles by taking into account the position of the device with respect to the user.

The use of wearables for human-machine interaction via gesture recognition is a particularly important topic, specifically in the context of service robots. In [181] a fuzzy logic controller is proposed for controlling a mobile robot using visual and depth information provided by a Kinect2 device. In [182] a vision-based system along with a 3-axis accelerometer is used for human-robot interaction, proposing both static and dynamic gesture recognition modules using artificial neural networks and hidden Markov models. In [6] two 3-axis accelerometers attached to both wrists of an operator are used to control a robotic arm. One is used for launching different kinds of interactions (static or dynamic) while the other activates or deactivates the Human-Robot Interaction (HRI) system. Different methods of receiving the human controller's information are also proposed in the literature, including vision [181, 182, 6] and natural language [183, 3, 184].

As an example, in [107] presents the deployment of two different wrist wearable devices, as shown in [6], called ControlaBLE and OperaBLE for the two wrists of an operator. Both wearables are composed of a micro-controller, accelerometer, gyroscope and battery, and use Bluetooth Low Energy (BLE) connectivity for controlling a robotic arm. A finite state machine of possible interactions between the wearables and different interaction states is then proposed. The hardware architecture is composed of two Raspberry Pi 2 low energy programmable boards, one in the user part of the pipeline and another in the final robotic arm activating six servos. A motion recognition algorithm called LoMoCa (Low Motion Characterization) is also proposed and executed in the Raspberry Pi that receives the information from the Bluetooth-connected wearables. Finally, commands are transferred to the second Raspberry Pi to move the robot.

12.2. AI at home

Regarding the use of AI at home, [185] focused on the indoor luminance level, which is affected by natural light, artificial lighting and shading devices.A black-box method is proposed based on a divide-and-rule strategy to determine natural illumination and artificial lighting separately. Natural illumination is estimated by an ANN that receives an input vector with the following components: date, hour, outdoor luminance, diffuse radiation, global radiation, and blind state. Artificial lighting is determined by a polynomial interpolation method, which manages the voltage applied to regulate light intensity. The ANN structure were composed of two hidden layers with 12 neurons each, and a sigmoid activation function. ANN parameter estimation was accomplished with a set of 57000 measurements subdivided into training (75%), validation (20%) and test (5%) sets, respectively. The proposed system was validated under real conditions over a period of time from March to July, obtaining a relative error of 1.7% on average.

In the context of personalized menus [186], the system Diet4You was originally proposed in [187], with new components added this year for the generation of nutritional plans taking into account user preferences and cultural factors. Diet4You is composed of two main blocks. The first is the Nutritional Plan Generator (NPG), designed to provide a recommended nutritional plan for a given person. The second one is the Personalized Menu Planer (PMP), which is able to deal with additional restrictions, like medical constraints (diabetics, food allergies), personal preferences, and cultural factors. The reasoning mechanism is Case-Based Reasoning (CBR) [188], which reuses previous menu configurations, corresponding hard constraints, and user preferences to meet a personalized recommendation menu for a given user. The FNDDS and FPED databases offered by the USDA (United States Department of Agriculture) [189] are used as sources of knowledge for the nutritional prescription.

12.3. AI in education

Finally, regarding the third and final topic, AI in education (Fig. 21), aims to identify weaknesses in the learning progress of students and to improve their lexicon of an individual as a result of an educational process. Since a higher lexicon indicates a higher understanding in a domain, early detection of missing lexicon in students is key to identifying weaknesses in their learning progress. Studies on lexical availability include [190], which presents a quantitative and a qualitative approach to lexical availability in mathematics for a specific group of students.

For AI in education [191] introduced Lexmath, a platform that helps describe and quantify a student's lexicon in different mathematical subjects. This platform collects data from students using lexical availability tests. To correctly relate students and the different Bayesian networks to be generated, three indexes are proposed: number of different words, relative frequency, number of words and number of tables of conditional probability. The method consists of the following steps:

1. For every class, a Global Graph is created, taking into account all the words mentioned in the class.
2. For every student, a list is created containing all the words the student did not mention.
3. A subgraph considering each word the student did not mention is built from the global graph.
4. Every subgraph is converted to a network removing edges which belong to cycles, taking into account the frequency and order for each node.
5. A priori probabilities are assigned to every network, obtaining an a priori Bayesian network.
6. Evidence is added to every a priori Bayesian network. Evidence corresponds to a word the student mentioned during the test.
7. A specific node is analyzed.
8. Nodes are ordered in decreasing probability of appearance, and the result is informed as a group taking into account the ID of the student.

13. Discussion and current trends

In this section we present some discussions related to the aforementioned sections and the current trends and perspectives in each field of research.

13.1. Models: advancing in data science

Despite the progress made, it is necessary to continue looking for more efficient and effective mechanisms, improved solutions both in performance (decrease in the failure rate) and in cost (resources, time, price, etc.). A possible line of action is to look for hybrid models that combine the good qualities of the base models to obtain more robust solutions, the ability to model and integrate data, to work with datasets with imbalances or smaller, and in general eliminating the deficiencies of the previous ones.

Another possible line of action is to look for new models that have among their starting requirements to optimize new characteristics, that are disruptive, and this brings new ways of addressing the problem. Narrow AI will continue to spread in this digital age, as the infrastructure is very advanced and it will be relatively easy to generate new applications.

Undoubtedly, one of the main challenges for the near future is to create standard explaining tools that allow non-specialists to understand AI decisions. This will certainly helps to increase the acceptance of AI in society. Explainability of black box models is one of the crucial aspects that should improve, especially, in critical domains. In the last three years, with the advent of XAI [33], many authors proposed various techniques in this field [20].

A key to the design of new models in AI is the trade-off between performance and complexity. A procedure for achieving such a trade-off favorably is to increase the model complexity, which allows for improvement in performance, while controlling or assessing the generalizability of the system by proper statistical methods. Optimally, this would maximize performance and minimize variability of performance. However, this also depends on the nature of the data being processed, and thus the selection of a model architecture to achieve a given performance is a *rule of thumb*, that is, one cannot expect it to be totally reliable for every engineering and scientific application. Good examples of this fact are the application of the well-known deep learning (DL) architectures to specific scenarios, e.g. GoogLeNet, AlexNet, LeNet, or the development of CAD systems using a fixed-complexity (i.e., linear) SVM. In the latter case, the design of the system is more focused on preprocessing and feature extraction and selection steps rather than the classification or prediction stages (unlike the DL-based approaches).

On the other hand, open issues in fields such as systems interoperability, security, semantic analysis of human cognition, behavior and organization, trust and reputation management, etc. seem to be appropriate for hybrid models where ontologies must play a fundamental role.

13.2. Ethology

Human computational neuroethology offers great challenges and opportunities. The goal is to be able to set up a neuroethological experimental capture system in almost any natural environment for a human, i.e. at home, at work, while easing themselves, maximizing the ecological validity of the experiment while preserving measurement and analysis accuracy. This is far from being feasible currently, due to the still emerging wireless EEG devices, and related devices based on near infrared spectroscopy.

From the point of view of the applications, it is clear that such experimental environment would be extremely useful for the analysis of a variety of neurodegenerative diseases, as well as the assessment of the impact of treatments, which actually is done on a qualitative basis. Neuroethological research can also be introduced in the industry, in order to measure with precision the impact of the workplace on the worker at the neural and postural levels. In this regard, we are also involved in the study of such effects in the framework of the mechanical machining when the operator is working numerically controlled machines.

Figure 22 illustrates this environment, where we use a wet wireless EEG to obtain the neural signal (upper left image shows a 3D rendering of the brain activation in some specific band). The body motion and pose is recorded by means of depth imaging (lower left image of a kinect depth map), and inertial sensors (right image of the Rokoko avatar). If such kind of studies can be translated into aggressive environments like the metal industry, they can be also implemented in many other productive activities, helping to improve the preventive health screening of workers, and increasing their productivity.

Another area of great potential impact is the study of falls in the aging population, which can be

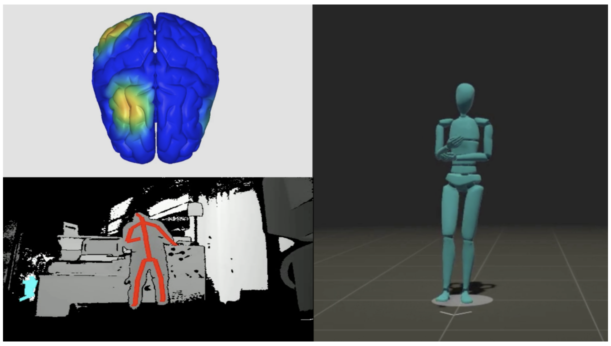

Figure 22: The ongoing research on the neuroethological interactions in industry machining working environments includes inertial sensors, depth sensors, and wireless EEG.

associated to neural degenerative diseases, but can also be spontaneous events in healthy persons. Falls in aging people are a source of multiple complications that degrade the quality of life of the persons. Careful non-invasive monitoring may serve to detect early neural signatures that would prevent such events, or rise early alarms. However, the greatest impact of the neuroethological research is far from being realized. Synchronous observation of brain activity and behavior response is called to impact many areas of human activity.

The human learning process involves many facets of brain maturation, plasticity and evolution in response to the external stimulus, which can be a teacher or a technological object, such as an anthropomorphic robot. How does the child react to such interactions is a matter of interest for the future of humanity, because how we educate our children will impact in the future state of society.

Another related emerging area of work is the so called *mobile brain imaging research*, where much of the work done is related to the reproduction of conventional EEG based experiments but allowing some freedom of movement to the subject. For instance, new mobile applications are proposed to facilitate data collection in diverse setting [192]. Interaction of walking activity and visual acuity in the increased activation of the sensorimotor cortex can be studied with these new tools [193]. Even the measurement of auditory brain evoked potentials while ciclying outdoors have been reported [194].

New datasets are being published in order to stimulate computational research in this exciting new area[195]. Big data availability will encourage the application of the most recent computational innovations, such as the DL architectures that have revolutionize several industrial fields, such as machine translation and image processing in medicine as well as in other areas.

13.3. Affective Computing

Research in designing applications with affective capabilities is constantly increasing. With this growth, affective computing is for sure an integral part of the development of future technologies concerning the human being. In recent years an important move has been perceived towards continuous current emotion recognition for real-life environments [196].

Health care is probably the primary beneficiary of the future affective computing technologies. Some developments have helped physicians to understand mentally disabled patients. Thanks to the growth in artificial intelligence, ML and the Internet of the Things, health care applications are already benefiting from advanced patient monitoring devices that use facial and vocal coding techniques. The detection of different diseases and mental disorders, including stress, depression and anxiety, is a reality to date thanks to the augmenting capacities offered by advanced wearables.

It is reasonable to expect that emotion detection and interaction personalization to better suite a person's emotional state will become an integral part of HMI in a few years. This will also be a starting point of a realistic human-machine symbiosis. In this regards, robotic devices equipped with affective computing will elevate the human-robot link to the level of human-human relationships.

In the close future, the research in portable brain interfaces providing neuroimaging will continue growing. A greater insight into the brain mechanisms underlying the highly complex affective aspects of the human being have still to be discovered. Every step in this direction will help affective computing to be a leading area in the development of novel health care applications.

Further from image processing, [185] proposes an intelligent control system for an office whose end objective is to adapt the artificial lighting in order to provide pleasant illumination in combination with the available natural lighting, while becoming sustainable by using only the necessary energy. The ANN used for this purpose only has two hidden layers since the number of features was relatively low, but the results using lighting data from Marc to July suggest that the model could be effective in predicting the available natural light.

Many learning problems can be addressed by means of DL methods due to their potential to extract abstract features from data. Some applications do not involve classification or detection, but put the focus on the feature extraction itself. This is the reason why pure feature extraction models such as autoencoders are versatile and can help in other learning problems. In [45], several of these applications of deep feature learners are presented: data visualization, image denoising, anomaly detection and semantic hashing in text documents.

13.4. Bioinspired Systems

In recent years there has been a large increase of new algorithms with the label "bio-inspired" (see [197] for a number of examples). Most of the new approaches simulate or take inspiration from animal (in majority of cases) and plant behavior, generally incorporating their adaptive mechanism in the natural world in order to devise new search or optimization algorithms. The algorithms that mimic the behavior of social insects is a clear example: Artificial Bee Colony (ABC) algorithm, Genetic Bee Colony (GBC) algorithm, Firefly algorithm, Ant colony optimization, etc.

The frontiers between different fields like bio-inspired computing and natural computing are not clear and depend on the author's definition. It is commonly accepted that bio-inspired computing integrates all such meta-heuristics, but also other methods with biological inspiration such as artificial neural networks and neural networks with a stronger simulation of the biological neural network mechanisms.

Bio-inspired approaches include also all the methods of the broad field of evolutionary computing, including the methods that focus on swarm intelligence like Particle Swarm Optimization (PSO) and solutions based on bird flocking, bacteria foraging and fish schooling, methods in which the collective intelligence or coordination of the group serves to obtain an emergent behavior that resolves a problem. Note that some of these concepts are taken from other fields like artificial life or complex systems.

Nevertheless, regardless of the particular field in which an author feels better to place his/her research, the researchers in this field or fields with bio-inspiration must be self-critical with the boom of, especially, such new metaheuristic solutions [197]. It must be carefully contrasted what is new and what is included in other traditional search algorithms or what novelty is provided in a new bio-inspired metaheuristic. Besides, the proposals should be competitive with other methods in the state of the art. In this sense, a key aspect of the design of evolutionary and swarm intelligence algorithms is studying their performance in terms of statistical comparisons [198].

Apart from this rise of metaheuristics, bio-inspired computing will progress in providing the dual perspective discussed in the introduction, where bio-inspired methods not only provide new approaches to solve problems as biological systems do (direct engineering), but also they can provide new knowledge about the underlying mechanisms of their functioning (reverse engineering). Moreover, new computing paradigms, from the Map/Reduce model that lies underneath Big Data architectures to Ephemeral Computing, Exascale Computing and Quantum Computing [199] will provide a novel framework for the design and deployment of bio-inspired algorithms and optimization methods.

As previously remarked, multidisciplinarity is and will continue to be a key component in this double interrelation and, hopefully, this field of research will continue as a meeting point for researchers in all these areas.

13.5. Robotics

The use of Artificial Intelligent methods in Robotics is growing at a fast pace, and at the same time, the applications and uses of Robotics are being introduced in more fields. The interaction with humans is clearly where there is an exponential growth in the later years and it is a very promising field to produce more benefits for society.

The human-robot interaction has different aspects to consider as shown in previous sections. First, the physical interaction by using robots to assist disabled or elderly people to achieve a better quality of life. Also, emotional interaction will provide more amicable and adaptive interactions with robots. Finally, the applications in education and with social robots are the more challenging ones to introduce the robots in our daily life.

Of course, the other field that will feel a great grow is the industrial applications of robotics, where there is already many areas to improve by the application to Robotics of recent techniques from ML (DL, CNN, etc.) and the use of new massively parallel computation resources (GPUs).

13.6. Machine/deep learning and Big Data analysis

DL NNs stand as one of the most promising research fields within ML in some prospective applications, e.g. neuroscience. Their commoditization has been favored by the ease of use of pretrained networks. Nevertheless, CNNs have been already established as the standard tool for most computer vision tasks. Nevertheless, there is still room for improvement. The integration of deep networks into probabilistic models may allow employing already studied robust Bayesian frameworks to enhance the accuracy and reliability of intelligent systems based on deep neural architectures.

As shown in previous sections, ML, computer vision and DL techniques provide a new arena for data processing in the neurosciences. Advances in these areas have allowed 1) to exploit the information contained in the data, 2) to fuse information from different sources and different in nature and 3) deal with vast amount of data (Big-Data problem). The combination of them have revolutioned the research in many fields of science and, of course, in the neurosciences where traditionally, only classical statistical methods to test differences between groups have been applied.

Nevertheless, ML methods and DL networks have constraints that restrict their scope of use. On the one hand, in the traditional ML classification workflow, specific and predefined statistical features have to be computed/extracted before they are fed into the classifier. Additionally, a feature selection stage may help to use simpler classifiers, avoiding the overfitting problem and maximizing the classification accuracy. On the other hand, DL methods learn specific features extracted from the data manifold, whilst they try to improve the classifier performance. In other words, FE is indeed included into the learning stage, not being limited to a specific FE method and being defined by the use of millions of parameters. This provides models that can outperform statistical and ML approaches, at the cost of the need for having large enough databases the DL model can learn from. Otherwise, when the sample size is limited or more precisely the ratio sample size over number of predictors is small, overfitting may arise, diminishing the generalization performance of the generate model. In this case, DL methods operating in several fields also require a little help from preprocessing techniques, e.g. neuroimaging.

Thus, another research line consists on the development of optimization and self-optimization methods to refine the architectures or even, to generate custom networks depending on the input data, its characteristics and the specific problem to be solved. There are some research work in this direction, using evolutionary computing for the improvement of the hyperparameters and the architecture of the neural network. Moreover, the intensive use of computing resources in DL and Big-Data, makes necessary the optimization of the neural architectures according to the available computing resources and eventually, to be energy-aware, which constitutes an important research line. On the other hand, the development of hybrid methods and information fusion techniques play an important role in the exploitation of all the available data and to be able to learn multi-modal and complex models with enough generalization capabilities.

Nowadays, the availability of large image databases (as in the case of Autism studies or Parkinson diagnosis), along with massively parallel processor architectures (such as GPUs) to compose heterogeneous systems (containing both, CPUs and GPUs) makes possible the practical use of DL architectures for exploratory and discriminative analyses. In fact, one of the main research lines in DL consists on the development of new methods to explore where the neural networks focus their attention while they learn to separate classes. Furthermore, visualization methods in CNN networks can be exploited to compute regions of interest and to rank them.

Indeed, one of the most relevant tendencies in current Big Data analysis is the commoditization of ML models and, in particular, DL models. In other words, models are packaged into standard libraries which are ready to apply by end users. As an example, two relevant methodologies for Big Data analysis are i) the one that approximates methods that carry out a direct fusion of models and ii) the paradigm that provides an exact fusion of models [200], and both may be found in the specialized literature and in standard Machine Learning libraries, such as Mahout or MLlib.

This trend increases the importance of procedures to combine several already existing methods in order to enhance the performance. Therefore, advances in big data analysis will significantly benefit from the development of meta-methods which draw on already existing approaches, so that a wide range of base methods can be employed with the same metamethod. This way the knowledge acquired by the base methods can be exploited to attain more

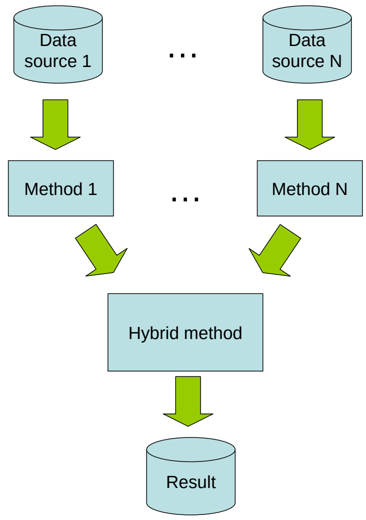

Figure 23: Hybridization of methods which process different data types.

challenging goals.

The ever-increasing diversity of kinds of available data is also very relevant for practical application of Big Data techniques. Classic approaches were focused on the analysis of a specific data type, so that they can not be applied straightforwards to datasets which comprise different kinds of information. In order to overcome this difficulty, a popular strategy consists in the combination of different approaches which process diverse information types. Hybridization of methodologies and algorithms stands as a promising research line, since it is a suitable way to cope with the complexity of the data flows that ML is applied to. Figure 23 represents the hybridization concept, where different data sources are processed by methods tailored to their data types, and their outcomes are combined by the hybrid method to yield the final result.

13.7. Neuroscience, Biomedical and Well-being Applications

The scope of section 10 falls within the remit of the concept of Neuroscience Applications. Given the broad scope, we aimed to provide an indicative summary of the research area which we cannot claim to be exhaustive or even too comprehensive. Nevertheless the selected studies covered several hot topics which are of particular significance in this research field. The subsections comprised EEG-BCI systems exploring the relationship between evoked signals and specific tasks as gait; object handling, speaking or gaming, wearable devices or interfaces with application in monitoring aging or breathing; cognitive tasks improved by ML to help in the acquisition of numerical skills or creativity; and medical applications as assisting in anesthesia practicing or visual interfaces. Needless to say that specific BCI systems, wearable signal acquisition, cognitive assessment and validation of learning processes or assisting technologies will be quite relevant topics in the field of neuroscience applications.

In addition, section 11 provided only a partial view into some representative topics rather than attempt to be all-inclusive. Some works were related to PD, investigating the acoustic neurostimulation and the instability of phonation of these subjects, whilst others described the difference between ischemic and heart-rate related events using the continuous wavelet transform or dealt with a method to automatically locate and segment the optic disk and the excavation in retinal fundus images to differentiate normal from glaucomatous eyes in the clinical evaluation. Finally, the biomedical applications in this section 11 were focused on assessing differences in activation of both hemispheres in stroke survivors during a motor task usually employed for brain-computer interface control; and the description of a tool for the guided and safe composition of pipelines to treat a specific kind of sequence in RNA-proteins.

Moreover, in section 12 the combination of sensors, connected devices, computing resources, advanced communications, and real-time interactions is leading to the creation of ubiquitous systems at a scale and complexity previously unimaginable. AI applications will touch almost every aspect of our lives; education, assistance at home, and mobile devices are some of the fields addressed in the papers summarized in this review. The success of AI in such diverse fields requires both new and traditional artificial intelligence techniques, better understanding and leverage of large data sets which may be heterogeneous, and the ability to build new models and make accurate predictions in a wide variety of scenarios under complex conditions.

14. Conclusions

As a conclusion, we have comprehensively analyzed novel advances in AI, DS and all their supporting tools, based on several modelling paradigms, such as the bio-inspired, hybrid or statistical approaches, and technologies, e.g. bioelectrical devices, medical imaging, or robotics. The paper was organized in three conceptual blocks, that is, i) theoretical models and learning architectures enhancing advances in DS and AI, ii) special thematic issues within the scope of AI, and iii) several applications in the research fields covered throughout the paper.

Most of these advances were presented and discussed in the IWINAC conference, held in June, 3-7, 2019, in Almería, Spain. In this sense, novel insights in the understanding of the brain function and emotions, were shown by addressing the current technological challenges, i.e. the design of robust BCI-based systems for neural data processing and analysis, brain pattern recognition in neurological diseases, interfacing with physical systems or the problem of emotional state recognition. Moreover, the basis or background required to develop such applications, and many others in the field of biomedical research, were also described in the first part of the essay. From models, ontologies and hybrid bio-inspired systems, to ML and DL approaches, the proposed methods allow a huge amount of bioinspired programming strategies aimed at providing efficient computational solutions to engineering and medical problems, in different applications domains such as biomedical systems, big data or neuroscience.

All these advances will be crucial for the new era of AI, which is revolutionizing and reshaping our style of life and society. Moreover, AI, DS and supporting fields will help in providing systematic and autonomous systems that provide useful insights, predictions, recognitions and analytical solutions from the available big data.

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References

[1] M. Martínez-Ibañez, A. Ortiz, J. Munilla, D. Salas-Gonzalez, J. M. Górriz, J. Ramírez, Isosurface modelling of datscan images for parkinson disease diagnosis, in: Understanding the Brain Function and Emotions, Springer International Publishing, Cham, 2019, pp. 360–368.

[2] J. Wright, A. Yang, A. Ganesh, S. Sastry, Y. Ma, Robust face recognition via sparse representation, IEEE TPAMI 31 (2) (2009) 201–227.

[3] M. Almagro, V. Fresno, F. de la Paz, Speech gestural interpretation by applying word representations in robotics, Integrated Computer-Aided Engineering 26 (1) (2019) 97–109.

[4] F. Laport, F. J. Vazquez-Araujo, P. M. Castro, A. Dapena, Hardware and software for integrating brain–computer interface with internet of things, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 22–31.

[5] O. Carugo, F. Eisenhaber, Data Mining Techniques for the Life Sciences, Methods in Molecular Biology, 1st Edition, Humana Press, a part of Springer Science+Business Media, 2010.

[6] P. Neto, J. N. Pires, A. P. Moreira, Accelerometer-based control of an industrial robotic arm, in: RO-MAN 2009-The 18th IEEE International Symposium on Robot and Human Interactive Communication, IEEE, 2009, pp. 1192–1197.

[7] Y. Lecun, Deep learning, conference at the usi (2015).

[8] W. Liu, Z. Wang, X. Liu, N. Zeng, Y. Liu, F. E. Alsaadi, A survey of deep neural network architectures and their applications, Neurocomputing 234 (2017) 11 – 26. `doi:https://doi.org/10.1016/j.neucom.2016.12.038`.
URL `http://www.sciencedirect.com/science/article/pii/S0925231216315533`

[9] S. B. Daily, M. T. James, D. Cherry, J. J. Porter III, S. S. Darnell, J. Isaac, T. Roy, Affective computing: historical foundations, current applications, and future trends, in: Emotions and Affect in Human Factors and Human-Computer Interaction, Elsevier, 2017, pp. 213–231.

[10] R. W. Picard, Affective computing, MIT press, 2000.

[11] M. Zaharia, R. Xin, P. Wendell, T. Das, M. Armbrust, A. Dave, X. Meng, J. Rosen, S. Venkataraman, M. Franklin, A. Ghodsi, J. Gonzalez, S. Shenker, I. Stoica, Apache spark: A unified engine for big data processing, Communications of the ACM 59 (11) (2016) 56–65.

[12] D. A. Waldman, D. Wang, V. Fenters, The added value of neuroscience methods in organizational research, Organizational Research Methods 22 (1) (2019) 223–249.

[13] A. K. Triantafyllidis, A. Tsanas, Applications of machine learning in real-life digital health interventions: Review of the literature, Journal of medical Internet research 21 (4) (2019) e12286.

[14] H. Plassmann, V. Venkatraman, S. Huettel, C. Yoon, Consumer neuroscience: applications, challenges, and possible solutions, Journal of Marketing Research 52 (4) (2015) 427–435.

[15] J. Blake, C. Bult, Beyond the data deluge: data integration and bioontologies, Journal of Biomedical Informatics 39 (3) (2006) 314–320.

[16] F. Dosilovic, M. Brcic, N. Hlupic, Explainable artificial intelligence: A survey, in: 41st International Convention Proceedings, LNCS, MIPRO, Springer International Publishing, doi:10.23919/MIPRO.2018.8400040., 2018, pp. 210–215.

[17] B. W. Israelsen, N. R. Ahmed, I can assure you [...] that it's going to be all right"–a definition, case for, and survey of algorithmic assurances in human-autonomy trust relationships., ACM Computing Surveys https://doi.org/10.1145/3267338 (2019) article no. 113.

[18] G. Marcus, Deep learning: A critical appraisal, ArXiv (2018) arXiv:abs/1801.00631.

[19] M. Turek, Explainable artificial intelligence (xai) (2017) [cited July, 2017].
URL `https://www.darpa.mil/program/explainable-artificial-intelligence`

[20] R. Guidotti, A. Monreale, S. Ruggieri, D. Pedreschi, F. Turini, F. Giannotti, Local rule-based explanations of black box decision systems, arXiv (2018) preprint arXiv:1805.10820.

[21] R. S. Sutton, A. G. Barto, Introduction to Reinforcement Learning,, MIT Press. Cambridge, MA., 1998.

[22] A. Gomez-Valadés, R. Martínez-Tomás, M. Rincón-Zamorano, Ontologies for early detection of the alzheimer disease and other neurodegenerative diseases, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Vol. 11847 of LNCS, Springer International Publishing, 2019, pp. 42–50.

[23] G. Sciavicco, I. S. Eduard, A. Vaccari, Towards a general method for logical rule extraction from time series, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Vol. 11847 of LNCS, Springer International Publishing, 2019, pp. 3–12.

[24] R. Agrawal, T. Imielinski, A. Swami, Mining association rules between set of items in large databases, in: SIGMOD '93: Proceedings of the 1993 ACM SIGMOD international conference on Management of data, 1993, pp. 207–216. `doi:10.1145/170036.170072`.

[25] G. Bologna, Propositional rules generated at the top layers of a cnn., in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Vol. 11847 of LNCS, Springer International Publishing, 2019, pp. 432–440.

[26] D. Díaz-Vico, J. Prada, A. Omari, J. R. Dorronsoro, Deep support vector classification and regression, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Vol. 11847 of LNCS, Springer International Publishing, Cham, 2019, pp. 33–43.

[27] I. A. Illan, J. M. Górriz, J. Ramirez, F. J. Martinez-Murcia, D. Castillo-Barnes, F. Segovia, D. Salas-Gonzalez, Support vector machine failure in imbalanced datasets, in: Understanding the Brain Function and Emotions, Springer International Publishing, Cham, 2019, pp. 412–419.

[28] J. Mediavilla-Relaño, A. Gutierrez-López, M. Lázaro, A. R. Figueiras, A principled two-step method for example-dependent cost binary classification, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Vol. 11847 of LNCS, Springer In-

ternational Publishing, 2019, pp. 13–22.
[29] L. Bregman, The relaxation method of finding the common point of convex set and its applications to the solution of problems in convex programing, USSR Computational Mathematics and Mathematical Physics 7 (3) (1967) 200–217.
[30] A. Almonani, E. Sánchez, Uninformed methods to build optimal choice-based ensembles, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Vol. 11847 of LNCS, Springer International Publishing, 2019, pp. 58–65.
[31] F. Fernández, Á. Sánchez, J. F. Vélez, A. B. Moreno, Symbiotic autonomous systems with consciousness using digital twins, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Vol. 11847 of LNCS, Springer International Publishing, 2019, pp. 23–32.
[32] S. Miguel-Tomé, An experimental study on e reationships among neural codes and the computational properties of neural networks, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Vol. 11847 of LNCS, Springer International Publishing, Cham, 2019, pp. 44–57.
[33] A. B. Arrieta, N. Díaz-Rodríguez, J. Del Ser, A. Bennetot, S. Tabik, A. Barbado, S. García, S. Gil-López, D. Molina, R. Benjamins, et al., Explainable artificial intelligence (XAI): Concepts, taxonomies, opportunities and challenges toward responsible AI, arXiv preprint arXiv:1910.10045 (2019).
URL https://arxiv.org/abs/1910.10045
[34] G. Montavon, W. Samek, K.-R. Müller, Methods for interpreting and understanding deep neural networks, Digital Signal Processing 73 (2018) 1–15.
[35] D. Charte, F. Charte, S. García, M. J. del Jesus, F. Herrera, A practical tutorial on autoencoders for nonlinear feature fusion: Taxonomy, models, software and guidelines, Information Fusion 44 (2018) 78–96.
[36] F. Charte, A. J. Rivera, F. Martínez, M. J. del Jesus, Automating autoencoder architecture configuration: An evolutionary approach, in: Understanding the Brain Function and Emotions, Springer International Publishing, Cham, 2019, pp. 339–349.
[37] K. Janocha, W. M. Czarnecki, On loss functions for deep neural networks in classification, arXiv preprint arXiv:1702.05659 (2017).
URL https://arxiv.org/abs/1702.05659
[38] A. C. Bahnsen, D. Aouada, B. Ottersten, Example-dependent cost-sensitive decision trees, Expert Systems with Applications 42 (19) (2015) 6609–6619.
[39] V. López, A. Fernández, S. García, V. Palade, F. Herrera, An insight into classification with imbalanced data: Empirical results and current trends on using data intrinsic characteristics, Information sciences 250 (2013) 113–141.
[40] D. Charte, F. Charte, S. García, F. Herrera, A snapshot on nonstandard supervised learning problems: taxonomy, relationships, problem transformations and algorithm adaptations, Progress in Artificial Intelligence 8 (1) (2019) 1–14.
[41] V. M. Vargas, P. A. Gutiérrez, C. Hervás, Deep ordinal classification based on the proportional odds model, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 441–451.
[42] A. Krizhevsky, I. Sutskever, G. E. Hinton, Imagenet classification with deep convolutional neural networks, in: Advances in Neural Information Processing Systems 25, Curran Associates, Inc., 2012, pp. 1097–1105.
[43] F. Martin-Rico, F. Gomez-Donoso, F. Escalona, M. Cazorla, J. Garcia-Rodriguez, Artificial semantic memory with autonomous learning applied to social robots, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Springer International Publishing, Cham, 2019, pp. 401–411. doi:10.1007/978-3-030-19651-6_39.
[44] P. Duque, J. M. Cuadra, E. Jiménez, M. Rincón-Zamorano, Data preprocessing for automatic wmh segmentation with fcnns, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Springer International Publishing, Cham, 2019, pp. 452–460. doi:10.1007/978-3-030-19651-6_44.
[45] D. Charte, F. Charte, M. J. del Jesus, F. Herrera, A showcase of the use of autoencoders in feature learning applications, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Springer International Publishing, Cham, 2019, pp. 412–421. doi:10.1007/978-3-030-19651-6_40.
[46] Y. Bengio, I. Goodfellow, A. Courville, Convolutional networks, in: Deep learning, Vol. 1, MIT Press, 2017, pp. 326–366.
[47] B. Vega-Márquez, A. Carminati, N. Jurado-Campos, A. Martín-Gómez, L. Arce-Jiménez, C. Rubio-Escudero, I. A. Nepomuceno-Chamorro, Convolutional neural networks for olive oil classification, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Springer International Publishing, Cham, 2019, pp. 137–145. doi:10.1007/978-3-030-19651-6_14.
[48] V. Ruiz, Á. Sánchez, J. F. Vélez, B. Raducanu, Automatic image-based waste classification, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Springer International Publishing, Cham, 2019, pp. 422–431. doi:10.1007/978-3-030-19651-6_41.
[49] J. Redmon, A. Farhadi, Yolov3: An incremental improvement, arXiv preprint arXiv:1804.02767 (2018).
URL https://arxiv.org/abs/1804.02767
[50] L.-E. Imbernón Cuadrado, Á. Manjarrés Riesco, F. de la Paz López, Fer in primary school children for affective robot tutors, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Springer International Publishing, Cham, 2019, pp. 461–471. doi:10.1007/978-3-030-19651-6_45.
[51] T. Fukunaga, S. Kubota, S. Oda, W. Iwasaki, Grouptracker: Video tracking system for multiple animals under severe occlusion, Computational Biology and Chemistry 57 (2015) 39 – 45, 13th Asia Pacifi c Bioinformatics Conference, HsinChu, Taiwan, 21-23 January 2015. doi:https://doi.org/10.1016/j.compbiolchem.2015.02.006.
URL http://www.sciencedirect.com/science/article/pii/S1476927115000237
[52] G. Hoyle, The scope of neuroethology, The Behavioral and Brain Sciences 7 (367–412) (1984).
[53] J.-P. Ewert, Neuroethology: An Introduction to the Neurophysiological Fundamentals of Behavior, Springer International Publishing, 1980.
[54] D. Mobbs, J. J. Kim, Neuroethological studies of fear, anxiety, and risky decision-making in rodents and humans, Current Opinion in Behavioral Sci-

ences 5 (2015) 8 – 15, neuroeconomics. doi:https://doi.org/10.1016/j.cobeha.2015.06.005.
URL http://www.sciencedirect.com/science/article/pii/S2352154615000832

[55] M. Brewer, Research design and issues of validity, in: H. Reis, C. e. Judd (Eds.), Handbook of Research Methods in Social and Personality Psychology, Cambridge University Press, Cambridge:, 2000.

[56] M. A. Arbib, Rana computatrix to human language: towards a computational neuroethology of language evolution, Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences 361 (1811) (2003) 2345–2379. arXiv:http://rsta.royalsocietypublishing.org/content/361/1811/2345.full.pdf, doi:10.1098/rsta.2003.1248.
URL http://rsta.royalsocietypublishing.org/content/361/1811/2345

[57] A. C. Grant, S. G. Abdel-Baki, A. Omurtag, R. Sinert, G. Chari, S. Malhotra, J. Weedon, A. A. Fenton, S. Zehtabchi, Diagnostic accuracy of microeeg: A miniature, wireless eeg device, Epilepsy & Behavior 34 (2014) 81 – 85. doi:https://doi.org/10.1016/j.yebeh.2014.03.015.
URL http://www.sciencedirect.com/science/article/pii/S1525505014000961

[58] J. W. Kam, S. Griffin, A. Shen, S. Patel, H. Hinrichs, H.-J. Heinze, L. Y. Deouell, R. T. Knight, Systematic comparison between a wireless eeg system with dry electrodes and a wired eeg system with wet electrodes, NeuroImage 184 (2019) 119 – 129. doi:https://doi.org/10.1016/j.neuroimage.2018.09.012.
URL http://www.sciencedirect.com/science/article/pii/S1053811918307961

[59] W. O. Tatum, Handbook of EEG interpretation., Demos Medical Publishing, 2014.

[60] D. J. Anderson, P. Perona, Toward a science of computational ethology, Neuron 84 (1) (2014) 18–31.

[61] J. Wang, Y. Chen, S. Hao, X. Peng, L. Hu, Deep learning for sensor-based activity recognition: A survey, Pattern Recognition Letters 119 (2019) 3–11.

[62] M. Vrigkas, C. Nikou, I. A. Kakadiaris, A review of human activity recognition methods, Frontiers in Robotics and AI 2 (2015) 28.

[63] E. Ratti, S. Waninger, C. Berka, G. Ruffini, A. Verma, Comparison of medical and consumer wireless Eeg systems for use in clinical trials, Frontiers in human neuroscience 11 (2017) 398.

[64] J. G. Cruz-Garza, J. A. Brantley, S. Nakagome, K. Kontson, M. Megjhani, D. Robleto, J. L. Contreras-Vidal, Deployment of mobile Eeg technology in an art museum setting: evaluation of signal quality and usability, Frontiers in human neuroscience 11 (2017) 527.

[65] M. Graña, J. de Lope Asiain, A short Review of Some Aspects of Computational Neuroethology, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 275–283.

[66] R.-H. P., de Lope Asiain J., G. na M., Deep learning prediction of gait based on inertial measurements, in: Understanding the Brain Function and Emotions. IWINAC 2019, Vol. 11486, Springer, 2019, pp. 275–283.

[67] M. S., de Lope Asiain J., G. na M, Recognizing cognitive activities through eye tracking, in: Understanding the Brain Function and Emotions. IWINAC 2019, Vol. 11486, Springer, 2019, pp. 275–283.

[68] M. Pantic, L. J. Rothkrantz, Toward an affect-sensitive multimodal human-computer interaction, Proceedings of the IEEE 91 (9) (2003) 1370–1390.

[69] C. Breazeal, B. Scassellati, How to build robots that make friends and influence people, in: Proceedings 1999 IEEE/RSJ International Conference on Intelligent Robots and Systems. Human and Environment Friendly Robots with High Intelligence and Emotional Quotients, Vol. 2, IEEE, 1999, pp. 858–863.

[70] J. Marín-Morales, J. L. Higuera-Trujillo, A. Greco, J. Guixeres, C. Llinares, E. P. Scilingo, M. Alcañiz, G. Valenza, Affective computing in virtual reality: emotion recognition from brain and heartbeat dynamics using wearable sensors, Scientific reports 8 (1) (2018) 1–15.

[71] V. Vinayagamoorthy, M. Gillies, A. Steed, E. Tanguy, X. Pan, C. Loscos, M. Slater, Building expression into virtual characters, in: Eurographics Conference State of the Art Reports, 2006.

[72] P. Schmidt, A. Reiss, R. Dürichen, K. V. Laerhoven, Wearable-Based Affect Recognition—A review, Sensors 19 (19) (2019) 4079.

[73] A. Luneski, E. Konstantinidis, P. Bamidis, Affective medicine: a review of affective computing efforts in medical informatics, Methods of information in medicine 49 (03) (2010) 207–218.

[74] R. Faria, A. Almeida, Affect recognition, in: Computational Intelligence and Decision Making. Intelligent Systems, Control nad Automation: Science and Engineering, Vol. 61, Springer, 2013, pp. 355–363.

[75] J. C. Castillo, Á. Castro-González, A. Fernández-Caballero, J. M. Latorre, J. M. Pastor, A. Fernández-Sotos, M. A. Salichs, Software architecture for smart emotion recognition and regulation of the ageing adult, Cognitive Computation 8 (2) (2016) 357–367.

[76] P. Gómez-López, F. Montero, M. T. López, Empowering Ux of Elderly People with Parkinsonś Disease via Bci Touch, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 161–170.

[77] M. Á. Vicente-Querol, A. S. García, P. Fernández-Sotos, R. Rodriguez-Jimenez, A. Fernández-Caballero, Development and Validation of Basic Virtual Human Facial Emotion Expressions, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 222–231.

[78] J. Caicedo-Acosta, D. Cárdenas-Peña, D. Collazos-Huertas, J. I. Padilla-Buritica, G. Castaño-Duque, G. Castellanos-Dominguez, Multiple-instance lasso regularization via embedded instance selection for emotion recognition, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 244–251.

[79] J.-J. De Groot, E. Barakova, T. Lourens, E. van Wingerden, P. Sterkenburg, Game-based human-robot interaction promotes self-disclosure in people with visual impairments and intellectual disabilities, in: Ferrández-Vicente et al. [201], pp. 262–272.

[80] L. M. Belmonte, R. Morales, A. S. García, E. Segura, P. Novais, A. Fernández-Caballero, Trajectory Planning of a Quadrotor to Monitor Dependent People, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer,

2019, pp. 212–221.
[81] R. Sánchez-Reolid, A. Martínez-Rodrigo, A. Fernández-Caballero, Stress Identification from Electrodermal Activity by Support Vector Machines, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 202–211.
[82] R. Panduro, E. Segura, L. M. Belmonte, P. Novais, J. Benet, A. Fernández-Caballero, R. Morales, Advanced Trajectory Generator for Two Carts with Rgb-D sensor on Circular Rail, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 181–190.
[83] N. K. Benamara, M. Val-Calvo, J. R. Álvarez-Sánchez, A. Díaz-Morcillo, J. M. F. Vicente, E. Fernández-Jover, T. B. Stambouli, Real-Time Emotional Recognition for Sociable Robotics Based on Deep Neural Networks Ensemble, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 171–180.
[84] M. Val-Calvo, J. R. Álvarez-Sánchez, A. Díaz-Morcillo, J. M. F. Vicente, E. Fernández-Jover, On the Use of Lateralization for Lightweight and Accurate Methodology for Eeg Real Time Emotion Estimation Using Gaussian-Process Classifier, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 191–201.
[85] D. Palacios-Alonso, C. Lázaro-Carrascosa, A. López-Arribas, G. Meléndez-Morales, A. Gómez-Rodellar, A. Loro-Álavez, V. Nieto-Lluis, V. Rodellar-Biarge, A. Tsanas, P. Gómez-Vilda, Assessing an Application of Spontaneous Stressed Speech-Emotions Portal, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 149–160.
[86] L. Fernández-Aguilar, A. Martínez-Rodrigo, J. Moncho-Bogani, A. Fernández-Caballero, J. M. Latorre, Emotion Detection in Aging Adults Through Continuous Monitoring of Electro-Dermal Activity and Heart-Rate Variability, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 252–261.
[87] J. Sorinas, J. M. F. Vicente, E. Fernández-Jover, Brushstrokes of the Emotional Brain: Cortical Asymmetries for Valence Dimension, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 232–243.
[88] D. Varela, J. Santos, Crowding Differential Evolution for Protein Structure Prediction, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 193–203.
[89] J. Orellana, R. Contreras, et al., Bacterial resistance algorithm. an application to cvrp, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 204–211.
[90] S. Torres-Alegre, Y. Benchaib, J. M. F. Vicente, D. Andina, Application of Koniocortex-Like Networks to Cardiac Arrhythmias Classification, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 264–273.
[91] J. Machin, A. Solanas, Conceptual description of nature-inspired cognitive cities: Properties and challenges, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 212–222.
[92] F. J. Gil-Gala, R. Varela, Genetic Algorithm to Evolve Ensembles of Rules for On-Line Scheduling on Single Machine with Variable Capacity, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 223–233.
[93] Ó. Carrasco, B. Crawford, R. Soto, J. Lemus-Romani, G. Astorga, A. Salas-Fernández, Optimization of Bridges Reinforcements with Tied-Arch Using Moth Search Algorithm, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 244–253.
[94] R. Mencía, C. Mencı'a, R. Varela, Repairing Infeasibility in Scheduling via Genetic Algorithms, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 254–263.
[95] A. Shukla, H. Karki, Application of robotics in onshore oil and gas industry : A review. part i, Robotics and Autonomous Systems 75 (2016) 490–507. `doi:10.1016/j.robot.2015.09.012`.
[96] B. Da Silva, G. Konidaris, A. Barto, Learning parameterized skills, arXiv preprint arXiv:1206.6398 (2012).
[97] G. D. Konidaris, Autonomous robot skill acquisition, Ph.D. thesis, University of Massachusetts Amherst, open Access Dissertations, 384. `https://scholarworks.umass.edu/open_access_dissertations/384` (May 2011).
[98] C. Devin, A. Gupta, T. Darrell, P. Abbeel, S. Levine, Learning modular neural network policies for multi-task and multi-robot transfer, in: 2017 IEEE International Conference on Robotics and Automation (ICRA), IEEE, 2017, pp. 2169–2176. `doi:10.1109/ICRA.2017.7989250`.
[99] G. Baldassarre, M. Mirolli, Intrinsically motivated learning systems: an overview, in: G. Baldassarre, M. Mirolli (Eds.), Intrinsically motivated learning in natural and artificial systems, Springer, 2013, pp. 1–14. `doi:10.1007/978-3-642-32375-1_1`.
[100] P. Langley, J. E. Laird, S. Rogers, Cognitive architectures: Research issues and challenges, Cognitive Systems Research 10 (2) (2009) 141–160.
[101] M. Graña, A. Triguero, An approach to teach nao dialogue skills, in: Ferrández-Vicente et al. [201], pp. 301–308.
[102] A. Romero, F. Bellas, J. A. Becerra, R. J. Duro, Bootstrapping autonomous skill learning in the mdb cognitive architecture, in: Ferrández-Vicente et al. [201], pp. 120–129.
[103] S. Orlando, F. de la Paz López, E. Gaudioso, Design and implementation of a robotics learning environment to teach physics in secondary schools, in: Ferrández-Vicente et al. [202], pp. 69–76.
[104] J. Gines Clavero, F. J. Rodriguez, F. Martín Rico, A. M. Guerrero, V. Matellán, Using probabilistic context awareness in a deliberative planner system, in: Ferrández-Vicente et al. [202], pp. 157–166.
[105] F. E. Casado, A. Nieto, R. Iglesias, C. V. Regueiro, S. Barro, Robust heading estimation in mobile phones, in: Ferrández-Vicente et al. [202], pp. 180–190.

[106] J. Estévez, J. M. López-Guede, Control of transitory take-off regime in the transportation of a pendulum by a quadrotor, in: Ferrández-Vicente et al. [202], pp. 117–126.

[107] L. Roda-Sanchez, T. Olivares, C. Garrido-Hidalgo, A. Fernández-Caballero, Gesture control wearables for human-machine interaction in industry 4.0, in: Ferrández-Vicente et al. [202], pp. 99–108.

[108] D. Obregón, R. Arnau, M. Campo-Cossio, J. G. Arroyo-Parras, M. Pattinson, S. Tiwari, I. Lluvia, O. Rey, J. Verschoore, L. Lenza, J. Reyes, Precise positioning and heading for autonomous scouting robots in a harsh environment, in: Ferrández-Vicente et al. [202], pp. 82–96.

[109] M. Kassawat, E. Cervera, A. P. del Pobil, Multi-robot user interface for cooperative transportation tasks, in: Ferrández-Vicente et al. [202], pp. 77–81.

[110] M. Kosinski, D. Stillwell, T. Graepel, Private traits and attributes are predictable from digital records of human behavior, Proceedings of the National Academy of Sciences of the United States of America 110 (15) (2013) 5802–5805.

[111] T. Murdoch, A. Detsky, The inevitable application of big data to health care, JAMA–Journal of the American Medical Association 309 (13) (2013) 1351–1352.

[112] Z. Obermeyer, E. Emanuel, Predicting the future-big data, machine learning, and clinical medicine, New England Journal of Medicine 375 (13) (2016) 1216–1219.

[113] X.-W. Chen, X. Lin, Big data deep learning: Challenges and perspectives, IEEE Access 2 (2014) 514–525.

[114] L. Zhang, L. Zhang, B. Du, Deep learning for remote sensing data: A technical tutorial on the state of the art, IEEE Geoscience and Remote Sensing Magazine 4 (2) (2016) 22–40.

[115] Y. Guo, Y. Liu, A. Oerlemans, S. Lao, S. Wu, M. Lew, Deep learning for visual understanding: A review, Neurocomputing 187 (2016) 27–48.

[116] G. Litjens, T. Kooi, B. Bejnordi, A. Setio, F. Ciompi, M. Ghafoorian, J. van der Laak, B. van Ginneken, C. Sánchez, A survey on deep learning in medical image analysis, Medical Image Analysis 42 (2017) 60–88.

[117] P. Lakhani, B. Sundaram, Deep learning at chest radiography: Automated classification of pulmonary tuberculosis by using convolutional neural networks, Radiology 284 (2) (2017) 574–582.

[118] Z. Ruiz-Chavez, J. Salvador-Meneses, C. Mejía-Astudillo, S. Diaz-Quilachamin, Analysis of dogs's abandonment problem using georeferenced multi-agent systems, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Springer International Publishing, Cham, 2019, pp. 297–306.

[119] S. Hamreras, R. Benítez-Rochel, B. Boucheham, M. A. Molina-Cabello, E. López-Rubio, Content based image retrieval by convolutional neural networks, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Springer International Publishing, Cham, 2019, pp. 277–286.

[120] K. Thurnhofer-Hemsi, E. López-Rubio, N. Roé-Vellvé, M. A. Molina-Cabello, Deep learning networks with p-norm loss layers for spatial resolution enhancement of 3D medical images, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Springer International Publishing, Cham, 2019, pp. 287–296.

[121] J. García-González, J. M. Ortiz-de Lazcano-Lobato, R. M. Luque-Baena, E. López-Rubio, Background modeling by shifted tilings of stacked denoising autoencoders, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Springer International Publishing, Cham, 2019, pp. 307–316.

[122] J. Benito-Picazo, E. Domínguez, E. J. Palomo, E. López-Rubio, Deep learning-based security system powered by low cost hardware and panoramic cameras, in: From Bioinspired Systems and Biomedical Applications to Machine Learning, Springer International Publishing, Cham, 2019, pp. 317–326.

[123] C. R. Pereira, D. R. Pereira, F. A. d. Silva, C. Hook, S. A. T. Weber, L. A. M. Pereira, J. P. Papa, A step towards the automated diagnosis of parkinson's disease: Analyzing handwriting movements, in: 2015 IEEE 28th International Symposium on Computer-Based Medical Systems, 2015, pp. 171–176. `doi:10.1109/CBMS.2015.34`.

[124] F. Martinez-Murcia, J. Górriz, J. Ramírez, A. Ortiz, the Alzheimer's Disease Neuroimaging Initiative, et al., A Spherical Brain Mapping of MR Images for the Detection of Alzheimer's Disease, Current Alzheimer Research 13 (5) (2016) 575–588.

[125] A. Ortiz, F. J. M. Murcia, J. Munilla, J. M. Górriz, J. Ramírez, Label aided deep ranking for the automatic diagnosis of parkinsonian syndromes, Neurocomputing 330 (2019) 162–171.

[126] F. J. Martinez-Murcia, A. Ortiz, J. M. Górriz, J. Ramírez, F. Segovia, D. Salas-Gonzalez, D. Castillo-Barnes, I. A. Illán, A 3d convolutional neural network approach for the diagnosis of parkinson's disease, in: Natural and Artificial Computation for Biomedicine and Neuroscience, Springer International Publishing, Cham, 2017, pp. 324–333.

[127] F. J. Martinez-Murcia, J. M. Górriz, J. Ramírez, A. Ortiz, Convolutional neural networks for neuroimaging in parkinson's disease: Is preprocessing needed?, International Journal of Neural Systems 28 (10) (2018) 1850035, exported from https://app.dimensions.ai on 2018/09/20. `doi:10.1142/s0129065718500351`.
URL `https://app.dimensions.ai/details/publication/pub.1105862616`

[128] E. Finn, X. Shen, D. Scheinost, M. Rosenberg, H. Jessica, M. Chun, X. Papademetris, R. Constable, Functional connectome fingerprinting: Identifying individuals using patterns of brain connectivity, Nature neuroscience 18 (Oct. 2015).

[129] M. Sabzekar, H. Sadoghi Yazdi, M. Naghibzadeh, Relaxed constraints support vector machines for noisy data, Neural Computing and Applications 20 (5) (2011) 671–685.

[130] T. G. Stewart, D. Zeng, M. C. Wu, Constructing support vector machines with missing data, Wiley Interdisciplinary Reviews: Computational Statistics 10 (4) (2018) e1430.

[131] R. Akbani, S. Kwek, N. Japkowicz, Applying support vector machines to imbalanced datasets, in: Machine Learning: ECML 2004, Springer Berlin Heidelberg, Berlin, Heidelberg, 2004, pp. 39–50.

[132] D. Castillo-Barnes, F. J. Martinez-Murcia, F. Segovia,

I. A. Illán, D. Salas-Gonzalez, J. M. Górriz, J. Ramírez, Comparison between affine and non-affine transformations applied to i[123]-fp-cit spect images used for parkinson's disease diagnosis, in: Understanding the Brain Function and Emotions, Springer International Publishing, Cham, 2019, pp. 379–388.

[133] M. Leming, J. Suckling, Deep learning on brain images in autism: What do large samples reveal of its complexity?, in: Understanding the Brain Function and Emotions, Springer International Publishing, Cham, 2019, pp. 389–402.

[134] K. López-de Ipiña, H. Cepeda, C. Requejo, E. Fernandez, P. M. Calvo, J. V. Lafuente, Machine learning methods for environmental-enrichment-related variations in behavioral responses of laboratory rats, in: Understanding the Brain Function and Emotions, Springer International Publishing, Cham, 2019, pp. 420–427.

[135] D. López-García, A. Sobrado, J. M. González-Peñalver, J. M. Górriz, M. Ruz, Multivariate pattern analysis of electroencephalography data in a demand-selection task, in: Understanding the Brain Function and Emotions, Springer International Publishing, Cham, 2019, pp. 403–411.

[136] F. J. Martinez-Murcia, A. Ortiz, R. Morales-Ortega, P. J. López, J. L. Luque, D. Castillo-Barnes, F. Segovia, I. A. Illan, J. Ortega, J. Ramirez, J. M. Górriz, Periodogram connectivity of eeg signals for the detection of dyslexia, in: Understanding the Brain Function and Emotions, Springer International Publishing, Cham, 2019, pp. 350–359.

[137] A. Ortiz, P. J. López, J. L. Luque, F. J. Martínez-Murcia, D. A. Aquino-Britez, J. Ortega, An anomaly detection approach for dyslexia diagnosis using eeg signals, in: Understanding the Brain Function and Emotions, Springer International Publishing, Cham, 2019, pp. 369–378.

[138] G. Kedia, L. Harris, G.-J. Lelieveld, L. Van Dillen, From the brain to the field: the applications of social neuroscience to economics, health and law, Brain sciences 7 (8) (2017) 94.

[139] M. N. Tennison, J. D. Moreno, Neuroscience, ethics, and national security: the state of the art, PLoS biology 10 (3) (2012).

[140] R. J. Barry, A. R. Clarke, S. J. Johnstone, C. A. Magee, J. A. Rushby, EEg differences between eyes-closed and eyes-open resting conditions, Clinical Neurophysiology 118 (12) (2007) 2765–2773.

[141] F. Laport, F. J. Vazquez-Araujo, P. M. Castro, A. Dapena, Brain-computer interfaces for internet of things, Multidisciplinary Digital Publishing Institute Proceedings 2 (18) (2018) 1179.

[142] L. F. Velásquez-Martínez, F. Zapata-Castaño, J. I. Padilla-Buritica, J. M. F. Vicente, G. Castellanos-Dominguez, Group differences in time-frequency relevant patterns for user-independent bci applications, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 138–145.

[143] S. Ezquerro, J. A. Barios, A. Bertomeu-Motos, J. Diez, J. M. Sanchez-Aparicio, L. Donis-Barber, E. Fernández-Jover, N. Garcia-Aracil, Bihemispheric beta desynchronization during an upper-limb motor task in chronic stroke survivors, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 371–379.

[144] D. Palacios-Alonso, C. Lázaro-Carrascosa, R. Mas-García, J. M. F. Vicente, A. Gómez-Rodellar, P. Gómez-Vilda, Distinguishing aging clusters and mobile devices by hand-wrist articulation: A case of study, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 11–21.

[145] M. Ponticorvo, M. Schembri, O. Miglino, How to improve spatial and numerical cognition with a game-based and technology-enhanced learning approach, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 32–41.

[146] O. Gigliotta, M. Ponticorvo, F. Doricchi, O. Miglino, Midpoint: A tool to Build Artificial Models of Numerical Cognition, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 88–96.

[147] F. Rotondaro, M. Ponticorvo, O. Gigliotta, M. Pinto, M. Pellegrino, S. Gazzellini, P. Dolce, O. Miglino, F. Doricchi, The Number Interval Position Effect (NipE) in the mental bisection of numerical intervals might reflect the influence of the decimal-number system on the Gaussian representations of numerosities: a combined developmental and computational-modeling study, Cortex 114 (2019) 164–175.

[148] A. Cerrato, M. Ponticorvo, O. Gigliotta, P. Bartolomeo, O. Miglino, The assessment of visuospatial abilities with tangible interfaces and machine learning, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 78–87.

[149] O. Gigliotta, M. Ponticorvo, F. Doricchi, O. Miglino, Midpoint: A tool to build artificial models of numerical cognition, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 88–96.

[150] F. H. Zunjani, A.-M. Olteţeanu, Cognitive ai systems contribute to improving creativity modeling and measuring tools, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 97–107.

[151] M. P. Bonomini, M. Val-Calvo, A. Díaz-Morcillo, J. M. F. Vicente, E. Fernández-Jover, Autonomic modulation during a cognitive task using a wearable device, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 69–77.

[152] E. Lang, A. Tomé, I. Keck, J. Górriz-Sáez, G. Puntonet, Brain connectivity analysis: A short survey, Neural Computing and Applications 412512 (2012) 1–21.

[153] J. A. Gaxiola-Tirado, M. Rodríguez-Ugarte, E. Iáñez, M. Ortiz, D. Gutiérrez, J. M. Azorín, The effect of tdcs on eeg-based functional connectivity in gait motor imagery, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 3–10.

[154] M. H. Kryger, T. Roth, W. C. Dement, et al., Principles and practice of sleep medicine (2017).

[155] A. A. Fingelkurts, A. A. Fingelkurts, C. F. Neves, Natural world physical, brain operational, and mind phenomenal space–time, Physics of Life Reviews 7 (2)

(2010) 195–249.

[156] J. Hernández-Muriel, J. Mejía-Hernández, J. Echeverry-Correa, A. Orozco, D. Cárdenas-Peña, Hapan: Support tool for practicing regional anesthesia in peripheral nerves, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 130–137.

[157] A. Lozano, J. S. Suárez, C. Soto-Sánchez, J. Garrigós, J.-J. Martínez, J. M. F. Vicente, E. Fernández-Jover, Neurolight alpha: Interfacing computational neural models for stimulus modulation in cortical visual neuroprostheses, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 108–119.

[158] J. Enderle, J. Bronzino, Introduction to biomedical engineering, Academic press, 2012.

[159] E. R. Dorsey, A. Elbaz, E. Nichols, F. Abd-Allah, A. Abdelalim, J. C. Adsuar, M. G. Ansha, C. Brayne, J.-Y. J. Choi, D. Collado-Mateo, et al., Global, regional, and national burden of Parkinson's disease, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016, The Lancet Neurology 17 (11) (2018) 939–953.

[160] D. Mozaffarian, E. J. Benjamin, A. S. Go, D. K. Arnett, M. J. Blaha, M. Cushman, S. R. Das, S. De Ferranti, J.-P. Després, H. J. Fullerton, et al., Executive summary: heart disease and stroke statistics—2016 update: a report from the American Heart Association, Circulation 133 (4) (2016) 447–454.

[161] G. Gálvez-García, A. Gómez-Rodellar, D. Palacios-Alonso, G. de Arcas-Castro, P. Gómez-Vilda, Neuroacoustical stimulation of parkinson's disease patients: A case study, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 329–339.

[162] M. M. Hoehn, M. D. Yahr, Parkinsonism: onset, progression, and mortality, Neurology 17 (5) (1967) 427–427.

[163] A. Gómez-Rodellar, D. Palacios-Alonso, J. M. F. Vicente, J. Mekyska, A. Á. Marquina, P. Gómez-Vilda, Evaluating instability on phonation in parkinson's disease and aging speech, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 340–351.

[164] C. F. Biscay, P. D. Arini, A. I. R. Soler, M. P. Bonomini, Differentiation between ischemic and heart rate related events using the continuous wavelet transform, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 352–360.

[165] R. Verdú-Monedero, J. Morales-Sánchez, R. Berenguer-Vidal, I. Sellés-Navarro, A. Palazón-Cabanes, Automatic measurement of isnt and cdr on retinal images by means of a fast and efficient method based on mathematical morphology and active contours, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 361–370.

[166] O. Echaniz, M. Graña, Biothings: A pipeline creation tool for par-clip sequence analsys, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 327–336.

[167] A. Garvey, V. Lesser, A survey of research in deliberative real-time artificial intelligence, Real-Time Systems 6 (3) (1994) 317–347.

[168] D. J. Musliner, E. H. Durfee, K. G. Shin, Circa: A cooperative intelligent real-time control architecture, IEEE Transactions on Systems, Man, and Cybernetics 23 (6) (1993) 1561–1574.

[169] A. J. Garvey, V. R. Lesser, Design-to-time real-time scheduling, IEEE Transactions on systems, Man, and Cybernetics 23 (6) (1993) 1491–1502.

[170] S. Zilberstein, Operational rationality through compilation of anytime algorithms, AI Magazine 16 (2) (1995) 79–79.

[171] J. A. Stankovic, The many faces of multi-level real-time scheduling, in: Proceedings Second International Workshop on Real-Time Computing Systems and Applications, IEEE, 1995, pp. 2–5.

[172] A. Solin, S. Cortes, E. Rahtu, J. Kannala, Inertial odometry on handheld smartphones, in: 2018 21st International Conference on Information Fusion (FUSION), IEEE, 2018, pp. 1–5.

[173] H. Yan, Q. Shan, Y. Furukawa, Ridi: Robust imu double integration, in: Proceedings of the European Conference on Computer Vision (ECCV), 2018, pp. 621–636.

[174] J. Callmer, D. Törnqvist, F. Gustafsson, Robust heading estimation indoors using convex optimization, in: Proceedings of the 16th International Conference on Information Fusion, IEEE, 2013, pp. 1173–1179.

[175] Z.-A. Deng, Y. Hu, J. Yu, Z. Na, Extended kalman filter for real time indoor localization by fusing wifi and smartphone inertial sensors, Micromachines 6 (4) (2015) 523–543.

[176] V. Renaudin, M. Susi, G. Lachapelle, Step length estimation using handheld inertial sensors, Sensors 12 (7) (2012) 8507–8525.

[177] J. Fernandez-Conde, P. Cuenca-Jimenez, R. Toledo Moreo, Improving scheduling performance of a real-time system by incorporation of an artificial intelligence planner, in: Proceedings of the 8th International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 127–136.

[178] J. Fernandez, K. Ramamritham, Adaptive dissemination of data in time-critical asymmetric communication environments, Mobile Networks and Applications 9 (5) (2004) 491–505.

[179] J. Fernandez-Conde, D. Mozos, Pull vs. hybrid: Comparing scheduling algorithms for asymmetric time-constrained environments., in: ICWN, 2008, pp. 222–228.

[180] S. O. Madgwick, A. J. Harrison, R. Vaidyanathan, Estimation of imu and marg orientation using a gradient descent algorithm, in: 2011 IEEE international conference on rehabilitation robotics, IEEE, 2011, pp. 1–7.

[181] D. Zhou, M. Shi, F. Chao, C.-M. Lin, L. Yang, C. Shang, C. Zhou, Use of human gestures for controlling a mobile robot via adaptive cmac network and fuzzy logic controller, Neurocomputing 282 (2018) 218–231.

[182] N. Mendes, J. Ferrer, J. Vitorino, M. Safeea, P. Neto, Human behavior and hand gesture classification for smart human-robot interaction, Procedia Manufacturing 11 (2017) 91–98.

[183] D.-T. Lin, D.-C. Pan, Integrating a mixed-feature model and multiclass support vector machine for facial

expression recognition, Integrated Computer-Aided Engineering 16 (1) (2009) 61–74.
[184] M. Eppe, S. Trott, J. Feldman, Exploiting deep semantics and compositionality of natural language for human-robot-interaction, in: 2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), IEEE, 2016, pp. 731–738.
[185] M. Martell, M. Castilla, F. Rodriguez, M. Berenguel, An indoor illuminance prediction model based on neural networks for visual confort and energy efficiency optimization purposes, in: Proceedings of the 8th International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 146–157.
[186] M. Sanchez-Marre, K. Gibert, B. Sevilla-Villaneva, Combining data-driven and domain knowledge components in an intelligent assistant to build personalized menus, in: Proceedings of the 8th International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 167–180.
[187] I. Aguiló, et al., Generating complete menus from nutritional prescriptions by using advanced cbr and real food databases, in: Recent Advances in Artificial Intelligence Research and Development: Proceedings of the 20th International Conference of the Catalan Association for Artificial Intelligence, Deltebre, Terres de L'Ebre, Spain, October 25-27, 2017, Vol. 300, IOS Press, 2017, p. 166.
[188] R. L. De Mantaras, D. McSherry, D. Bridge, D. Leake, B. Smyth, S. Craw, B. Faltings, M. L. Maher, M. T. Cox, K. Forbus, et al., Retrieval, reuse, revision and retention in case-based reasoning, The Knowledge Engineering Review 20 (3) (2005) 215–240.
[189] D. B. Haytowitz, Information from usda's nutrient data bank, The Journal of nutrition 125 (7) (1995) 1952–1955.
[190] P. Urzúa, K. Sáez, M. S. Echeverria, Disponibilidad léxica matemática: análisis cuantitativo y cualitativo, Revista de lingüística teórica y aplicada 44 (2) (2006) 59–76.
[191] P. Salcedo, R. Contreras, et al., Computing the missing lexicon in students using bayesian networks, in: International Work-Conference on the Interplay Between Natural and Artificial Computation, Springer, 2019, pp. 109–116.
[192] S. Blum, S. Debener, R. Emkes, N. Volkening, S. Fudickar, M. G. Bleichner, EEg recording and online signal processing on android: A multiapp framework for brain-computer interfaces on smartphone, BioMed research international (2017).
[193] A. S. Oliveira, B. R. Schlink, W. D. Hairston, P. König, D. P. Ferris, Restricted vision increases sensorimotor cortex involvement in human walking, Journal of neurophysiology 118 (4) (2017) 1943–1951.
[194] J. E. Scanlon, K. A. Townsend, D. L. Cormier, J. W. Kuziek, K. E. Mathewson, Taking off the training wheels: Measuring auditory P3 during outdoor cycling using an active wet Eeg system, Brain research 1716 (2019) 50–61.
[195] J. Wagner, R. Martínez-Cancino, S. Makeig, Trial-by-trial source-resolved Eeg responses to gait task challenges predict subsequent step adaptation, Neuroimage 199 (2019) 691–703.
[196] P. Tzirakis, S. Zafeiriou, B. Schuller, Real-world automatic continuous affect recognition from audiovisual signals, in: Multimodal Behavior Analysis in the Wild, Elsevier, 2019, pp. 387–406.
[197] D. Molina, J. Poyatos, J. D. Ser, S. García, A. Hussain, F. Herrera, Comprehensive taxonomies of nature- and bio-inspired optimization: Inspiration versus algorithmic behavior, critical analysis and recommendations, ArXiv abs/2002.08136 (2020).
[198] J. Carrasco, S. García, M. Rueda, S. Das, F. Herrera, Recent trends in the use of statistical tests for comparing swarm and evolutionary computing algorithms: Practical guidelines and a critical review, Swarm and Evolutionary Computation 54 (2020) 100665.
[199] J. D. Ser], E. Osaba, D. Molina, X.-S. Yang, S. Salcedo-Sanz, D. Camacho, S. Das, P. N. Suganthan, C. A. C. Coello], F. Herrera, Bio-inspired computation: Where we stand and what's next, Swarm and Evolutionary Computation 48 (2019) 220–250.
[200] S. Ramírez-Gallego, A. Fernández, S. García, M. Chen, F. Herrera, Big data: Tutorial and guidelines on information and process fusion for analytics algorithms with mapreduce, Information Fusion 42 (2018) 51–61.
[201] J. M. Ferrández-Vicente, J. R. Álvarez-Sánchez, F. de la Paz-López, J. Toledo-Moreo, H. Adeli (Eds.), Understanding the Brain Function and Emotions, Vol. 11486 of Lecture Notes in Computer Science, IWINAC 2019, Springer, Cham, 2019.
[202] J. M. Ferrández-Vicente, J. R. Álvarez-Sánchez, F. de la Paz-López, J. Toledo-Moreo, H. Adeli (Eds.), From Bioinspired Systems and Biomedical Applications to Machine Learning, Vol. 11487 of Lecture Notes in Computer Science, IWINAC 2019, Springer, Cham, 2019.