e-mentor

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2014, nr 3 (55)

S. Thaler, *Lessons from connectionism in differentiating knowledge*, „e-mentor" 2014, nr 3 (55), s. 81–86, DOI: 10.15219/em55.1112.

Lessons from connectionism in differentiating knowledge types

Stephen Thaler

Recent progress in the field of computational creativity has supplied an unanticipated model of the neurobiological knowledge management system known as the brain. Close examination of this model offers an alternative language for the field of knowledge management as well as a means for implementing cognitive agents coming closer than ever to emulating human intelligence and consciousness.

Knowledge management (KM) theorists have proposed a number of frameworks for distinguishing different types of knowledge. Oftentimes we hear distinctions such as *explicit* versus *tacit*[1], *content-based* or *relational*[2], or *new* contrasted with *established* knowledge[3]. With close to three decades experience in emulating cognitive function in neural networks, the author finds such delineations interesting, to say the least, foreseeing a general debate that mirrors the ongoing dialogue between high- and low-level psychologists: the former group seeks to model human behavior on the basis of beliefs, desires, fears, and hopes, primitives that tend to be as cyclic in definition as KM terms such as 'explicit' or 'tacit'. The latter group takes a totally different tack, asserting as Crick[4] did, that all we are, our intelligence, personalities, perhaps even soul, is the outcome of neural mechanics. Such reductionism may ultimately diminish certain mystiques, but the capture, development, sharing, and effectiveness of knowledge is about to enter a boom period exactly because of this new outlook.

Herein, correspondence is made between these high-level KM principles and the function of artificial neural systems, in the hope of seeding an alternative group think that transcends epistemological perspectives that predate cognitive neuroscience and connectionism[5] by centuries. Accepting this newer perspective, important lessons are to be learned that will contribute greatly not only novel KM strategies, but also to the construction of synthetic cognitive systems that may very well supplant humans as mentors.

Artificial neural systems

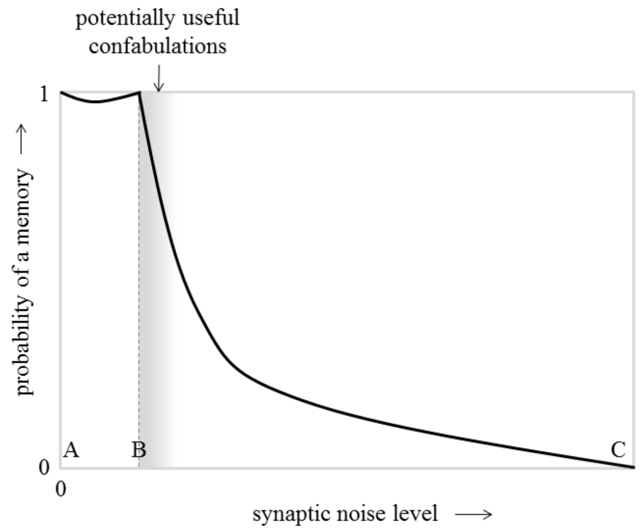
Unlike computer programs, artificial neural networks build models of any conceptual space without recourse to human-conceived rules. Just as in the brain, simple switching elements called *neurons* collectively encode information about the environment they have been exposed to through the self-organization of the connection strengths joining them. As a result, all things the net observes within the external microcosm are tokenized as distributed colonies of neurons, bound together by such connections. The spatiotemporal correlations between these *synaptically* encoded entities are likewise captured in other linkages. In effect such *connectionist* systems are the natural means to quickly construct world models, as they autonomously carve their environments into statistically repeating themes and establish causalities and relationships between the things and scenarios encountered therein.

But recognition of entities and their relationships is not all that the brain does. Arguably, most of the activity of cognition and consciousness has to do with the internal genesis of ideas that may be forming well outside the context of activities within the external universe. Such generative mental processes may be qualitatively and quantitatively modeled through the consideration of the ubiquitous entropic forces known as chaos and noise.

[1] D. Snowden, *Complex Acts of Knowing – Paradox and Descriptive Self Awareness*, „Journal of Knowledge Management" 2002, Vol. 6, Special Issue 2, p. 100.
[2] M. Hayes, G. Walsham, *Knowledge sharing and ICTs: A relational perspective*, [in:] M. Easterby-Smith, M.A. Lyles, *The Blackwell Handbook of Organizational Learning and Knowledge Management*, Blackwell, Malden 2003, p. 54.
[3] *Ibidem*.
[4] F. Crick, *The astonishing hypothesis: the scientific search for soul*, Charles Scribner's Sons, New York 1994.
[5] Connectionism is a set of approaches common to artificial intelligence, cognitive psychology, cognitive science, neuroscience, and philosophy of mind, that models mental processes as the emergent behaviors of interconnected networks of simple processing units.

To illustrate, consider the scenario of a totally quiescent brain wherein the only way to change brain state is through the presentation of a succession of environmental states to it, resulting in a series of perceptions. In the absence of an evolving external world, it is the spontaneous, fluctuations to the brain's processing elements that drive it through the sequence of states that we recognize as stream of consciousness. Recent investigations[6, 7] implicate global neurotransmitter release as the primary source of such disturbances to the neural networks of the brain.

Figure 1. The cusp-like transition between rote and creative pattern generation by a synaptically perturbed neural net



Not only does such synaptic noise drive the cognitive transitions of the mind, but it also governs the veracity of the resulting brain states. For instance, in Figure 1, the probability of seeding an intact memory (in contrast to a false memory or confabulation) is shown as a function of the magnitude of random disturbances to the connection weights of any neural system, whether synthetic or biological. The shape of this curve may range from a plateau followed by a dramatic drop off, to the cusp-like behavior shown.

Without changing inputs to, or introducing internal disturbances to the neural system, at point A, turnover of the activation patterns, tantamount to stream of consciousness, vanishes. Gradually increasing the noise level to point B, the weight variations produce a succession of memories at an even, linear clip. However any additional level of weight perturbations, represented by the gray tapered regime, produces a very useful effect, namely the generation of plausible, yet faulty memories that represent slight twists upon the system's direct experiences (i.e., potential ideas). At this synaptic noise level the rhythm of memory generation changes from linear and rapid to sporadic and slow. Finally, as excessive amounts of noise are added to the neural system (C), its outputs become nonsensical with little turnover of output patterns.

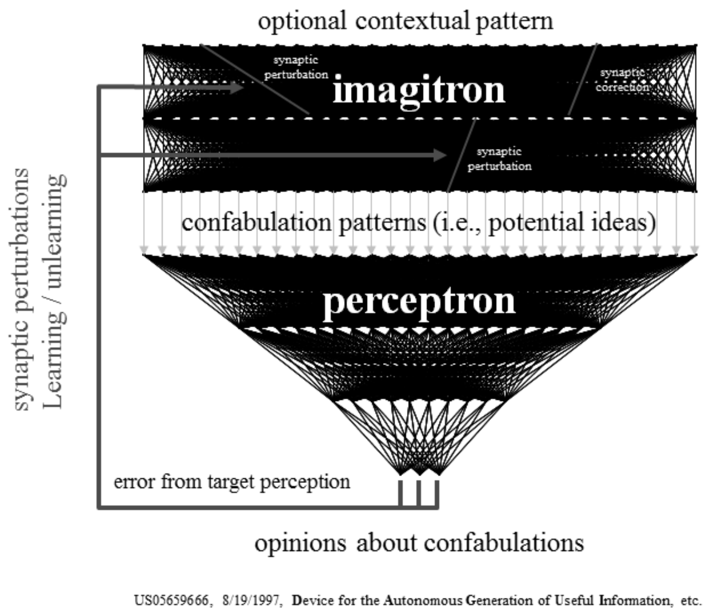
From an evolutionary perspective, point B is exactly the cusp a brain must reside on, since minor variation in a single control parameter, the mean synaptic noise level can transition this cognitive system from rote to creative mode, as when environmental pressures are high and the host organism is pressed for a solution other than the ones it already knows.

In engineering creative AI systems, the effect illustrated in Figure 1 is extremely valuable since the introduction of synaptic noise at just the right level (B) stimulates an artificial neural network to become an idea generator[8, 9, 10]. Within neurobiology, the most likely candidate for such synaptic perturbation is represented by global release of stress-related neurotransmitters such as adrenaline that diffuse into the synaptic clefts to supplement the normal packets of neurotransmitters systematically broadcast across these gaps. The system's intended release of such molecules represents signal and the random diffusion of their 'rogue' counterpoints, noise. If another agency takes charge of the signal to noise ratio, it may drive the net from rote to creative mode, based upon demands placed upon it by the environment. Having found a noteworthy solution to a challenge, the global release of other *potentiating* neurotransmitters prepare the neural system to absorb this promising confabulation as a memory.

By combining a synaptically perturbed neural net, an „imagitron", with a quiescent partner, known as a „perceptron", a so-called „Creativity Machine" (Figure 2) is produced, the latter net continuously mining the output stream of the perturbed net until a solution pattern is found. If no such patterns are discovered, the perceptron may increase the synaptic perturbation level in proportion to its „frustration", to create more 'twisted' possibilities from the imagitron. The search for useful ideas and strategies is vastly improved by allowing the perceptron to reinforce those confabulations deemed valuable to it. In this

[6] S. Thaler, *The creativity machine paradigm*, [in:] E.G. Carayannis (ed.), *Encyclopedia of Creativity, Invention, Innovation, and Entrepreneurship*, Springer Reference, 2013, pp. 447–456.
[7] S. Thaler, *Synaptic Perturbation and Consciousness*, to be published in „International Journal of Machine Consciousness", December 2014.
[8] S. Thaler, *Device for the Autonomous Generation*, US Patent 5,659,666, 1994.
[9] S. Thaler, *A quantitative model of seminal cognition: the creativity machine paradigm*, [in:] *Mind II Conference*, conference proceedings, Dublin 1997.
[10] S. Thaler, *The creativity machine paradigm*, *op.cit.*, p. 449.

Figure 2. A simple Creativity Machine, US patent 5,659,666 and subsequent derivatives



way, the system bootstraps to progressively higher levels of creative efficacy, as older false memories offering utility or value, combine to produce improved notions. In effect, this biologically inspired architecture emulates the cycles of synaptic perturbation and reinforcement achieved in the brain through the alternating chemical diffusion of stress- and learning-related neurotransmitters.

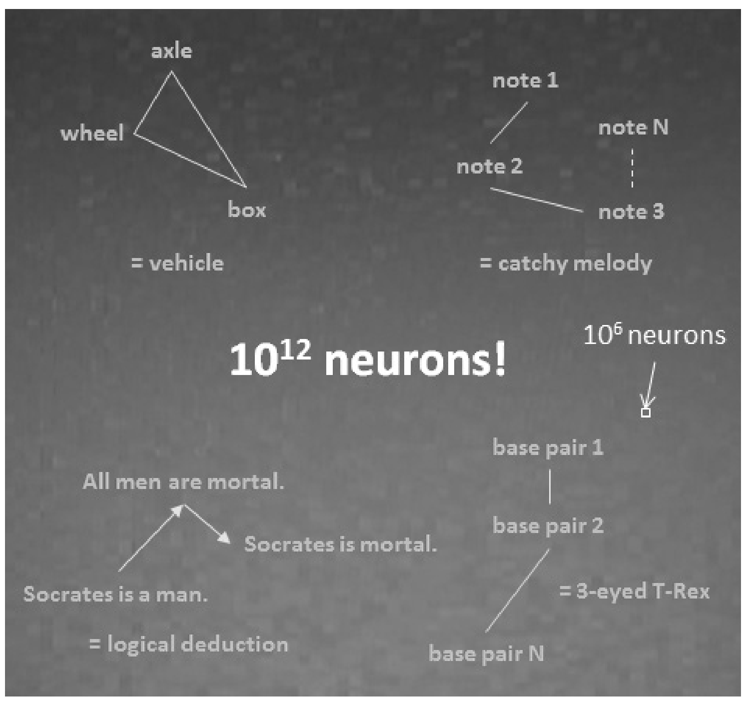
As briefly noted above, when Creativity Machines are driven from rote to creative function, the rhythm or prosody with which they generate neural activation patterns, tantamount to thoughts, transitions from a quick linear clip to a slower and more sporadic pace. The linear pattern turnover is dominated by memories and the more tentative rhythm by the potentially useful confabulations forming the basis of viable ideas. In short, the high-level psychological explanation for this phenomenon is that creativity is „harder" than memory recall making its delivery more tentative. From a low-level, computational perspective, this sporadic flow of creative cognition stems from the Brownian motion of stress related neurotransmitters into the synaptic clefts connecting neurons[11].

The very large scale integration of Creativity Machines into discovery systems

Of course Creativity Machines are not limited to just two neural networks as the canonical form shown in Figure 2, but can and most often do incorporate myriad neural modules, as intimated in Figure 3. Within these extensive neural architectures a wealth of possible revelations continuously seed themselves upon uniformly distributed synaptic fluctuations, taking the form of extended associative chains. Representative, hypothetical discoveries are being depicted in the figure below, ranging from juxtapositional invention, musical composition, deductive logic, and genomic synthesis.

Implicit within such extensive neural systems, now in development, is that noise, predominantly in the form of synaptic perturbations, seeds the activation of certain neural modules into either memories or confabulations. With any given module simultaneously communicating its activation state

Figure 3. Myriad imagitrons connecting into valuable associations outside the purview of perceptrons. The background of this figure represents the activations of an actual synthetic cortex having ten times more neurons than the human brain



[11] S. Thaler, *Synaptic Perturbation and Consciousness*, *op.cit.*

to all others within the assembly, associated neural clusters begin to link and strengthen their connections with one another so as to form latent chains or pathways that may later reactivate upon random synaptic perturbations.

Such a linking process is thought to be constantly occurring within the cortical networks of the brain, beyond the scrutiny of any monitoring perceptrons. These associative chains and loops are tantamount to incubating ideas, being the combination of both memories and confabulations[12]. As the level of stress neurotransmitters such as adrenaline subsequently subsides, for instance after a good night's rest, these latent discoveries are observed by the brain's now more quiescent perceptrons. It is just this kind of relaxation process that accounts for the mind's incubation of discoveries as well as its subconscious accumulation of implicit knowledge.

In building synthetic cognitive systems, often incorporating more neurons than the human cortex, the author has discovered that the best technique for recovering such ideational chains is through a process known as „foveation" wherein Creativity Machines similar to that in Figure 2, scan the neural system in search of freshly activating knowledge that offers novelty, utility, or value to monitoring perceptrons. In essence, the imagitron constantly 'invents' positions to place an attention window within the field of cortical activations. Having located knowledge relevant to the monitoring nets, the synaptic noise within the imagitron is lowered in proportion to the perceptron predicted utility of the located content, causing the attention window to be itinerant to a given piece of neural real estate.

The lesson to be learned from such *foveational* schemes is that the brain is restricted by its design to being aware of only one thing at a time as a similar neural network directed attention window roams over the activation patterns forming within cortex. Therefore, for one brief instant, certain data comes into focus. Meanwhile, all the myriad bits of remaining information, encoded within synaptic connection weights, remain dormant, waiting to be activated by stochastic disturbances and discovered by the roving internal spotlight of the mind.

The nexus between KM and connectionist knowledge frameworks

Having briefly reviewed how artificial and biological neural nets manage and generate information, the high level KM and connectionist nomenclatures are contrasted and compared. In addition to seeking a general correspondence between the high- and low-level perspectives, speculation is raised as to how this newer thinking could lead to significant paradigm shifts in knowledge management.

Explicit versus Tacit

Explicit knowledge is that which may be held consciously in mental focus, in a form that can be readily communicated to others[13]. On the other hand, tacit knowledge is inherently subconscious and difficult to articulate, as are the intuitive and unexplainable scripts that tend to automatically execute in our minds as we encounter familiar situations to which we respond with minimal deliberation.

Brought into correspondence with the cognitive model of the Creativity Machine, explicit knowledge is that currently being discovered by a foveating perceptron. Tacit knowledge is that which may form as a latent notion, a preformed associative chain, awaiting later discovery by monitoring neural assembles. Similarly, such chains may encode well established, automatic behaviors that may be later rediscovered through synaptic noise stimulation.

For the autonomous machine intelligence intimated in Figure 2, the perceptron stage is equivalent to the human consumer in KM schemes. In effect, there is much implicit information cumulatively stored within the imagitron module that has the potential to become explicit. Such a transition occurs if and when the perceptron stage associates significance to the information patterns it observes activating from noise. At that point, the nucleated pattern has focus and may be fine-tuned via the perceptron's injection of moderate levels of synaptic disturbance. Thereafter, the knowledge becomes more explicit via the strengthening of connection weights, that process serving to form tokenized entities and encode the relationships between them. In effect, the brainstorming session between these two modules is reminiscent of the so-called Knowledge Spiral[14] within which implicit knowledge is first extracted by humans to become explicit. Thereafter, this information is resubmitted to the KM system to produce the next generation of tacit knowledge.

Both high- and low-level views suggest that there is a never ending generative loop between the implicit and explicit. The primary advantage of the self-bootstrapping Creativity Machine is that the process is totally automated, reducing time scales to nanoseconds, whereas individual humans in the loop slow the process to seconds (or longer if teams of humans are involved).

For the Creativity Machine, the end product is not an answer per se, but a more focused and inter-

[12] S. Thaler, *A proposed symbolism for network-implemented discovery processes*, [in:] *World congress on neural networks (WCNN'96)*, conference proceedings, San Diego 1996, pp. 1265–1268.
[13] D. Bray, *SSRN-Literature Review – Knowledge Management Research at the Organizational Level*, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=991169, [04.18.2013].
[14] I. Nonaka, H. Takeuchi, *The knowledge creating company: how Japanese companies create the dynamics of innovation*, Oxford University Press, New York 1995, p. 284.

rogatable system that has cumulatively shifted its expertise through many conversion cycles between explicit and tacit knowledge. Following such an iterative self-learning process the Creativity Machine may readily activate into explicit knowledge based only upon supplied clues regarding the information sought.

Content-based or relational

To reiterate, when a thing or activity from the external environment is presented to a neural net, two distinct activities occur: (1) the pattern representing the external stimulus is automatically decomposed into its essential features (i.e., its content) and (2) the remaining connective layers learn the relationships between such features. Again, content and relationships are simultaneously assessed and encoded within numerically based connection weights. Both tasks are achieved simultaneously through the adaptation of synaptic connection weights, the net result being that at the synaptic level, the distinction between content and relationships is blurred. Things are encoded as the synaptic relationships between neurons with the interaction between such content likewise simulated through the same synaptic binding process.

Worthwhile noting is that each time a neural net learns from scratch, it tends to produce an alternative world model, decomposing its knowledge environment into different primitives and relationships. So not only does the distinction between content and relationships vanish, our suspicion is confirmed that no single world model fits it all. This last observation represents an important lesson for KM since the neurobiological agents known as humans are constantly revising their views and opinions, thereafter committing them to silicon as part of the knowledge spiral. The net result is that knowledge management systems, as well as knowledge itself, tends to perform a somewhat desultory, random walk rather than arriving at a final and logical conclusion.

New versus established knowledge

Drawing upon the Creativity Machine principle, the activation of known versus novel information is simply a matter of synaptic noise level within the system. These two genres of information may be easily distinguished based upon either their novelty or their statistically gleaned activation rates. Important to note is that in the case of an artificial neural system generating knowledge, novelty may be assessed objectively, whereas in the case of humans such an evaluation is typically subjective. Nevertheless, the rhythm or prosody with which such pattern-based notions occur remains a valid discriminator between new and established knowledge.

In contrast, the high level perspective on seminal cognition is subjective in nature, boiling down to two the categories offered by Boden, so-called personal (P) and historical (H) creativity[15]. In the former case, the acquired knowledge has been blindly rediscovered by an individual or small group. In the latter, the information is judged novel through societal consensus.

The nexus between high-level psychology, education, and connectionist knowledge frameworks

Beyond the parlance and strategies of KM, other paradigm shifts are about to occur in high-level psychological views of information and artificial neural systems that will likely impact definitions and theories related to psychology and education.

Stress- versus curiosity-driven knowledge

Ultimately, a large share of knowledge management systems will become based in connectionist AI. To properly interpret and disambiguate human queries and to respond in context, they will require the Creativity Machine principle to mull and then generate text or voice mediated information exchange with humans. To activate the factual informational patterns, these synthetic cognitive systems will require neural network based critic nets to purposely apply the low levels of synaptic noise. To generate more theoretical factoids, they will need to intelligently inject increasing levels of noise, the equivalent of stress-associated neurotransmitters, as when humans are faced directly or indirectly with pressing environmental challenges.

Viewed as interacting connectionist systems driven by synaptic noise, KM and human cognitive systems will be mutually aware of their affective states, with the machine intelligence understanding how to stimulate either stress or learning neurotransmitter release using a number of available metrics, some invasive (e.g., brain implants and functional brain scans) and others (e.g., conversational rhythm) not. Essential to their understanding will be that there is an inherent tradeoff in human cognition between mental states conducive to learning, and attention deficit modes dominated by internal network chaos, where creativity reigns.

The potential decline of the importance of natural language in both KM and education

Realizing that natural language is such a heavy component of KM strategies, it is important to note that the new class of machine intelligence described herein, the Creativity Machine, is relatively transparent in its operation. Such a system need not introspect as humans do prior to articulating

[15] M. Boden, *The creative mind: myths and mechanisms*, Weiden and Nicholson, London 1990.

its knowledge. However, unlike humans, we may peer directly into an artificial cortex, equipped with appropriate neural decoders, and directly witness what is being thought.

Of course, humans within the loop of KM strategies will always exchange their thoughts via the written, typed, or spoken world, but now the querying of automated knowledge systems will radically change for the better.

The blurring of 'embedded' and 'embodied knowledge'

Sensky[16] distinguishes between the disembodied knowledge of a system outside of a human mind (e.g., a queriable database) and embodied knowledge taking shape via a human body's combined nervous and endocrine systems. In effect, the Creativity Machine paradigm allows machines to emulate both a brain and an endocrine system, the latter flooding the former with simulated neurotransmitters in response to environmental challenges and opportunities.

For the computational component of any KM system, such existential concern will probably take the form of a sense of duty to truth maintenance, timely delivery of query results, and an empathic rapport with human counterparts based upon the synthetic agent's understanding of its own cognitive mechanisms.

Discussion

As progress is made in studying and emulating the brain's knowledge management system, the language employed in KM circles is likely to recruit the lessons learned from artificial neural systems and connectionism. Chief among such lessons is that models of any world may be achieved using the computational equivalent of the synaptic interconnects of the brain. Rather than exist as symbols residing within hardware, conceptual spaces are absorbed via a distributed system of numerical connection weights. Information activates therein as patterns seeded upon both noise and supplied contexts. In effect, all such reclaimable knowledge is available but suppressed (i.e., tacit) until the time it is called upon. Then, rather than being recovered as symbols, the information reconstructs itself as a neural activation pattern understood only by those observing neural nets that have become experienced in their interpretation.

Speaking as a connectionist, the neural correlates of mind have been discovered, emulated in software, and recently scaled via parallel hardware schemes to human dimensions. Such synthetic consciousness, represented in the Creativity Machine, is the basis of the cognitive agents of the future, the virtual instructors who will understand better than their human predecessors the fine line between lucid attention and dreamy creativity. They will know these things as they introspect upon their own cognitive processes and conclude that definition itself is elusive, circular, and metaphorical, as in the case within at least a portion of the existing, high-level KM lexicon.

References

M. Boden, *The creative mind: myths and mechanisms*, Weiden and Nicholson, London 1990.

D. Bray, *SSRN-Literature Review – Knowledge Management Research at the Organizational Level*, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=991169.

F. Crick, *The astonishing hypothesis: the scientific search for soul*, Charles Scribner's Sons, New York 1994.

M. Hayes, G. Walsham, *Knowledge sharing and ICTs: A relational perspective*, [in:] M. Easterby-Smith, M.A. Lyles, *The Blackwell Handbook of Organizational Learning and Knowledge Management*, Blackwell, Malden 2003.

I. Nonaka, H. Takeuchi, *The knowledge creating company: how Japanese companies create the dynamics of innovation*, Oxford University Press, New York 1995.

T. Sensky, *Knowledge Management*, „Advances in Psychiatric Treatment" 2002, Vol. 8, No. 5, pp. 387–395.

D. Snowden, *Complex Acts of Knowing – Paradox and Descriptive Self Awareness*, „Journal of Knowledge Management" 2002, Vol. 6, Special Issue 2, pp. 100–111.

S. Thaler, *A proposed symbolism for network-implemented discovery processes*, [in:] *World congress on neural networks (WCNN'96)*, conference proceedings, San Diego, California 1996, pp. 1265–1268.

S. Thaler, *A quantitative model of seminal cognition: the creativity machine paradigm*, [in:] *Mind II Conference*, conference proceedings, Dublin 1997.

S. Thaler, *Device for the Autonomous Generation*, US Patent 5,659,666, 1994.

S. Thaler, *Synaptic Perturbation and Consciousness*, to be published in „International Journal of Machine Consciousness", December 2014.

S. Thaler, *The creativity machine paradigm* [in:], E.G. Carayannis (ed.), *Encyclopedia of Creativity, Invention, Innovation, and Entrepreneurship*, Springer Reference, 2013, pp. 447–456.

[16] T. Sensky, *Knowledge Management*, „Advances in Psychiatric Treatment" 2002, Vol. 8, No. 5, pp. 387–395.

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