Bmed-H
e-ISSN: 2582-7405
Transaction on Biomedical Engineering Applications and Healthcare
Vol-5 Issue-2, October 2024

Intelligence of Brainless Cell: Principles, Opportunities, and Challenges (Review)

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Abstract

Living cells have the ability to display complicated behaviors and decision-making activities similar to those related to higher-level intelligence. In this sense, cells have striking intelligence. Although cell/cellular intelligence (CI) is a new developing field of study, research on this subject has mushroomed seeking applications in health care and in other fields. By learning and understanding cellular language, medicine doctors can assist the cells of patients how to do their job. They may practice 'telling' cells in their own language what they need them to do. The propose of this article was to set down the causes and applications of CI.

Keywords

Artificial intelligence, Biocomputing, Biological intelligence, Cell intelligence, Organoid intelligence.

INTRODUCTION

Many operational definitions for intelligence are encountered in the literature depending on the context in which it is used. Intelligence is the capability for learning, understanding, critical thinking, reasoning, creativity, planning, problems solving, etc. [1]. Each cell is an intelligent system being able to live independently on its own. Cells listen to the environmental "broadcast" - receiving news from molecular messengers and signals. This signal incorporation system allows cells to sense, weigh and process enormous numbers of external and internal signals to make decisions on their own. Living cells sense and respond to alterations in external or internal environments. With no cognitive ability, they could not gain nutrition needed for growth, survive unavoidable ecological changes [2].

Cell intelligence is not restricted to one species and does not end at one cell type, or a specific cellular activity. Intelligence is a basic attribute of all cells on the planet. Even, the simplest and smallest cells have to modify their physiology and behavior to new conditions. Learning, defined as the adjustment of behavior by experience, is one of the key improvements in the evolution of life [3]. Intelligence has evolved in numerous taxa from bacteria to vertebrates and is prevalent in the marine environment [4].

Several fundamental kindled questions in cognitive science have been raised: What is the secret language of cells? If a cell doesn't have a brain, how could it still navigate its surroundings? How an independent brainless cell in nature has outstanding abilities to compose decisions and take fruitful action? How can a single-celled organism save memories - although it has no nervous system? Is having a memory of past events enough to enable an individual cell to take smarter decisions about the future? How can information gathered from dealings with the physical world be decoded in chemical/physical modifications in an organism, and how is it decoded as future? How cells sense and incorporate information from their environment variations during disease progression? Herein, we have provided models and reasons that give manifestations of CI such as division, specialization, communication, fission, fusion. These cellular-like processes allow scientists to get back mechanisms that happen during development such as cell migration, cell movement, cell differentiation and specialization, as well as compartmentalization and inter-cellular communication [5]. Such concepts often motivate current brain-inspired learning algorithms [6]. Living cells do not attempt to make guesses but, instead, use developmental processes in order for their brains to achieve an efficient wiring configuration [7]. While dearth of functional specialization can jeopardize survival, excessive specialization can also be a fatal end for living systems [8].

According to a theory on “Dynamics of Intelligence”, it is feared that artificial intelligence (AI) technology will keep on increasing, while CI will keep on decreasing [9]. In reality, this theory proposes that intelligence is transformed from one form (CI) into another form (AI). It goes without saying that learning and understanding cellular language will impact various scientific disciplines. Just to give an example, cancer cells can be 'told' to stop dividing or at least to 'convince' them to gather at a position where surgeons can easily eradicate them. Cells within an injured limb or organ may be 'told' to renew it. This review covers CI, the main areas of application. It concludes that essential improvements are needed to be addressed in order to confront the challenging question of reducing the gap between profound learning algorithms and brain-like cognition.

METHODS

While the literature is very rich in AI publication, it is poor in papers dealing with CI. Data were collected from different search engines such as google Scholar, PubMed, and ScienceDirect to acquire coverage of relevant literature. The key terms used for gathering fitting information were "Cellular Intelligence", "Cell Memory", "Natural Intelligence", "Human Intelligence", "Artificial Intelligence", and "Dynamics of Intelligence". The titles and abstracts of 200 documents were firstly screened to isolate those that were qualified for inclusion for full-text review. Based on the fact viruses are acellular structures, we believe that articles discussing and debating "intelligence of viruses" could be included under "Cellular Intelligence". Also excluded from this review all articles published in "None-English" language. Fifty-Nine documents excluded as duplicate documents and an additional 70 were excluded after the initial screening procedure. The remaining 71 documents were evaluated for inclusion in the review.

RESULTS AND DISCUSSION

Intelligent cell has a "box" which is able of gathering and integrating a range of physically different and unanticipated signals as the basis of problem-solving decisions. Learning in unicellular organisms has been explored largely in bacteria, ciliates and acellular slime moulds, and there are some reliable reports verifying learning in *Stentor* sp., *Paramecium* sp. *Tetrahymena* sp., and *Physarum* sp.

Intelligence of single celled procaryotic organisms

Chemical communication between microorganisms has long been described the literature. Later, many studies have discovered that cells are also sensitive to physical signals such as light, sounds, electrons or electromagnetic waves [4]. Signal incorporation system that allowed cells to sense, weigh and process enormous numbers of external and internal signals to make decisions on their own, describe their adaptive abilities within.

Prokaryotes show high-level of regulatory networks creating suitable adaptations to stress situations that maximize the chance of survival. They also exhibit remarkable capacities for intercellular signalling. Noncoding RNAs might be involved as a part to generate a specific bacterial behaviour by multiple gene regulation networks [10]. Although microbes are sensitive to certain antibiotics, they can quickly gain resistance against these antibiotics. The degree of adaptation has its genetic roots that could be noncoding RNA or illegible on the genome [10].

In the wild, most bacteria are very quiet exhibiting a limited range of behaviours in response to environmental deviations [11]. Bacteria use bioelectricity both to establish memories and for biocommunication [12]. Some bacteria swim across their environment as alone individuals. However, cells of most species of bacteria—favour living in condensed societies called "biofilms" affixed to surfaces. Biofilms are not simply compact accumulations of bacterial cells. The concept of "bacterial intelligence" includes complex adaptive behaviour displayed by single cells, and unselfish or collaborative populations of like or unlike cells interceded by chemical signalling that stimulates physiological or behavioural alterations in cells and affects colony structures [13]. Bacterial cell-to-cell chemical communication that depends on the production, detection and response to extracellular signalling molecules is a phenomenon known as "Quorum sensing; QS" [14]. It allows clusters of bacteria to synchronously change behaviour in response to variations in the population concentrations and species composition of the neighbouring community [14].

Quorum sensing (QS) is used by many bacteria to coordinate population density-dependent alterations in behaviour [12, 15]. Quorum sensing encompasses manufacturing of and response to diffusible or secreted signals, which can differ considerably across different types of bacteria. In many species, QS coordinates to modulate bacterial sociality and virulence functions interactions both within a species and among species. Furthermore, populations of bacteria use minimum sensing to judge their own concentrations and modify their behaviours accordingly [16].

It has been proposed that a bacterial colony loosely imitates a biological neural network. Some bacteria like myxobacteria or bacterial moulds (Figure. 1A) can show more behaviour as a population [16]. Biofilms of *Bacillus subtilis* or *Staphylococcus aureus* (Figure. 1B) may form on living (biotic) or non-living (abiotic) surfaces. Such biofilms communicate by using multiple forms of electric signals to coordinate growth so that the deepest cells of the biofilm do not starve [17]. Within the biofilm, the bacteria share the labour of preserving the colony and differentiate into structure specialized for their function. *Pseudomonas aeruginosa* biofilm (Figure. 1C) shows extracellular ground proteins secreted by bacteria as a scaffolding for their population. The deeply wrinkled exterior of the biofilm maximizes the region within which the bacteria can absorb oxygen [16]. Also, it probably helps them gather nutrients and discharge waste products efficiently. Both QS and biofilm formation play a role in the pathogenesis of the microorganisms and their acquisition of drug resistance [18].

Bacterial colonies can organize themselves in response to nutritional stress or under antibiotic stress. The coordinating bacterial cells specialize into diverse roles. Cells at the edge are highly exposed to risks and must reproduce ferociously to enlarge the biofilm. In addition, they also have contact with the most nutrients and oxygen. Cells on the inward rely on others for their critical supplies but they may survive longer. A huge grouping of microorganisms has the capacity to overcome being recognized by the immune system because they alter their surface antigens so that any guard mechanisms designed against previously found antigens are now ineffective with the newly formed ones.

Endogenous adaptive mutagenesis has been proposed as a possible mechanism by which bacterial colonies have evolved. It is as if a bacterium is predetermined to permit hypermutation in a select group of genes suitable for changing environmental conditions. Additionally, these hyper-mutations can be shared through plastid exchange and span quickly through the colony. Therefore, it can be appreciated that there is a resemblance of a memory-learning algorithm in bacterial colonies. A single bacterium does not learn much on its own. The algorithmic 'learning' of the collaborative efforts at the multi-generational level. It is not similar to animal learning that takes place inside of an organism and during its lifetime [20].

Intelligence of single celled eukaryotic organisms

During cellular evolution, further functions resulted in the more complicated and sophisticated cellular nanobrains of eukaryotic cells [21]. Some of the mind-like aspects of life might be solely mechanical origin. Single cell organisms possess no synapses make purposeful intelligent functions using their cytoskeletal microtubules [22]. Cell motility reveals its intelligence [23].

Plasma membrane and cortex are parallel to the 'skin' and the 'muscle' of a cell. In this model, bulk cytoplasm including mitochondria, other organelles and intermediate filaments are analogous to the "guts and inerds" of the cell body.

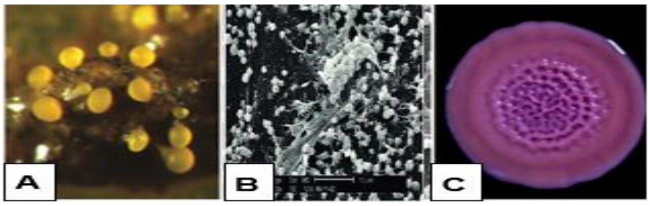

Figure. 1

The presence of "eye-like" structures in cells would imply the existence of a data processing system that would advocate calling cells intelligent. The cell skeleton is the decision maker, "where cellular consciousness resides". From the stand point of the 'intelligent cell' the centrosphere (centrioles and radial array of microtubules) is the 'brain' of the cell [4, 22, 23, 24]. The geometric characteristics of centrioles fits the best conserved features in nature. Centrioles are able to plot the course of light sources in a one-to-one pattern. Comparable to our bodies, it projects the 'eyes' in the form of two centrioles. It makes a lot of sense to imagine that if one centriole maps the 'longitude' of the source, the other, which is oriented perpendicular to the first, maps the 'latitude' of the source [23]. Similarly, its 'nerves' correspond to a display of microtubules which radiate away from the centre of the centrosome joining the centrosphere unbranchingly with the cellular 'musculature' found in the cortex. The situation is very similar of nerves joining the brain (centrosome) to a collection of muscles (microplasts). One more line of reasoning to support microtubules as worthy candidates for cellular 'nerves' arises from experiments that intervene with microtubules if microtubules assembly- inhibiting drugs, such as nocodazole, are added to the cell it is still able to move all parts of its body. However, in this procedure, the outstanding coordination of the characteristic shape changes is lost. Thus, it appears that the seen destabilization of the radial array of microtubules is the signal that is spread along the microtubules like along 'nerves'. A major objection against the claim that cells are able of detecting the light sources at a distance is that the infrared beam may heat up the medium as it traverses through. Another opposition may assert that the beam causes chemical fluctuations in the medium which set up a chemo-attractive gradient for the adjacent cells [23].

From the stand point of the 'intelligent cell' the nucleus represents the main bank. It encloses the blueprints and directions that have developed over one billion years of evolution. These instructions tell the cell how to work, how to reconstruct itself (involving its 'nerves' and 'brain') following every cell division. Also, it includes how the cell act and interact with other cells as they shape and preserve an organism [23].

Intelligence of unicellular protozoans

Protozoan ciliates, for instance *Paramecium caudatum*, although it seems to be unable to associate darkness with electric shocks, it is able of learning to associate intense light with incentive such as electric shocks in its swimming medium [25]. Further, *Tetrahymena* has the ability to 'memorize' the geometry of its swimming area. Cells that were removed and restricted in a droplet of water, recapitulated circular swimming courses upon release.

P. caudatum, another ciliate, can also be habituated and also learn to seepage a tube-web. There are signs that the protozoon can associate two types of stimuli. They can be 'taught' to associate electrical and vibration stimulation. Other forms of discriminatory learning can also happen [26]. In other words, this influence is a conditioned modification or operant habituation. Habituation is broadly considered to be one of the 'least' forms of learning.

Experiments reveal that some protozoa, for example the ciliate *Stentor coerulens*, can learn. If provoked by mechanical stimuli the ciliate defensively retracts. Experiments suggest that combinations of mechanoreceptor 'senses' offers the little protozoon the talent of learning simple tasks. The creature can learn the top escape route from a very simple maze – a thin tube.

The true slime mould *Physarum polycephalum* (Figure. 2) which belongs to the Amoebozoa phylum is located at the crossroads between the kingdoms of fungi, plants, and animals. This unique organism offers insight into the early evolutionary history of eukaryotes - to which also humans belong. Slime moulds manage to have different behaviours that are equivalent to those of animals who have muscles and nerves with ganglia – i . e. simple brains. They share amazing similarities with the system of synaptic links in animal brains [3].

Figure. 2

Researchers have found how *P. polycephalum* keeps memories- although it has no nervous system [27]. This slime mould entirely consists of interconnected tubes of varying diameters which grow and shrink in diameter in reaction to a nutrient source [28]. Further investigation. It has been demonstrated [28] that *P. Physarum* has an exceptional learning, communication and memory capabilities.

Also, *Phycomyces blakesleeanus* has been discovered to have striking ability to learn after-a-fashion. The fungus naturally goes after light. This is fundamentally their way of coming across open areas to liberate their spores. The sporangiophores of *Phycomyces* can develop habituation to light. That is, it can ‘learn’ to overlook or tone-down reactions to light stimuli that are recure too often [29]. Slime moulds are analogous to a bag of amoebae enclosed in a thin slime sheath. To some extent, biotic processes can be considered analogous to intelligence. *Physarum* is a massive single cell, with tens of thousands of nuclei suspended in an uninterrupted mass of protoplasm. This single amoeba-like cell may sweep several centimetres or even meters, acting as the largest cell on earth presented in the Guinness Book of World Records. In this shape, *Physarum* is a superbly competent hunter. Learning and memory have been detected in protoplasmic slime [30]. When detectors on its cell membrane sense good sources of nutrients, contractile networks of proteins (strongly related to those found in human muscle) start pumping creeks of cytoplasm in that direction, moving the slime mould toward what it wants [27].

To investigate decisions-guided memories, researchers joined microscopic observations of the adjustment of the tubular network of the mould with theoretical modelling. *P. polycephalum* is an ideal model system for linking basic cognitive functions to biological mechanisms [27]. Individual cells of cellular slime moulds collaborate to form complex structures or travel as multicellular entities. For example, *P. polycephalum* was found to be able of ‘calculating’ the shortest track to food [31]. When placed in a maze, where a food source at two portals of the maze is found. In attempt to solve simple puzzles, the slime mould was observed to spread out its slimy tendrils all over the maze. Though, when the food was located, the whole plasmodium condensed into a small of strands [31] demonstrated that this creature moves at a stable rate around one centimetre per hour at room temperature, but this differs with the moisture of its environment.

Curiously, this memory lasts in the mould for hours, even when the stimuli themselves stop. A single renewed stimulus after a 'silent' interval will leave the mould anticipating another to come in the rhythm it learned before [31]. Therefore, *P. polycephalum* has been described as an aneural organism because it uses information from earlier experiences to acclimatize its behaviour, but the mechanisms by which this is undertaken unknown [3].

In *Dictyostelium discoideum* was used as a model organism for the analysis of cooperative cell migration [32]. It was found that extracellular cyclic adenosine 3’,5’-monophosphate (cAMP) functions as a diffusible chemical guidance signal for cell clustering. This has been believed to be vital in multicellular morphogenesis. Investigation of the dynamics of cAMP-mediated signalling [32] revealed a switch from propagating waves to steady status during cell development. More recent studies on *D. discoideum* using a mathematical model coupling [33] showed that the internal biochemical kinetics has great repercussions from single cell motility to clustering, on, and even on the positioning behaviour. Slime moulds maximize cell growth compelled by nutrient and energy costs [33]. They exploit physically simulated fluid to ship nutrients and chemical-like signals to adapt to complicated, shifting environments [34].

A unicellular organism that lacks a brain shows rather complex quasi-intelligent behaviour. The cell contains a box which is able of collecting and integrating an array of physically diverse and unforeseeable signals as the basis of problem -solving decisions. To solve the Traveling Salesman Problem, a combinatorial test with exponentially increasing complexity, in linear time [35, 36], needs a computer to look at a list of cities and find out the shortest road, so that each city is visited just once (Fig 3). When more cities are added to the circuit, the problem gets more and more complex. Having four cities on the list, there are only three conceivable routes to select between. With eight cities, the job jumps up to 2,520 routes. In other words, it becomes exponentially difficult, and would take most systems a whole many more time to figure out the finest route. The optimization capacity is increasingly enhanced with the rise in the number of track points [36].

According to the devised amoeba-based computer (ABC) [37], the shortest optimal solution to the traveling salesman problem (TSP) is exemplified by the shape of the organism in which the nutrient absorption is maximized while the danger of being subjected to aversive light stimuli is minimized. The shortness of the TSP course found by ABC, therefore, acts as a quantitative measure of the decision-making ability of the organism. The exact mechanism by which an organism makes multi-objective decisions remains unclear [35]. These outcomes may lead to the advancement of a unique analogue computers enabling estimated solutions of complex optimization problems in linear time.

Intelligence of Multi Celled Eukaryotic Organisms

Intelligence of Plant Cells

Cognition and bioluminescence do not only operate in animals, but also in plants. Scientists realize that plants possess electrical and chemical signalling systems, may have memory, and display brainy behaviour in the absence of brains [38]. It has been reported [2] that Darwin denoted that the roots are the "brains" of a plant. Plants express various forms of CI, particularly in reaction to environmental stressors. Following attack by herbivores, the remnants of herbivores saliva left on the damaged plant leaves deliver a chemical signal to other cells in the same plant or even a neighbouring one, warning them to trigger defence mechanisms [39, 40]. For example, salicylic acid, which is one of the vital phytohormones for regulating plants' immune systems [41]. Plasmodesmata are protein channels connecting the cell walls of adjacent plant cells. They enable communication and the transfer of solutes and small proteins from one plant cells to another. Like any other living thing, plants comprehend and respond to touch, even painful touch. Plants are also able of habituation. For instance, the plant (*Mimosa pudica*) (Figure 4) is sensitive to touch [42]. If fingered, its compound leaves fold-up. This reaction protects the plant from grazing animals.

This type of response is surely a little bit similar to memory. The term 'plant smarts' has been coined by the Italian horticultural botanist Stefano Mancuso. According to Mancuso, plants in their pre-conditioned responses do appear to possess a sort of memory.

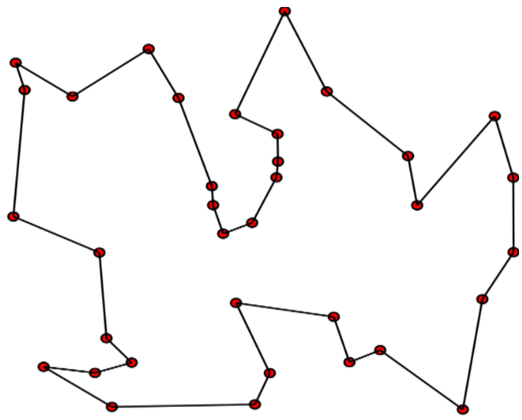

Figure. 3

Figure. 4

Moreover, the growing tips of roots or shoots act the same as 'command centres' for directing signals within a plant, signalling whether to promote or to slow other tissues. Besides chemical signals, electrical impulses are also employed in cell–to-cell messaging. Plants can apparently 'compute' solutions to contradictory physiological demands [21, 43]. The plants' 'Memory' can be even more bizarre. Some plants select which bud shall turn to be the dominant apex by outside signals. In the case of *Bidens pilosa* seedlings, vexing one cotyledon can initiate a lateral bud on the opposing side. Generally, this is most obvious when the leading bud is cut, and the laterals are consequently 'released', the bud on the other side of the irritation one becoming the new "boss". The liberation of the lateral bud can be delayed by postponing the removal of the growing tip. This stimulation of the cotyledon can be 'remembered' even after very extended delay [44]. Plant responses are reasonably comparable in their complication to the behaviours of 'lower' animals as sea-sponges and jellyfish. If the very similar behaviours appeared in animals, they would be thought of as examples of primitive cognition.

Intelligence of Animal Cells

In multicellular organisms, cells gather to form specialized parts that cooperate to execute specific functions. Having these functions carried out by specialized cells is more effective than crowding all of them into one giant cell. Cell–cell interactions (CCIs) are crucial for coordinating biological processes and functions [45]. The cell membrane is the means by which the body pass information and converts environmental signals into behaviour. Cell receptors act as "nano-antennae" that are tuned to respond to every environmental signal (Figure. 5). These signals include specific environmental changes for instance vibrsaional, light, and sound energy fields, to mention some examples. Some receptors protrude inward oversee internal situation of the cell environment. Other receptors extend outword to observe external signals.

In a sense, receptots are equivalent to sensory nerves, while effector proteins represent the response to the resptor signals, i.e. they are equivalent to action generating motor nerves. In this regard, receptor/effector complex acts as an off/on button that translates environmental signals into cellular behavior. It is estimated that about 100,000s of such switchs in a sigle cell membrane.

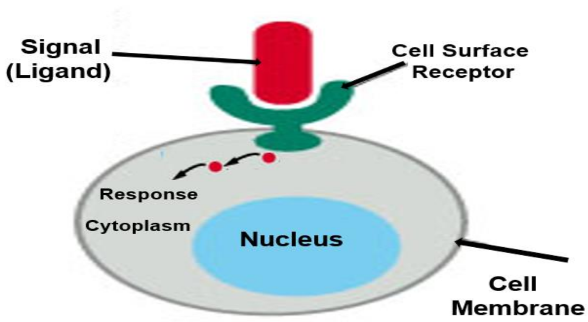

Figure. 5

Active nematic behaviour is amazingly potent model of many living systems, e.g., cytoskeletal filaments. During cellular migration, the motility of the individual cells seems to be highly synchronized with each other. When groups of cells move, some of them appear in a single leading edge of the group, while others present their bodies in the tail of the path. This action represents looks like very much the division of labour among partners of the group. It seems that they have motivated each other motility regulator systems [46]. They appear to coordinate their shape modifications in such a way that the entire group migrates directionally, Thus, the movements control systems seem to be able to inform each other about shape changes, direction and timing.

In brief, leading front ruffles while the trailing end retracts (Figure. 6). Since the directionality of motility reacts to obstacles and other unexpected events in the track of a moving cell, this great level of control appears 'intelligent' (that is, signal coordination and decision-making).

In analysing the motile behaviour of cells, one discovers the possibility that they may be able to detect things across a distance of diameter of one cell or more, as if they could observe them. This observation and several other similar ones raise the assumption that cells secrete and sense each other by certain 'recognition' molecules. However, it is difficult to comprehend how cells are capable of finding the source with such confidence regardless of the cell type. Although no chemical materials are secreted from crossings between guiding routes, the cells diagnose their arrival at such an intersection and begin to probe the optional tracks of the guiding 'roads' as if they possess a 'global image' of different dimensions of their environment.

Computational Allegory for Life

Prior to the introduction of AI, every living organism is known to be intelligent. Cellular behaviours may be genetically programmed into these cells by billions of years of evolution, however in that sense the cells are not so distinctive from robots programmed to respond in refined ways to their environment. The fact that cellular networks are similar to programs to certain extent was not in doubt. The abovementioned examples: Quorum Sensing in Bacteria, Slime Mould Behaviour, Plant Communication, and Neural Networks highlight the distinguished abilities of cells to interconnect, analyse information, make decisions, and show complex behaviours [23, 47].

Micro-phenomenology is a recent scientific field that enables us to search man lived experience very finely [23]. A computer can hold information in its memory and retrieve it quickly enough when the situation demands. The computer can do this a whole lot more effectively than us humans can ever dream of. The main branches include Machine Learning, Computer Vision, Natural Language Processing, Artificial Neural Networks, Robotics, Expert Systems and software improvement tools [48]. Although is not possible to count the precise number of all AI, a tentative number of 10X10 has been suggested in the year 2021 [9]. Artificial Intelligence assisted machines have affected the multidimentional life of every organism including humans. The cell as organism concerns above all. Indeed, AI displayed by several types of machines are discrete related to natural intelligence between living organisms including humans.

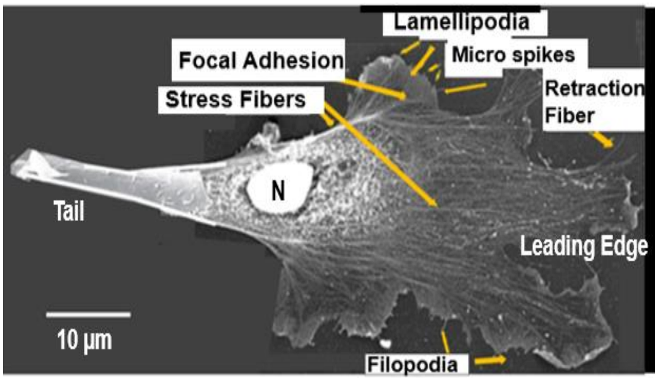

Figure. 6

Applications of Cell Intelligence

Understanding CI has the potential to inspire new advances in fields such as bioengineering, robotics, and AI. It is anticipated that different AI models and optimization algorithms (OA) will be are broadly used in various fields of technology and science. Herein two fields are discussed.

Applications in Agriculture

Micropredators that live in soil, including social predatory bacteria, possess complex interaction adaptive behaviours and metabolisms [49]. Soil biodiversity, accomplished in part by these micropredators, is of importance for carbon cycling and ecosystem functioning [49].

Bioaugmentation has been proposed as a method to enhance the 'intelligence' of microbial communities. This includes adding the genomes of autotrophic, carbon-fixing or nitrogen-fixing bacteria to their metagenome [49].

Appreciation of plant behaviour and intelligence is now one of the most thrilling and fast-moving frontiers in plant biology world. Plant intelligence in a quickly shifting and application of plant-plant communications in controlled plant systems. This can be useful to the employment of crops so that a balanced and durable agroecosystem can be reached [50]. It is well acknowledged that plants can be preconditioned or acclimatized. For instance, seeds can be solidified by exposure to cold, and come to be more tolerant of cold-periods than are seeds not so pre-habituated. Principally, when a plant reacts to a stimulus, the response can become faster during recurrence stimulations. Plants adaptively respond in numerous ways, including osmotic fine-tuning to calcium levels and by protein syntheses. Either cold or drought stress will enhance the expression of stress proteins. The physical adjustments fashioned by the stress can remain around following an initial stimulus. This lingering action preconditions the plant for additional stresses

e-ISSN: 2582-7405

Organoids, which are laboratory created tiny organs from stem cells have been combined with AI technology in what so called "Organoid artificial intelligence, OAI". An organoid is an artificially grown bulk of cells or tissue that looks like an organ. The efficacy of the application of AI-OA has been confirmed in vitro in the forecasting and optimization of length and number of microshoots or roots, biomass as well as optimization of environment to achieve maximum productivity and efficiency [51]. Further, these tools will be utilized in the entire food production ecosystem beginning with improvement agricultural productivity and ending with management of food distribution and food consumption to ensure food security [48, 52-53]. Machine learning can identify "genes of importance" that aid crops to grow with fewer fertilizer. It can also forecast extra traits in plants and disease conclusions in animals [54-55]. Figure. (7) depicts the potential positive applications of AI in various agricultural fields

Applications in medicine

Although AI offers great potential in the medical field, it is still in its infancy [66]. Dialogue among cells is very important aspect, but the detailed symbolic cellular language is not understandable to the general scientist. It is suggested that all cells speak the same language [56-57]. Microbes can affect human cells by interrupting or changing talks among human cells that are essential for health. Cell reprogramming is gaining a fertile background and garnering significant attention of health care organizations including therapy and pharmaceutical sciences. When considering health and disease, it is important for scientists to identify and understand the discussions among neurons, blood cells, the cells lining of organs, immunocytes, and the microbes which occur dostantly from the organ in question. Deep understanding of these essues will no doube help in understanding physiology of our body and discovering novel treatments.

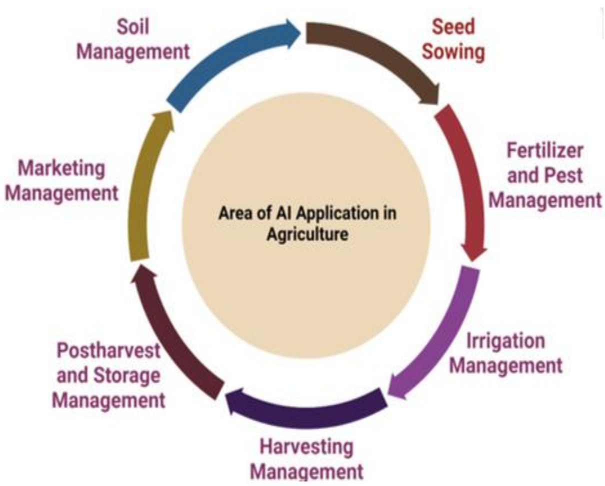

Figure. 7

With the expanding drug resistance against the existing antibiotics and antifungal medications, researchers are combining different selections to develop new strategies. These strategies depend on the use of antiquorum sensing compounds, thereby, disrupting the communication and virulence factors instead of killing or preventing the growth of the microorganisms [58]. One of the applications of AI in the pharmaceutical manufacturing is "Open Targets". This is a relatively new strategic attempt to survey the relationship between drug targets and diseases, as well as how some genes are linked to diseases [59]. In particular, superlative prospective in drug discovery, de novo drug design, and, preclinical development. CI-founded tactics serve to generate critical knowledge on molecular mechanisms relevant to diseases as well as drug action, targeting at prompt goal innovations in biopharmaceutical industries.

When it comes to cancers, the new revolutionary science of cellular dialogs has changed our opinion about cancer. It has been postulated that cancers are really intelligent colonies, where individual cells interconnect with each other to act as an organized group just as microbe populations do. Progress in DNA nanoengineering vow the development of modern computing devices in biological systems, with clinical deployment in nanoscale sensing, classification, diagnostics and therapeutics [60]. Diverse AI methods including least square support vector machine (LS-SVM) have been used for recognition and differentiation of cancer cells from normal heathy cells [61].

Artificial Intelligence-based algorithms hold large potential to pave the way to detect these genetic mutations and abnormal protein interactions at a very initial stage [62]. Researchers may possibly use AI in DNA, RNA and protein studies to better picture the outcomes of drug doses on living tissue over time and identify signaling systems during therapy [63]. DNA has been a specifically promising candidate for building molecular machines, because DNA molecules can be easily synthesized and changed to get particular functions and self-assembling characteristics.

With the advent of single-cell technologies, a huge quantity of single-cell RNA sequencing (scRNA-Seq) data has become largely available [44, 64, 65]. scRNA-seq Datasets on human testicular cells and the tumour immune microenvironment demonstrated the trustworthy and unique functionality of CellCall in intercellular communication examination and internal TF activity exploration [65].

More recently, convolutional neural networks have been applied in vitro using DNA strand-displacement circuits [66]. These circuits have been utilized to perform classification tasks. Unfortunately, categorizing breast cancer from cellular images has not been accomplished yet. They inverse about defense in oppostion to immune cells, microbes, and anti-cancer treatments and send molecules or even changed mitochondria to each other to help. It is similar to bacteria sharing genes that assist the colony fight against antibiotics.

The field of OAI mesmerizes dreames of science-fiction illusion but also energizes scientists to consider the scientific reality. Thev OAI outcomes will enable researchers to assess the efficacy of planned medications or treatments on an organoid tailored to a particular patient. In addition, unusual diseases and genetic complications that are challenging to mimic in animal models can be investigated [67]. An exciting

Figure. 8

development in this area is the systems of brain organoids (Figure. 8) that have been described recently [68]. Brain organoids are an ideal model that signify an important model for examining how environmental factors disturb constituents of neuronal function, including cognition and memory [69]. These fields are aiming at production of more intricate and exact models of human tissues and disorders. Insights into the progression and operation of human organs, as well as the mechanisms underlying many diseases, can be gained by using AI algorithms to analyze the data generated by organoid studies [70, 71].

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