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When Neural Networks meet Decisional DNA:

A Promising New Perspective for Knowledge Representation and Sharing

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Abstract. In this paper, we introduce a novel concept combining neural network technology and Decisional DNA for knowledge representation and sharing. Instead of using traditional machine learning and knowledge discovery methods, this approach explores the way of knowledge extraction through deep learning process based on domain's past decisional events captured by Decisional DNA. We compare our approach with kNN (k-Nearest Neighbours), Logistic Regression, and AdaBoost in classification tasks, and the results show that our approach is very promising regarding the enhancement of the accuracy of knowledge based predictions required in complex decision making problems.

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INTRODUCTION

Natural intelligence, as one of the most complex and mysterious phenomena that we are aware of, is evidently relying on our knowledge about the surrounding world. One definition of Artificial Intelligence (AI) is that it is the study of intelligent behaviour accomplished through computational methods (Brachman & Levesque 2004). Knowledge representation and reasoning within artificial man-made systems, therefore, is the field of AI that is mainly focused on how an agent makes decisions based on what it knows.

Then, what is knowledge? This is a question that has been discussed by philosophers since the ancient Greeks, and it is still not totally demystified. The Oxford Dictionary (2015) defines Knowledge as "*facts, information, and skills acquired through experience or education; the theoretical or practical understanding of a subject*". While Drucker (2011) defines it as "*information that changes something or somebody - either by becoming grounds for actions, or by making an individual (or an institution) capable of different or more effective action*". Natural knowledge requires that information acquisition and its usage is part of the process (O'Dell & Hubert 2011). Thus, for the AI field, we can argue that for knowledgeable act to happen information needs to be captured and used by computers (or agents).

Consequently, knowledge representation becomes a fundamental field dedicated to representing information about the world in a form that computer systems can utilize to solve complex tasks (Davis et al. 1993, Nakamatsu and Abe 2014). It is the study of thinking viewed as a computational process. Recent studies (LeCun et al. 2015; Gallant 2015; Lescroart et al. 2013) in Artificial Neural Networks (ANN) and brain psychology have found that the image representations in ANN are very similar to those in

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biological brains. The above has led to bio-inspired proposal presented briefly in this paper. We propose the Neural Knowledge DNA (NK-DNA), a framework utilising Deep Learning and Decisional DNA for neural network-based knowledge representation.

ARTIFITIAL NEURAL NETWORKS AND DEEP LEARNING

Machine learning, as the core of AI, addresses the question of how to build computer systems that can automatically improve themselves through experience (Jordan & Mitchell 2015). It is one of today's most rapidly growing technical fields of research, experimentation, and implementation. Recent progress in machine learning has been driven by the development of new theories and learning algorithms, such as for example the ANN.

ANN is a biologically-inspired programming paradigm which enables a computer to learn from observational data (Michael 2015). It consists of a network where information can be passed from one node to another, and these nodes in the network are called artificial neurons. The network typically is structured hierarchically, and its neurons are usually organized into layers such that each neuron in layer *l* connects to every neuron in layer *l*+1. Any layers in between the input layer and output layer are called hidden layers. The forward pass of an ANN is where information flows from the input layer, through any hidden layers, to the output. ANN learns during the backwards pass, which updates the connection's weights of the network (Jordan & Mitchell 2015).

Deep learning is a powerful set of techniques for learning enhancement in neural networks (Michael 2015). It allows computational models that are composed of multiple processing layers to learn representations of data with multiple levels of

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abstraction (LeCun et al. 2015). Deep learning learns sophisticated structure in large data sets by using the backpropagation algorithm to reveal how a neural network should change its internal parameters that are used to compute the representation in each layer from the representation in the previous layer (Wang, Weihong, et al. 2015; Michael 2015; LeCun et al. 2015). The essential aspect of deep learning is that these representations of features are not human-designed; they are learned from data using a general-purpose learning procedure (LeCun et al. 2015). Deep learning has dramatically advanced the state-of-the-art in image recognition, natural language processing, object detection, and many other domains such as drug discovery and genomics (Schmidhuber 2015; LeCun et al. 2015).

DECISIONAL DNA

In a broader sense, the presented research direction for machine learning plays an important role in our effort to bridge the gap between current society and the one embedded in semantic networks. The Semantic Web concept proposed in Berners-Lee, 2001 offers a future vision of the Web where both humans and machines are able to communicate and exchange information and knowledge. Our aimed "Neural Knowledge DNA; NK-DNA" empowers this vision by providing smart experience-based storage of information and knowledge in artificial systems which can be unified, enhanced, reused, and shared. The pillar notion behind the NK-DNA is experiential knowledge representation Decisional DNA (DDNA) which was coined some 10 years ago (Sanin & Szczerbicki 2006, 2006a) with further advancements in Sanin and Szczerbicki 2007, 2008, 2009; Mancilla et al 2010; Toro et al 2012; Sanin at al 2012; Sanchez et al 2013. DDNA motivation stems from the role of deoxyribonucleic acid

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(DNA) in storing and sharing information and knowledge. In nature, DNA contains "... the genetic instructions used in the development and functioning of all known living organisms. The main role of DNA molecules is the long-term storage of information. DNA is often compared to a set of blueprints and the DNA segments that carry this genetic information are called genes" (Sinden 2012). The idea behind DDNA was to develop an artificial system, an architecture that would support discovering, adding, storing, improving, and sharing information and knowledge among machines and organisations through experience. We proposed a novel Knowledge Representation (KR) approach in which experiential knowledge is represented by Set of Experience (SOE; Fig. 1) and is carried into the future by Decisional DNA (DDNA; Fig. 2) (Sanin & Szczerbicki 2006, 2007, 2008).

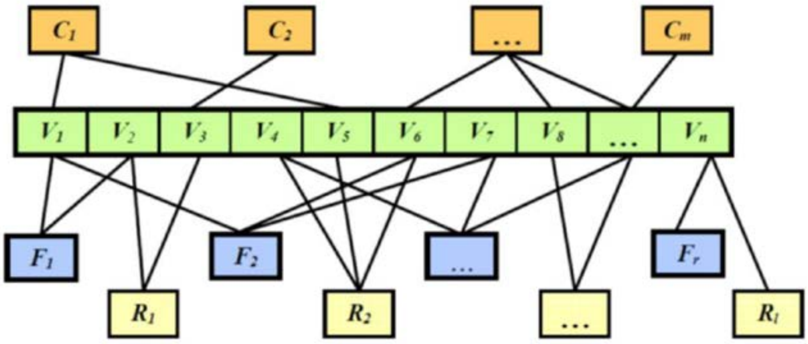

Fig. 1. SOE is the combination of 4 components that characterise decision making actions (variables V, functions F, constraints C, and rules R) and it comprises a series of mathematical concepts (logical element), together with a set of rules (ruled based element), and it is built upon a specific event of decision-making (frame element).

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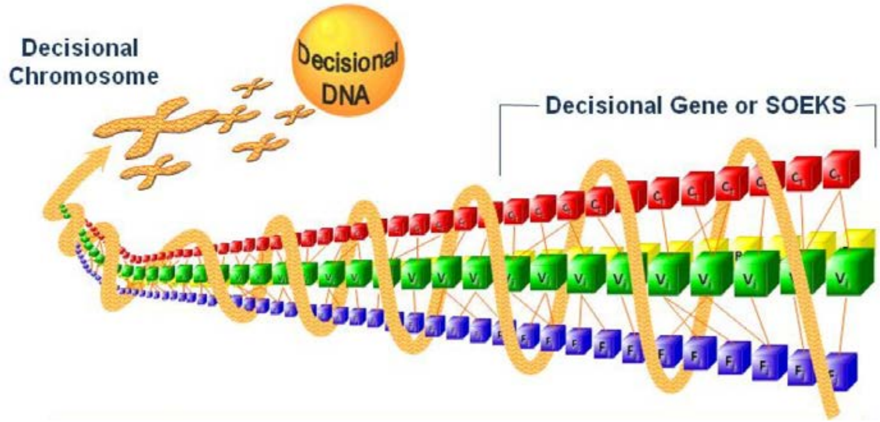

Fig. 2. Sets of Experience (Decisional Genes) are grouped according to their phenotype, creating Decisional Chromosomes, and groups of chromosomes create the Decisional DNA.

DDNA allows for many individual systems to share experiential knowledge, and it supports complex decision-making processes. Using experience as a form of knowledge is commonly suggested as a possible way to improve decision-making processes and to cope with knowledge inconsistences (Danilowicz and Nguyen 2000). Our recent computational experiments published in *Neurocomputing* (Wang et al. 2015) and *Cybernetics and Systems* (Zhang et al. 2015) present some interesting results related to artificial (man-made) systems that can be compared to human experience and its role in enhancing decision making processes. They add some additional understanding of our current research and explain that DDNA model actually acts in a similar way as the natural human decisional making process does. It is generally accepted that human experience improves with time, given that previous experiences support the decision making process carried out in the future. In Wang (2015) we show the same improvement of experience based decision making, using SOEs that are the building blocks of DDNA. Through extensive SOE role validation we show that when past experience is used (i.e. each previous experiment provides experience for the

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subsequent experiment), it introduces improvement every time a new experiment is performed. In the end, SOE gathers all experiences and, therefore, provides the best decisional performance (Wang et al. 2015; Zhang et al. 2015).

It is also generally accepted that both kinds of human experiences, good and bad decisional experiences, are part of our learning process, and as such, both help to improve decision-making processes. DDNA and SOE act in the same way - SOE absorbs past experience from all experiments without taking into consideration whether it is good or bad decisional experience. Good and bad experiences take part in the SOE learning process (in a similar way as they take part in human learning processes), thus providing better outcomes in comparison with systems that do not act in this way (Wang et al. 2015). These are very promising results that further define the cutting-edge standing regarding our research position - DDNA and SOE provide an artificial environment where human experience can be replicated in a very substantial way. This is why DDNA, when combined with artificial neural network to form NK-DNA, could prove a perfect support for the human-inspired deep learning process. This promise is explored further in the following Sections.

THE NEURAL KNOWLEDGE DNA FRAMEWORK

The proposed Neural Knowledge DNA (NK-DNA) framework is designed to enable knowledge to be captured, represented, and reused automatically among neural network-based AI systems. It consists of four main components, namely: Prognoser, Knowledge Repository, Trainer, and Deep Learning Engine (Fig. 3).

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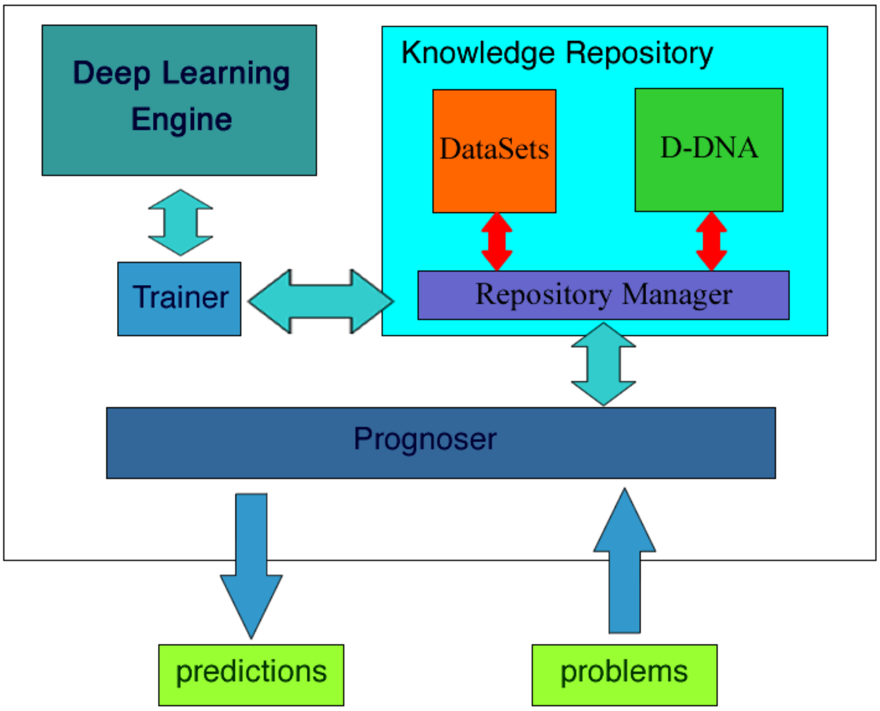

Fig. 3. Architecture of the NK-DNA framework

The Prognoser is in charge of analysing the scenario data, and searching matched experiential knowledge for reuse based on input problems' scenario data. In our case, we link every set of the Decisional DNA knowledge with a certain scenario describing the circumstance under which the experiential knowledge was acquired. After the searching process, if the Prognoser finds past and already existing matching knowledge, the Deep Learning Engine captures that knowledge via its NK-DNA representing information about how this knowledge can be reused in assisting with the developments of the structure of neural networks and weights and biases of each layer in the network. Therefore, the Deep Learning Engine creates a neural network according to our NK-DNA, and processes the input problems through the neural network enhanced by past experience. However, if there is no matching previous knowledge, The Prognoser traverses the DataSets in order to gather data similar to

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input problems, and calls Trainer to train the network with such data, and finally uses the trained network to process the input problems as depicted in Figure 3.

INITIAL EXPERIMENTS

In order to examine experimentally our concept, we tested the NK-DNA through prediction tasks by using the popular in machine learning horse colic dataset presented in the book *Machine Learning in Action* (Harrington 2012).

The aim of the experiment task is to predict whether a horse with colic would live or die. We compared the performance of our approach (i.e. the NK-DNA) with two classical algorithms of prediction: logistic regression (Harrington 2012) and AdaBoost (Collins et al. 2002). The results show that our approach over performed in prediction accuracy both logistic regression and AdaBoost (see Fig. 4. and Fig. 5.), therefore initially confirming the suitability of the proposed NK-DNA based knowledge representation and usage.

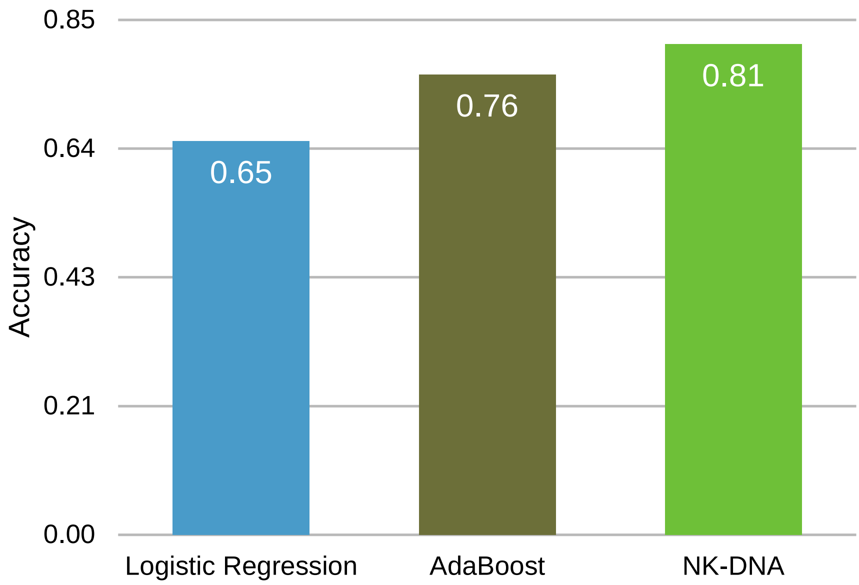

Fig. 4. The average prediction accuracy comparison

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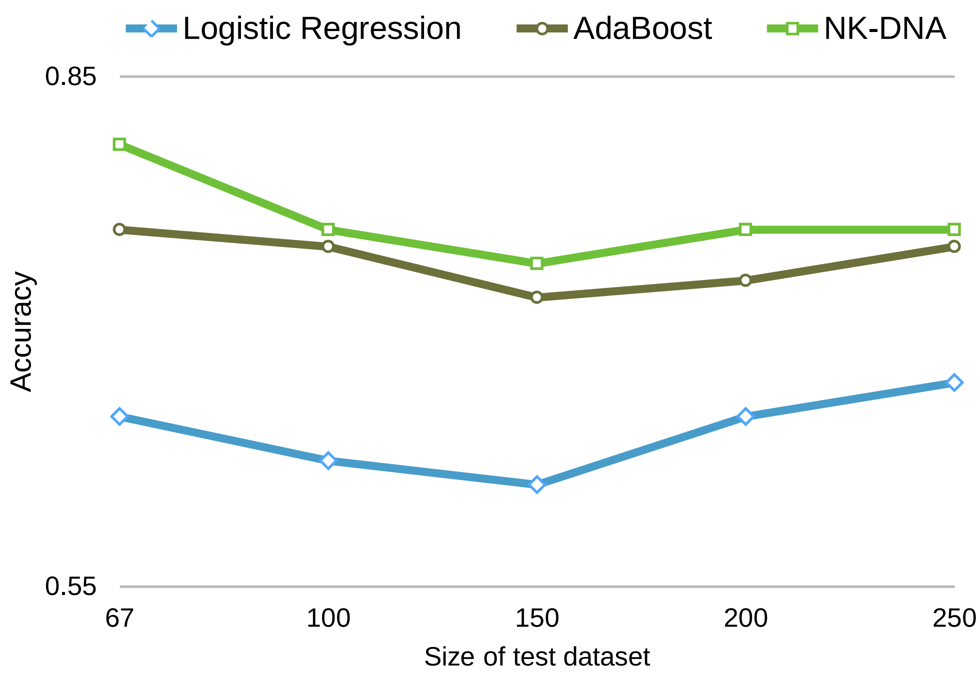

Fig. 5. The accuracy comparison using different test dataset size

CONCLUSIONS AND FUTURE WORK

In this paper, we sgnaled very briefly the initial concept of Neural Knowledge DNA, a framework utilising Deep Learning and Decisional DNA for neural network-based knowledge representation. By using the combined advantages of Decisional DNA and Deep Learning technologies, the NK-DNA enhances experiential domain knowledge acquisition, representation, reuse, and sharing. We tested the prediction accuracy of our approach in an initial experiment, and the results show that the NK-DNA is a very promising new vehicle for knowledge representation in artificially developed knowledge-based systems.

As the NK-DNA concept is at its early conceptual research stage, there are some further research tasks that are currently performed and will be reported to AI community very soon:

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- refinement and further development of the Deep Learning Engine,

- further development of new Decisional DNA functionalities required for the proposed platform,

- refinement of the Knowledge Repository,

- further design, development, and implementation of the Repository Manager.

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REFERENCES

Berners-Lee T., Hendler J., and Lassila O. (2001). The semantic web. *Scientific American*, 284(5), 28-37.

Brachman, R., and Levesque, H. (2004). *Knowledge representation and reasoning.* Elsevier: Philadelphia.

Collins, M., Schapire, R. E., & Singer, Y. (2002). Logistic regression, AdaBoost and Bregman distances. *Machine Learning*, 48(1-3), 253-285.

Danilowicz, C., Nguyen, N.T. (2000). Consensus-based methods for restoring consistency of replicated data. In: Klopotek et al. (eds), Advances in Soft Computing, Proceedings of 9th International Conference on Intelligent Information Systems 2000, Physica-Verlag-Springer: Heidelberg, 325-336.

Davis, R., Shrobe, H., & Szolovits, P. (1993). What is a knowledge representation?. *AI magazine*, 14(1), 17.

Drucker, Peter F. (2011). *The new realities*. Transaction Publishers: Rutgerrs University Piscataway.

Gallant, J. (2015). Brain reading: Mapping, modeling, and decoding the brain under naturalistic conditions. *2015 AAAS Annual Meeting (12-16 February 2015)*. AAAS.: Cambridge.

Harrington, P. (2012). *Machine learning in action*. Manning: St Marys, SA.

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Lecun, Y., Boser, B., Denker, J. S., Henderson, D., Howard, R. E., Hubbard, W., & Jackel, L. D. (1989). Backpropagation applied to handwritten zip code recognition. *Neural Computation*, 1(4), 541-551.

LeCun, Y., Bengio, Y., & Hinton, G. (2015). Deep learning. *Nature*, 521(7553), 436-444.

Lescroart, M. D., Nishimoto, S., & Gallant, J. L. (2013). Representation of object contour features in intermediate visual areas in the human brain. *Journal of Vision*, 13(9), 1000-1000.

Jordan, M. I., & Mitchell, T. M. (2015). Machine learning: Trends, perspectives, and prospects. *Science*, 349(6245), 255-260.

Mancilla L., Sanin, C., Szczerbicki, E. (2010). Smart knowledge sharing platform for e-decisional community, *Cybernetics and Systems: An International Journal*, 41(1), 17-30.

Michael A. N. (2015). *Neural Networks and Deep Learning*, Determination Press.

Nakamatsu K., Abe J.M. (2014). The paraconsistent process order control method, *Vietnam Journal of Computer Science*, 1(1), 29-37.

O'Dell, C., & Hubert, C. (2011). *The new edge in knowledge: how knowledge management is changing the way we do business*. John Wiley & Sons: Denver, CO.

Oxford Dictionaries. (2015). 'knowledge', Oxford University Press. Retrieved October 2015 from http://www.oxforddictionaries.com/definition/english/knowledge

Sanchez E., Toro, C., Artetxe, A., Grana, M., Sanin, C., Szczerbicki, E., Carrasco, E., & Guijarro, F., (2013). Bridging challenges of clinical decision support systems with a semantic approach. A case study on breast cancer. *Pattern Recognition Letters*, 34(14), 1758-1768.

Sanin, C., & Szczerbicki, E., (2006). Extending set of experience knowledge structure into a transportable language extensible markup language. *Cybernetics and Systems: An International Journal*, 37(2-3), 97-118.

Sanin, C., & Szczerbicki, E., (2006a). Using set of experience in the process of transforming information into knowledge. *International Journal of Enterprise Information Systems*, 2(2), 40-55.

Sanin, C., & Szczerbicki, E., (2007). Towards the Construction of Decisional DNA: A Set of Experience Knowledge Structure Java Class within an Ontology System. *Cybernetics and Systems: An International Journal*, 38(8), 859-878.

Sanin, C., & Szczerbicki, E. (2008). Decisional DNA and the smart Knowledge management system: A process of transforming information into knowledge. *Techniques and tools for the design and implementation of enterprise information systems*, Gunasekaran A., (Ed.), Idea: London, 2, 149-175.

Sanin, C., Mancilla, L., Szczerbicki, E., & CayfordHowell, P. (2009). Application of a Multi-domain Knowledge Structure: The Decisional DNA, in *Intelligent Systems for Knowledge Management* (pp. 65-86). Springer Berlin Heidelberg.

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Sanin, C., Toro, C., Zhang, H., Sanchez, E., Szczerbicki, E., Carrasco, E., Wang P., & Mancilla-Amaya, L. (2012). Decisional DNA: A multi-technology shareable knowledge structure for decisional experience. *Neurocomputing*, 88, 42-53.

Schmidhuber, J. (2015). Deep learning in neural networks: An overview. *Neural Networks*, 61, 85-117.

Sinden, R.R. (2012). *DNA Structure and Function*. Elsevier: Philadelphia.

Toro, C., Sanchez, E., Carrasco, E., Mancilla, L., Sanin, C., Szczerbicki, E., Grana, M., Bonachela, P., Parra C., Bueno G., & Guijarro F. (2012). Using Set of Experience Knowledge Structure to Extend a Rule Set of Clinical Decision Support System for Alzheimer Disease Diagnosis, *Cybernetics and Systems: An International Journal*, 43(2), 81-95.

Wang P., Sanin C., & Szczerbicki E., (2015). Evolutionary algorithm and Decisional DNA for multiple travelling salesman problem. *Neurocomputing*, 150, 50-57.

Wang, W., Yang, J., Xiao, J., Li, S., & Zhou, D. (2015). Face Recognition Based on Deep Learning. In *Human Centered Computing* (pp. 812-820). Springer International Publishing: Berlin.

Zhang, H., Sanin C., & Szczerbicki, E. (2015). Applying Decisional DNA to Internet of Things: The Concept and Initial Case Study. *Cybernetics and Systems: An International Journal*, 46(1-2), 84-93.

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