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How does generalization and creativity come into being in neural associative systems and how does it form human-like knowledge?

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ABSTRACT

This paper explains and models selected associative processes that take place in biological associative neural systems. Such associative systems allow us to form, expand, and exploit knowledge in a human-like way. They trigger artificial associations for previously trained and even new contexts taking into account the previous states of neurons of such systems, which are necessary for associative knowledge formation. The associative systems can automatically generalize and be creative. This paper reveals and explains the important generalization mechanisms of biological associative systems that can be modelled in artificial neural associative systems and used for practical associative neurocomputations. The associative mechanisms enable even generalization of rules or algorithms. These systems can reproduce generalization not only to train and classify static objects but also to form new sequences, which enables creativity of these systems. Because neuron groups are activated in a specific order, the associative conclusions are reached very quickly. Knowledge and active associations can also substitute many laborious and time-consuming searching processes that are used in contemporary computer science.

1. Introduction

Knowledge engineering is key to solving some of the fundamental challenges of today's computer science [22]. It facilitates more efficient and intelligent computer systems and further development of artificial intelligence. Knowledge forms automatically. It can be developed, expanded, verified, changed, and specified in a brain during one's life-time. Knowledge and all mental processes in brains of living creatures are available through active associations. Associations can be intentionally or passively triggered. They can change in time according to the changes in one's state of knowledge, needs, emotions, surroundings etc. All new or repeated incoming data also change associations and the recalled data. These changes enable our thinking, reasoning, learning, adapting, and behaving intelligently. All mental activities depend on knowledge that can be applied to many various situations only if they are at least partially similar to some others that have happened and been associated in the past. A brain naturally recalls the most similar facts and rules, which it next tries to apply to new situations.

Neural networks are usually treated as redundant distributed representation of knowledge [32], because it can more accurately represent graded values through coarse coding, where a value is encoded by the relative magnitudes of a number of broadly tuned units. Thus, similarity is represented by the shared units involved in the distributed representations of different items [32]. Neural network coding enables compression of represented data [4] and to use them for non-uniform learning [2]. Inhibitory connections and competition allow only the most strongly excited representations to prevail, with this selection process identifying the most appropriate representations for subsequent processing [32]. Moreover, inhibitory connections together with refraction process enable to excite also weaker representations. Neural networks allow also for fuzzy approximation [34] that is very important especially when dealing with symbolic and biometric data [26,35]. Repetitive schemes enable to adapt neural networks to represent and use them for recognition or classification [28,45]. Today, artificial neural networks mostly use non-linear artificial neurons [7,31,41,47,48], but non-linear continuous activation functions without activation threshold do not allow for some selective behaviours described in this paper (Fig. 3).

Generalization and creativity are common and natural for intelligent biological nervous systems. They are defined in many ways [8,18,25,29,41,44], however, they are still hard to model and use in today's computer systems. Although many methods of

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computational intelligence can generalize training samples [7,21,39,40,42,44], the achieved generalization is usually somehow limited and far from the abilities of human brains. It is particularly true for systems using fuzzy sets or various approximations of artificial neural networks achieved by the use of multidimensional functions. Computational creativity has been developing for many years in many areas: music, vision, art, linguistic, and for problem solving [41–44]. Creativity is usually modelled as an effect of approximation, extrapolation, generalization, addition of noise, damage, and disordering effects [8,9,19,36,42–44]. Researchers usually define creativity as the development of ideas, products, or solutions that are perceived as unique, novel, relevant, and useful. "*Creativity is defined as the tendency to generate or recognize ideas, alternatives, or possibilities that may be useful in solving problems, communicating with others, and entertaining ourselves and others*." [Robert E. Franken, Human Motivation] "*'Creative' refers to novel products of value, as in 'The airplane was a creative invention.' 'Creative' also refers to the person who produces the work, as in, 'Picasso was creative.' 'Creativity,' then refers both to the capacity to produce such works, as in 'How can we foster our employees' creativity?' and to the activity of generating such products, as in 'Creativity requires hard work.*'" – [Robert W. Weisberg, Creativity – Beyond the Myth of Genius] "*Creativity is any act, idea, or product that changes an existing domain, or that transforms an existing domain into a new one… What counts is whether the novelty he or she produces is accepted for inclusion in the domain*." [Mihaly Csikszentmihalyi, Creativity – Flow and the Psychology of Discovery and Invention] "*Creativity is nothing more than seeing and acting on new relationships, thereby bringing them to life*." [Joseph V. Anderson, Weirder than Fiction: the Reality and Myths of Creativity] "*Creativity is generating new ideas and concepts, or making connections between ideas where none previously existed*." [Mitchell Rigie and Keith Harmeyer, Smart Storming] "*Creativity is the ability to find new solutions to a problem or new modes of expression*; *thus it brings into existence something new to the individual and to the culture*." [Dr. Betty Edwards, Drawing on the Right Side of the Brain.] "*I define creativity as the act of turning new and imaginative ideas into reality. Creativity involves two processes: thinking, then producing. Innovation is the production or implementation of an idea. If you have ideas, but don't act on them, you are imaginative but not creative*." [Linda Naiman, Creativity at Work.] "*Creativity is the process of bringing something new into being. Creativity requires passion and commitment. It brings to our awareness what was previously hidden and points to new life. The experience is one of heightened consciousness: ecstasy*." [Rollo May, The Courage to Create] "*Creativity is seeing what everyone else has seen, and thinking what no one else has thought*." [Einstein, Quoted in Creativity, Design and Business Performance] "*Creativity is the ability to generate innovative ideas and manifest them from thought into reality. The process involves original thinking and then producing*." [Wikipedia] All these definitions do not explain where creativity comes from and how it is produced in brain structures. The following sections try to answer these questions in terms of associative processes and the generalization on the sequence level that take place in the biological and artificial associative neural systems.

Biological nervous systems can still generalize facts, rules, methods, and algorithms better than their computational counterparts. The acquired knowledge allows them to perform various intricate reasoning processes and be creative. Creativity could be more appropriate when using human-like brain structures and knowledge in a human-like manner. Human thinking is based on a nervous system and knowledge formed as consolidated associations between objects, actions, facts, rules etc [14]. The associations can be triggered according to the context defined by a situation, previous thoughts, surroundings, needs, emotions etc. The triggered associations produce some responses that can interact with surroundings as well as broaden one's knowledge. Moreover, the triggered associations can provide not only remembered facts and rules but also new ones according to the context of recalling that can be different from the contexts of previous training. Such behaviours are creative and occurs automatically. If creative behaviours are effective and adequate to a situation then they are intelligent; if intelligent behaviours are non-egocentric then they are wise.

The question is: how can human-like knowledge be formed and broadened in neural structures and what does it demand from neurons and their connections. Some kinds of knowledge can be represented by contemporary artificial neural networks and other computational intelligence systems. They can have the ability to generalize and even be creative but usually only on the level of static objects and sometimes representation of rules. The limitations of artificial neural networks can arise from too simple models of neurons [6,7] that hinder them from achieving important functionality of biological neurons and nervous systems. Artificial neural networks simply model and use only one group of elements of biological nervous systems – the neurons. However, biological nervous systems also contain various sense receptors, glial cells, and interneuronal space that also play important roles in associative, cognitive, and thinking processes as well as in knowledge formation, generalization, and creativity. Artificial and spiking models of neurons and their networks use these elements only in a limited fashion. Some of them are too simple and cannot reproduce real functionality of biological neurons that are important for modelling of associations and their triggering. The most popular artificial neurons and artificial neural networks use various continuous activation functions of neurons (e.g. sigmoidal, radial) [6,7,42]. These kinds of activation functions oversimplify or even change the real function of biological neurons. Continuous activation functions enable approximation but disable representation of groups of combinations. Continuous neurons can be very useful in computer science but they do not model the real functionality of biological neurons and their networks. Moreover, artificial neurons do not relax after their excitation and do not refract after their activation. They sum up all input signals regardless of the moment of influences of input signals. Artificial neurons usually synchronize such influences in time. In biological nervous systems the time of influences is very important for associative processes and possible next activations of connected neurons because it is varying. Furthermore, the neurons can actively affect the other connected neurons through synaptic connections. This is used and modelled in a rough way in typical artificial neural networks. However, biological neurons can also interact via interneuronal space which is a medium for conditional connections between them. This manifests in biochemical (based on hormone transmission) spreading of information inside particular parts of the brain or other biological neural nervous systems. Knowledge could not be formed efficiently and correctly in neural networks, if automatic conditional connecting of neurons were not possible [14]. Such automatic connecting is one of the fundamental features of real neurons that should be adequately modelled in artificial neural associative systems as described in this paper.

Knowledge is usually defined as awareness or a familiarity with someone or something, which can include facts, information, descriptions, and skills acquired through experience or education [25]. Computer science defines knowledge as a set of facts and rules stored and exploited using databases and expert systems [18,19,21] or an inner configuration of a neural network that has been created in a training process for a given set of training samples [7,39,40,46]. Human knowledge fails to work as a relational database because it requires fast and direct neuron communication to consolidate fact and rules and quickly recall