Brain Science, Brain-inspired Artificial Intelligence, and Applications in Business and Management

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Abstract Brain science and brain-inspired artificial intelligence have the potential for strengthening business and management. Brain-inspired artificial intelligence (AI) uses principles of brain science to build algorithms and AI systems with human-like intelligence. Some concepts (e.g., cognition, inference, memory, and intelligence) and principles of brain science are introduced in this paper. The research progress in several topics are also presented that include brain-inspired artificial intelligence and brain-inspired computing, project management and brain-inspired management, the integration of brain science into leadership (especially crisis leadership), and brain-inspired decision-making for business. Future research and trends in some topics are introduced.

Keywords: *brain science, artificial intelligence, business intelligence, management, leadership, decision making*

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1. Introduction

Recent advances in neuroscience and psychology have provided a fruitful avenue for leadership known as brain-inspired management. This area of brain-inspired management is an exciting area for managers to explore. The study of brain-inspired management has resulted in improvements in key areas of project management [1]. Leaders have been studied in crisis management and the application of brain science fundamentals work well in improving leadership skills [2]. Brain science has also been implemented in Human Resources (HR) to help choose the right employee to fill a position. This specialized task helps the manager by using key mathematical complexes to design a profile that the employee must fill. Some brain-inspired models are composed of complex computations that help managers solve complicated problems [3].

Project management methods exhibit innovative managerial solutions for managers who want to excel at their job. Complicated problems that managers face daily demand modern management methods (e.g., risk management, total quality management, configuration management, financing, simultaneous engineering, partnership and procurement) that have evolved from project management. A good understanding of history should help create a good understanding of complications in shaping, creating, and managing projects, and therefore add to the empirical wealth of the area of the projects [4].

Project management is a special set of applications for solving difficult or special projects. Associated with change, it has been practiced since early civilization. Humans have long since been using project management to survive and build better technology, however, it was only in the 1950s that project management began to be applied to the engineering field. It is still considered a dynamic research area in engineering. Many exciting and unique uses and outcomes can come from project management in today's current hi-tech environment. However, much of what is known and written is not built upon the past—it is a very progressive field, and much can be done with the right ideas. Today, project management and TIM (Technology Innovation Management) are simultaneous for improving current technology and engineering solutions [5,6].

Social behaviors and human stress are closely related. Their interrelation was disclosed through experiments that were completed in animal models of explaining how social interactions in rodents could lead to stress and how social behaviors could change in response to stressors. Human stress resulting from social interactions has been proven to greatly influence individual well-being/health greatly. Disruption of iron homeostasis in the human brain may influence the neurophysiological mechanism, cognition, as well as social behaviors. This will lead to the development of various neuropathologies eventually. The iron accumulation in the brain is most likely related to the outcome of stress-induced depression as well as pathophysiological changes that are typical of anxiety and mood disorders. The iron dysregulation in the brain has a

significant neurophysiological impact and is related to cognitive or behavioral modifications. The modifications can be further exacerbated by social contexts without promoting regular cognitive functions and normal social behaviors [7].

Advisers' strategies rely on their influence levels on clients and their merits. In addition, blood-oxygenation-level-dependent (BOLD) signals in the temporo-parietal junction are modulated by adviser's current influence levels on clients; relative merit prediction errors affect activities in the medial-prefrontal cortex. Both kinds of social information modulate ventral striatum responses. Through the demonstration of what happens in the brain and subconscious, and when people influence others, starts to explain biological mechanisms that shape inter-individual differences of social conducts. Advice-giving behaviors are driven by an interaction between an adviser's current influence level on a client and the accuracy of the adviser's advice relative to that of a rival adviser. The interaction between relative merits and rival adviser's merits and current level of influence on a client generally shape the advice confidence. Confidence is the highest when recent history indicates that an adviser has better performance than his/her rival, but the client still listened to the rival [8].

The Human Brain Project (HBP) is a ten-year initiative of Future and Emerging Technologies Flagship that was launched by the European Commission. Its objective is to create an ICT-based research infrastructure for cognitive neuroscience, brain research, and brain-inspired computing. The combination of activities in various areas will offer the possibility of ground-breaking insights that will considerably facilitate the development of artificial intelligence greatly [9].
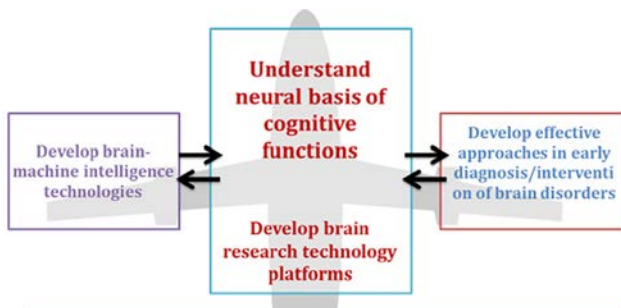

Figure 1. One body and two wings in the China Brain Project [10]

The human brain is a unique, truly intelligent system with various functions in cognition and very low energy consumption. The encoding and decoding of spike information, various kinds of spiking neurons (with distinct functions), multiple synaptic types and plasticity mechanisms, rules for conversion from short- to long-term memories, and the information processing integration at different levels (neurons, micro-circuits, regions in the brain) can bring potential operational principles for designing efficient models and algorithms for general AI. Neural systems process information in the way of binding storage and computation. Brain-inspired computing is very important for achieving strong AI in the era of big data. Therefore, the China Brain Project with the ''one body, two wings'' scheme has been launched based on brain science and brain-like intelligence. Basic research on

neural circuit mechanisms underlying cognition provides inputs to and receives feedback from two application wings of brain-inspired intelligence technology and brain disease diagnosis/intervention in the scheme. Figure 1 illustrates the project and its scheme. Neural principles of brain cognition are the "main body"; research and development in new technologies for brain computational intelligence and methods for the diagnosis and treatment of brain diseases are the "two wings" [10].

2. Brain, Intelligence, and Information Processing

Cognition, inference, and intelligence have been regarded as conscious mental functions of the human brain while perception, action, sensation, and memory have been regarded as the brain's subconscious mental functions. Permanent skills that are achieved in the form of long-term procedural memory are maintained by the posterior lobe of the cerebellum. The anterior lobe of the cerebellum is responsible for representing the body's status. Most acquired life functions are conscious while most inherited life functions are subconscious. Fulfilling almost all higher cognitive processes (e.g., comprehension, learning, problem solving, and long-term memory establishment) relies on the support of conscious and subconscious processes. Abstract Intelligence (αI) is defined as a general mathematical model for intelligence and it is an important theory in intelligence and brain science [11].

Information processing covers information acquisition, recording, organization, retrieval, display, and dissemination. The following are three information processing models [12]:

- Wickens' model: includes sensory processing, short-term sensory store, perceptual encoding, decision making and response selection, response execution, feedback and information flow, and attention.
- Welford's model: includes sensory input, short- and long-term memories, decision process, and action.
- Whiting's model: includes seven elements, i.e., things, input data, receptor systems, perceptual mechanism, translatory mechanism, effector mechanism, output, and feedback data.

3. Brain-inspired Artificial Intelligence and Brain-inspired Computing

The objective of brain-inspired artificial intelligence (AI) is to use more principles in brain science to develop AI systems. Brain science and brain-inspired technology aim to employ neuroscience principles in developing next-generation AI (with human-like intelligence) with the help of brain–machine interface technology. Recent progress in deep learning and AI has shown its capability of fulfilling cognitive tasks in some restricted specific fields [10]. The brain-inspired system (BIS) is a relatively new field of brain and intelligence science that deals with natural intelligence models in cognitive and AI systems as

well as formal models of the human brain that is analyzed and simulated using computational methods. BIS is an advanced and promising area of cognitive systems underpinned by transdisciplinary theories related to brain, cybernetic and cognitive science, denotational mathematics, knowledge, intelligence, and system [11].

An abstract intelligence model of the human brain is a top-level system model that reduces the intricate complexity of functional and structural models of the brain to lower-level details. The brain's system model helps BIS to mimic human's thinking, perception, inference and learning in many applications, including cognitive learning engines, cognitive control systems, cognitive robots, cognitive automobiles, cognitive translators, cognitive IoT, inter alia, unmanned systems as paradigms of brain-inspired systems [11].

In the human brain, memory and processing are highly entwined. Therefore, memory units are expected to play very important roles in brain-inspired systems. Brain-inspired computing is based on computing units with the co-location of memory and processing. This inspiration is referred to as in-memory computing; a memory unit that implements in-memory computing is referred to as computational memory [13].

A holistic approach to developing low-power architectures inspired by the human brain was presented, where system architecture, circuit design, learning algorithms, and process development and integration were simultaneously optimized. It was shown that emerging technologies (e.g., emerging resistive memories), coupled with novel brain-like paradigms (e. g., spike-coding and spike-time-dependent-plasticity), have potential in providing intelligent features in hardware that are like the brain in knowledge creation and processing. Encoding neuron values as pulses or spikes has been a trend in neuromorphic computing. This parsimonious signal coding was inspired by the manner of neurons in which the central nervous system interacts, resulting in a great energy saving [14].

Brain big data can be captured at molecular and neuronal circuitry levels using powerful neuroimaging technologies (e.g., electroencephalography (EEG), positron emission tomography (PET), magnetoencephalography (MEG), functional magnetic resonance imaging (fMRI), functional near-infrared spectroscopy (fNIRS), and wearable, portable micro and nano devices). Big data of the brain help scientists improve the understanding of human's learning, thinking, decision-making, memory, emotion, and social behaviors. Also, this kind of data helps to cure diseases, assists in mental health and well-being, contributes to further research and development of brain-inspired technologies [15].

Emotional intelligence plays a significant role in artificial intelligence due to the neurobiology and cognitive research of emotion. Many bio-inspired brain emotional learning (BEL) models have been developed and used in intelligent engineering successfully. BEL-based models that simulate the emotional learning mechanism in the limbic system have superior features of quick reaction and fast learning. A brain-like emotional learning algorithm was developed for fast classification. The genetic algorithm (GA) was used for optimally tuning weights and biases of amygdala and orbitofrontal cortex in the BEL neural network to increase the accuracy of BEL in classification. The amygdale plays a key role in emotional learning and reacting; the orbitofrontal cortex helps the amygdala in processing emotional stimulus [16].

Many deep learning (DL) systems are tied with reinforcement learning (RL) models that include: 1) an environment that can be expressed by features, 2) an agent that takes actions for changing the environment, and 3) an interpreter that announces the current state and actions of the agent. With a Markov decision model, DL can be evolved into a deep reinforcement learning (DRL) model, which can use the updates of system states, reward functions, and policy decision to make a suitable network control based on the maximum reward criterion.

DL and DRL are useful in the management of intelligent wireless network owing to their capability of brain-inspired pattern recognition [17]. They are also very useful in general business and management.

4. Brain-Inspired Management

Brain science can deliver management roles. Aspects of neuroscience and psychology have been applied to aspects of leadership and management. Harnessing brain abilities can facilitate the creation of optimal human's performance in crisis or stressful situations for leaders. The potential to increase leader efficacy through brain science is in its infancy and needs further research. Potential areas of benefit include methods to solve problems and decreased stress in high-stress situations. Potential managers need skills such as articulation, trust-building, sense making, and emotional intelligence. Emotional intelligence is composed of several parts: self-awareness, self-regulation, motivation, empathy, and social skills. It is important to understand collective goals of an organization prior to applying brain-inspired management. This will help a manager use skills in brain-inspired management [1].

Management science is very applicable to operational decision-making. When moving up the ladder, however, intuition, experience, and emotion influence decision-making. These interpretive methods provide a healthy combination of qualitative and quantitative methods systematically and provide such a basis for high-level decision-making (e.g., policy formation or the clarification of strategic intent) [2]. The mental process has been documented as experience and intuition, making decision-making highly emotional [1]. Management and decision-making can be a scientific and systematic approach. Complex computational methods for making decisions and the brain science behind it provide a stable reference and methodology for managers to make decisions that will be based not only on intuition and experience, but also on neuroscience and psychology which is far more advanced than previous decision-making management methods [2]. Managing people is a complex process and typically based on intuition, experience, and presentation. Using brain science to help choose employees, for example, can be one benefit for managers. Project managers can use this method for choosing project members and making other decisions [3]. Brain science provides a rational, computational problem-solving method to making good decisions [2].

Project management is a leadership tool for solving special tasks that managers use. However, failure to use project management techniques may result in a failure to progress as a company [4]. Probably the best qualities of project management are that it is competence based and technology driven. Since survival is the number one goal of companies today, using project management as an organization driven methodology may help organizations [18]. Brain-inspired management is simply stated, used to improve management tools and the manager's ability to manage by providing better tools [4].

5. Integrating Brain Science into Leadership

Improving the ability to make rational decisions, even during the most stressful situations is one of the most important features of brain science. The role of emotion in leadership and decision-making has been commonly accepted. The ability in decision-making can be degraded by a crisis. A crisis can be chaotic, dynamic, undefined in timescale, which requires quick but high-stakes decisions to be made. Successful brain science applications often depend not only upon the leader, but also upon human tendencies and limitations in crises. Leadership can be improved using brain science that help avoid anxiety and pessimism, thus avoiding the worst in a crisis [1].

Crisis leaders often face challenges and suffer life-or-death consequences due to challenging circumstances. Integrating much robust discussion of psychological/neurological phenomena and technologies for handling their impacts is significant. Having emotional intelligence and the knowledge of brain functions, overcoming the amygdala hijack, mitigating biases and heuristics, and understanding the latest brain science research are key for crisis leaders because they work for property protection, enhancing community resilience, and saving lives. The impacts of a leader's behaviors on outcomes in crisis management systems, for example, National Incident Management System (NIMS) and Incident Command System (ICS), have been investigated. Principles of brain science have been integrated into NIMS/ICS trainings. Research on brain functions in NIMS/ICS environments are useful in optimizing the NIMS/ICS implementation and improving crisis leadership. Integrating brain science into training systems for crisis leadership have been recommended. Further work has been suggested to better decide impacts of incorporating psychology and neuroscience into formal crisis leadership trainings [1].

6. Brain-Inspired Decision-Making for Business

The cycle of decision-making occurred within the human brain has been modelled by the SIDA (Sense-Inference-Decide and Act) cycle shown in Figure 2.

Brain-inspired decision-making is a promising and complicated technology that is rapidly gaining popularity in many areas of engineering, finance, healthcare, psychology, etc. [20,21]. The human brain was treated as a specific model for brain-inspired decision-making [20,21,22]. Machine learning, combinations of specific areas (psychology, brain functions, and technology), and technical indicators were used to present a complete picture of the tools associated with brain-inspired decision-making [21,23,24]. Japan has a consistent global technology research foundation and by looking at the fuzzy sets implementation in Japan, one can see they are far ahead of the competition on decision-making schemas [16,25]. Numerous international countries are participating in brain-inspired decision-making to improve life in their country [23,26].

Much of future research was directed toward locating and precisely developing an imitation on the parts of the brain and psychology which is responsible for decision-making [24]. By imitating the brain in specific aspects, research will be propelled forward, and it will be assured that brain-inspired decision-making can become a truly useful technology [27]. Currently with the beginning stages of use, for example in the financial sector to solve complicated problems, it is necessary to ensure there is much more research available for users [20].
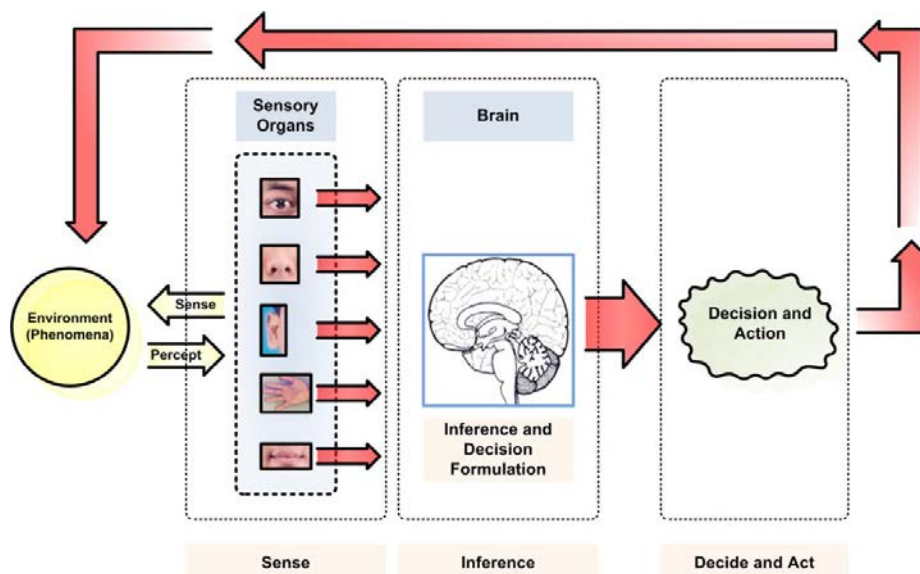

Figure 2. The SIDA (Sense-Inference-Decide and Act) cycle [19]

Because the neural trees and artificial intelligent risk management system (AIRMS) increased profitability on stocks, etc., it is necessary to research more complicated decision-making schematics [20]. Other researchers looked at specific parts of the brain such as the amygdala and psychology to develop a decision-making plan [16,21]. Future research is still necessary to present all the decision-making centers within the brain and all the factors which influence them [26].

One beneficial effect of the decision-making method on society is the ease in which problems can be solved. Complicated problems can be handled and solved as easily as possible without human input [22]. However, one negative effect on society is that with the ease of this decision-making method, it will likely be that many decisions will now be handled by machine learning or computers rather than gaining human input which can be a negative effect on society [28]. Technology progresses whether society wants it to or not. With this type of technology, it is also important to keep it out of wrong hands [26]. For corporations, it can be a profitable venture to automate or put problems of complicated management, technology, math, etc. in the hands of a computer. Society does need to set limitations on how this technology is used [25].

When a decision in a group is made, the outcome of one's decision probably relies on others' decisions. There is also a tradeoff between long-term incentives for the group and short-term incentives for an individual. The brain must evaluate group and individual utilities to decide an optimal strategy that maximizes one's total rewards in social interactions. The ventromedial prefrontal cortex encodes immediate expected rewards as the individual utility and the lateral frontopolar cortex encodes the group utility. The anterior cingulate cortex and the temporoparietal junction update beliefs regarding others' decisions during the interactions. A neurocomputational account has been provided regarding how a brain analyzes and decides effective strategies dynamically to make adaptive and collective decisions [29].

7. Conclusion

Many managers often rely on emotion, experience, and intuition for making decisions; however, brain-inspired management uses a combination of neuroscience and psychology. Brain-inspired management is one methodology in its infancy that can help project managers make appropriate decisions, even in times of crises. Project management is a useful methodology for the change process and other key processes in an organization. Leaders have been studied in crisis management and the application of brain science fundamentals work well in improving leadership skills. AI-based decision-making for management professionals provides a sound basis for better leadership.

The cerebellum is responsible for conscious thought and decision-making. Brain-inspired AI has the potential for strengthening decision-making. Brain-inspired decision-making is an ongoing technology that is just beginning to formulate new and improved algorithms. Further research is necessary in the field of brain-inspired

AI for decision-making and management so that leaders can take advantage of novel ways to handle crises and difficult decisions.

Machine learning, defining parts of the brain associated with decision-making, psychology, emotions, etc. are ways that can benefit brain-inspired decision-making by providing examples or methods for solving problems. Many complicated problems can be solved by searching for the right technique in decision-making. Globally, most countries are already using or researching decision-making processes. Artificial intelligence is important for the future; however, it must be handled with some care that society is not negatively affected by misuse.

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