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Collective Intelligence of Honey Bees for Energy and Sustainability

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Abstract. From the very beginning the most promising AI methods are inspired by human environment and nature. Especially, collective intelligence of non-human societies can surprised researchers and developers of new solutions. It is matter of specific abilities of particular species oriented on cooperation but moreover awareness of precisely defined goals and resources used in very optimal ways. For example we may admire methods of building cells by honey bee society and organizing of their works; therefore for example problems of tasks planning or optimization of collection of pollen by bees are being solved through certain sort of common intuition and collective intelligence. Proposed Bees algorithm (as an example of swarm algorithms) has been applied in continuous domains (optimization of neural networks) or combinatorial ones (scheduling jobs for a machine). The goal of this paper is presentation of collective intelligence useful in relatively new directions: energy acquisition and selected processes assuring sustainable development. Both directions seems to be very innovative and promising – especially in the ecosystems context.

Keywords: Collective intelligence * honey bees society * energy * sustainability * bee algorithms.

1 Introduction

For ordinary people honey bee colonies are useful insects producing honey and wax. In reality, honey bees play very important role in the nature delivering services in broadly understood ecosystem. Their activeness and products cover three main areas: *regulating, provisioning and cultural* – it is presented in Fig. 1. The provisioning services are essential for short- and long-term be society surviving while two other (regulating and culture) are closely related to the surroundings of apiary.

Regulating functions connected with pollination and biodiversity are strictly connected with interactions typical for complex ecological systems. Pollination is a process of transporting pollens among plants and therefore is inevitable for its reproduction in the vegetable world. This process depends on the symbiotic relationship between pollinator and pollinated plants and honey bees can be recognised as the major pollinator workhorse and the same are essential components of terrestrial ecosystem.

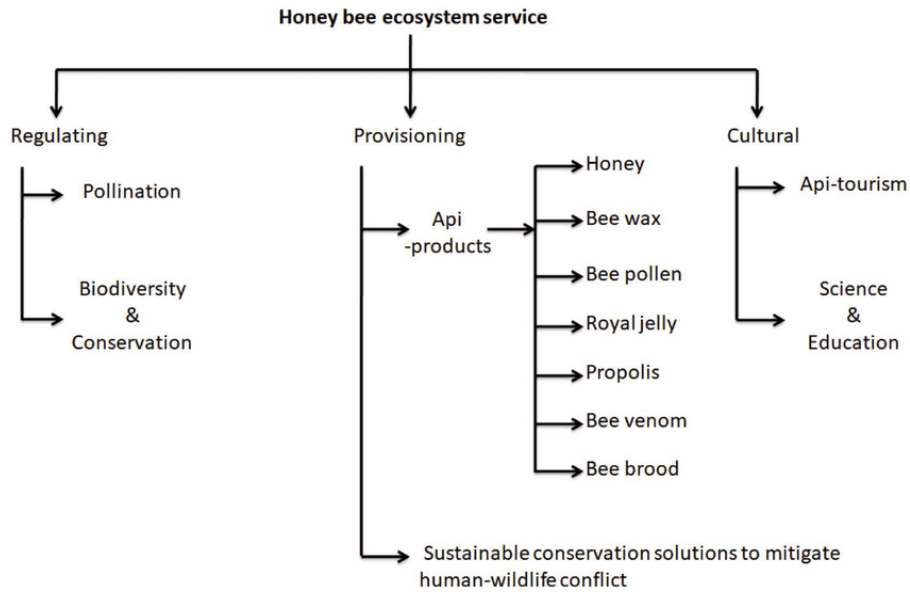


Fig. 1. Ecosystem Services of Honey Bees
Source: [2]

Bees are the most famous for their **provisioning** function. The product of beehive which is identified with their activities is honey. This product is a result of collection nectar by honey bees and further transformation involving their digestion system using enzymes. The total production of honey is systematically growing despite of real obstacles in bee-keeping mostly coming from human side: pollution, use pesticides and the like. The same tendency can be observed in wax production (see Fig.2).

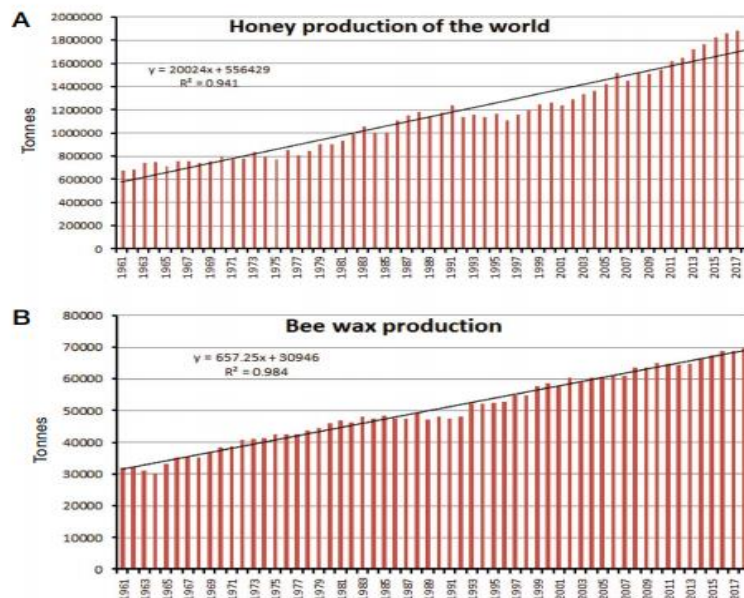


Fig. 2. World honey and wax production
Source: [24]

The third significant for people product is *propolis*. This extraordinary substance consisting of hundreds ingredients honey bees colonies use to seal the hive; very important property of propolis is antibacterial feature useful in medicine. The other api products are essential for bee colonies – people very rarely can utilize them.

The last itemized function defined as **cultural** is connected with impact and interaction apiary on environment; tourism managed around honey bees societies and generally speaking gathering knowledge about live and behaviour of the presented colonies create conditions for development of apiary sector.

As we discussed earlier, all the mentioned functions constitute the services in this specific ecosystem also in terms of sustainability and conservation determining progress of our civilization. Bees are symbols of diligence and sacrifice for common colony and their care for the welfare of the hive are appreciated in the proverbs of various nations for example:

The mystery and the willing of applying some natural habits of honey bee colonies prompted many researchers to investigation of bee societies live. All these research directions can be diversified in the following way.

Firstly, an essence and different aspects of their social live were defined as an important topic of investigation; such problems like communication among bees, cooperation typical for all phases in their life and common decision taking gather scientists from many areas. This kind of research creates opportunity for considering interdisciplinary aspects of honey bees society functioning. Therefore **collective intelligence** of honey bees is critical in these research.

Secondly, big activities and diligence of honey bees can be investigated in the **energy context**. There are at least two orientations in this area. During performing many tasks inside and out of the hive honey bees must rational use their energetic resources. It can be also (at least potentially) possible to use their mobility to transform it to useful for people energy.

Thirdly, honey bee colonies can be analysed from the point of their abilities to survive. The history of honey bees societies reaches over hundreds million years so these colonies elaborated special mechanisms assuring **sustainable development** of their civilization.

All these directions of research will be discussed in the next sections.

2 Honey bee intelligence

One of most fascinating phenomena in our world is behavior of animal societies especially working together for their own welfare. It is possible as a result of their developed brain and abilities to cooperate in colonies. Honey bees' brains is relatively small (comparable to sesame seed) but with more neurons than insects of similar size with greater brain density (ten times denser than the brains of mammals). Their sophisticated sensory system gives them excellent sight including keen smell, taste, and touch. In addition, their brains appear to have neuroplasticity with capabilities of learning, adapting and performing the same functions.

Honey bees are **smart** – there are many observations and experiments confirming their learning and memory capabilities – see: [25]; for example they can:

- identify and remember colors and landmarks,
- distinguish among different landscapes, types of flowers, shapes, and patterns,
- remember route details up to six miles over several days,
- conceptualize a map, determine the shortest distance between two points, and take a different route for their outbound and inbound journeys,
- navigate even in the dark.

Members of honey bee society are able to take on many **different roles in their lifetime**, each requiring different skills. The youngest bees are nurse bees, tending to the brood (the pupa or larva stage). Later they make the honey combs, forming perfect hexagonal shapes. Lastly, they become foragers, finding honey and bringing it back to the hive. It is worth to stress their abilities to

distinguish harmful fungi from harmless ones. They can prepare medication (mentioned earlier propolis) after discovering harmful fungi.

The most crucial ability of intelligent objects is **ability to think** – so how it looks in case of bee colonies? Experiments and observations show that honey bees do indeed have the ability to think. As it was announced - they have an ability to learn many new things very quickly (compared to other insects, they have a much greater ability to learn and remember). They are capable of abstract thought, decision-making, and planning. They also show an ability to count and an understanding of time. The foragers have to perform many tasks that require intelligence - they must find flowers, figure out if they are a good source of nectar, find their way back to the hive, and then share this information with the other foragers. They do not use tools in nature, but they can be taught to use tools. They may be capable of cultural transmission. Experiments have shown that when one bee was taught to pull a string to get a sugary reward, another bee learned the trick just by watching the first bee. Even more surprising, they could teach this trick to other bees - see: [25] .

Very significant ability which assure cooperation among honey bee society members is **communication**. Research on bee language was conducted by the Nobel Prize-winning biologist Karl von Frisch (see [8]). They have a sophisticated communication system using a symbolic language. This system is not found in any other animal. They communicate using “body language” and “dance.” When a honey bee finds a good source of nectar, she will return to the hive and tell the other bees where to find it by doing a dance to communicate both the location and quality of the source. Bees apply two sorts of dance in order to communicate food source and direction of where it can be found.

The simplest dance is the “round dance.” The bee dances around in a circle. The same the bee tells the others that the food source is very close. Other workers can go out immediately and just sniff around to find it; they know what to sniff for because they can smell the odor on the forager’s body or because she has given them a little tast. Details of this dance are presented in Fig. 3.

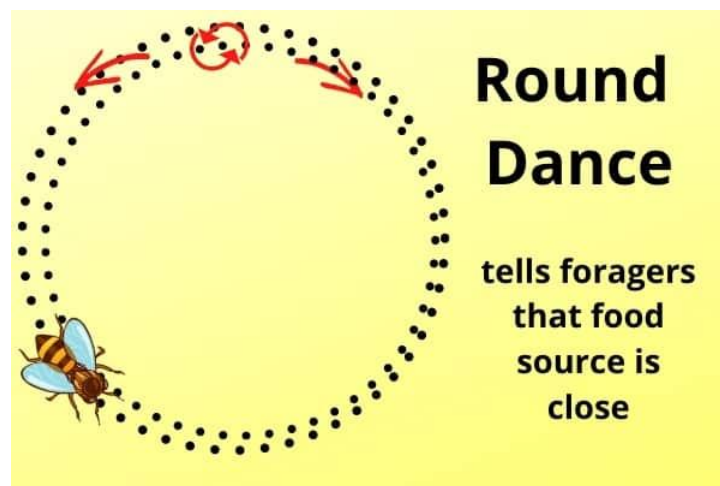


Fig. 3. The round dance of honey bees

Source: [21]

If the nectar source is further away, the forager does a “waggle dance” – presented in Fig. 4. The bee begins by walking in a straight line to indicate the direction of the food source relative to the sun. She then dances to create an angle which indicates the precise location of the food source relative to the sun. She waggles her body as she does this; the number of waggles indicate the distance to food.

Imagine a line connecting the hive and the food source, and another line connecting the hive to the spot on the horizon just beneath the sun. The

angle formed by those two lines indicates the location of the food source relative to the sun.

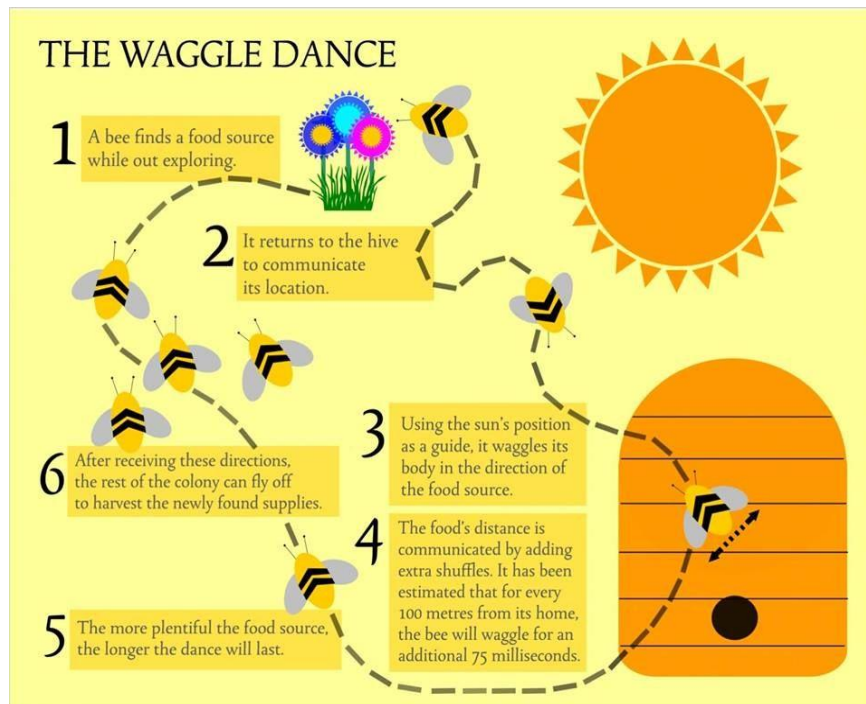


Fig. 4. The waggle dance of honey bees

Source: [22]

The bee adjusts the angle of her dance to account for the fact that the sun is always moving across the sky. The forager takes this into account and changes the angle of her dance every four minutes by one degree to the west.

Finally, the time she takes doing the dance indicates the strength of the headwind. This tells the other bees how much honey they need to eat to have enough energy for the trip. There are some differences in defining distance to the food source by particular species of bees; for example changing to the tail at about 40 meters for Italian and Caucasian bees. It also interesting that this changes at about 90 meters for Corniolan bees. Therefore we may say about dialects in the bee language.

It is curious additional feature of bees confirming their collective intelligence, namely *decision making process* – compare [28]. Foraging requires no central decision making. Each bee knows only about her own nectar source. If the nectar source is poor, she will quickly abandon it and will not do a waggle dance to direct her hive mates to it. Instead, she will watch the waggle dance of another bee who has found a good source of nectar and turn her foraging efforts to that source. On the other hand, if her source is good, she will work that source consistently and recruit other bees to join her.

Each individual bee makes her own individual cost-benefit analysis, which affects whether or not she will abandon a source or recruit other bees to it. If she abandons her source, she will follow another bee at random; she does not compare sources. Since only bees with good sources are recruiting, the bee who has abandoned her source will almost certainly move to a better source. The result is that the entire hive has optimized foraging-- the decisions of thousands of individual bees lead to optimal collection of food resources.

The value of a nectar source is not based only on the sugar content of the source—it appears that distance from the hive, weather conditions, the hive's nutritional status, the depletion of the source, and other pertinent factors

are all involved.

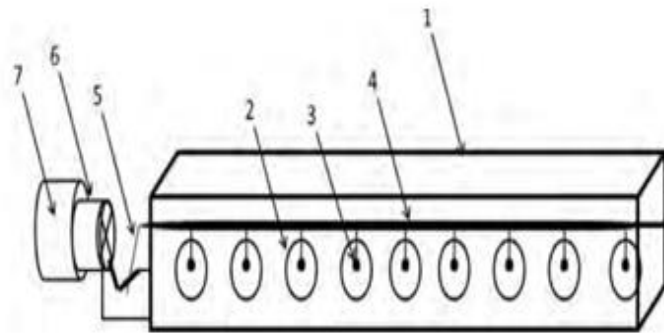
Honeybees make decisions collectively and democratically. Every year, faced with the life-or-death problem of choosing and traveling to a new home, honeybees stake everything on a process that includes collective fact-finding, vigorous debate, and consensus building. In fact, as world-renowned animal behaviorist Thomas Seeley reveals, these incredible insects have much to teach us when it comes to collective wisdom and effective decision making. A remarkable and richly illustrated account of scientific discovery, *Honeybee Democracy* brings together, for the first time, decades of Seeley's pioneering research to tell the amazing story of house hunting and democratic debate among the honeybees before flying swarm [17].

All these presented properties and capabilities confirm **collective intelligence** of honey bee colonies. They are able to discover new food source, compare results of searching, communicate essential information and make decisions collectively. Interesting facts about honey bee society are presented in [29] referring to their history, behaviour, and impacts on human traditions.

3 Honey bee and energy

The next defined challenge relates to searching new sources of energy. We are looking for a method to produce clean and cheap energy from the nature but also farm animals [12] and other form of human activities should be considered.

The original proposal of acquiring energy from honey bees hives was presented by H.F. Abou-Shaara see: [1]. According to his concept it is possible to apply the kinetic energy of honey bee mobility to produce electricity. The main component of this idea is placement of special devices on the paths of bee workers inside or outside of the hive. This device working outside of hives is presented with explanation how it works in Fig.5.

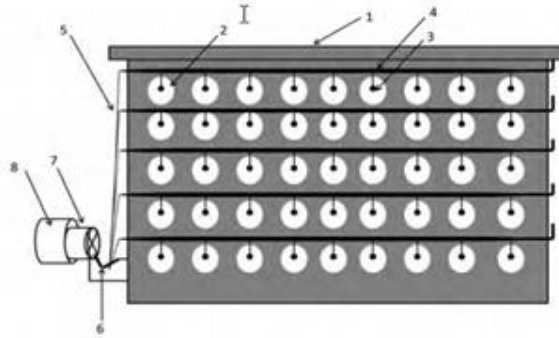


Parts of the external device working outside the hives. This device is a box (1) with dimensions (5x5x40 cm, HxLxW), this box is placed in front of the hive and contains holes (2) with a diameter of 7 mm per each, the bees can pass from these holes to push a small transparent ball (3) moving the tube (4), and then the arm (5) push the fan (6) to generate electricity from the dynamo (7). This dynamo can be used to charge batteries, and these batteries can be further used to operate various devices.

Fig. 5. External device of the hive

Source [1]

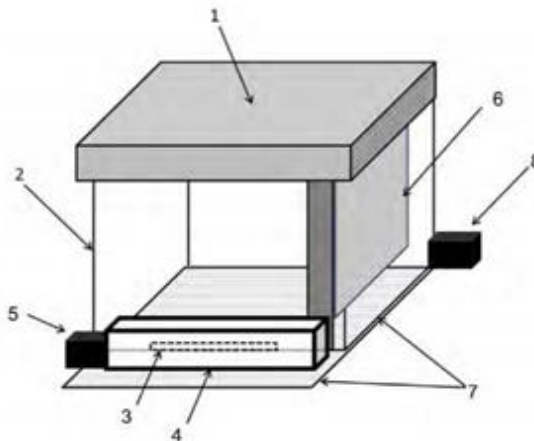
The next possible place of honey bees movement is the interior of the hive (especially workers in early stages of their live). They are employed to perform different actions connected with feeding larvae, producing wax, cleaning the hive etc. Similarly to the previous content of the device through pushing a small transparent ball is possible to generate electricity from the installed dynamo. Details of this solution is demonstrated in Fig. 6.



Parts of the internal device working inside the hives. This device contains the carrier frame (1) (with dimensions of 25x 42 cm Lx W) which contains holes (2) with diameter of 7 mm, and the bees can pass through these holes to push small balls (3), hence moving the horizontal tube (4), and moving part (5) which connects to an arm (6) to move the fan (7) to generate electricity by the dynamo (8). This dynamo can be used to charge batteries, and these batteries can be further used to operate various devices.

Fig. 6. Internal device of the hive
Source [1]

It is also possible to place separate improved devices (as a board of many tubes with balls) in different places inside and outside of the hive and connect partial outputs. This concept is showed in Fig. 7 – such combined solution should generate more power.



The positions of the devices in relation to the hive. The hive consists of upper cover (1), a box (2) and hive entrance (3). The external device (4) is placed in front of the entrance (3) to utilize the movements of the forager bees when entering or leaving the hive, while the fan and the dynamo (5) are placed beside the device. The internal device (6) is placed inside the hive beside the hive frames to utilize the movements of the bees inside the hive to generate electricity, while the fan and the dynamo (8) is placed outside the hive. The third device (7) is placed under the hive box while the fan and the dynamo (8) are placed outside the hive. The third device utilizes the movements of the bees inside and outside the hives because this device covers the hive bottom and the front part of the hive.

Fig. 7. Potential placement devices in the hive
Source [1]

The presented concept can be used close to existing apiaries. These devices are not expected to cause harmful impacts on the colonies or disturb daily (outside of the hive) or 24 hours (inside of the hive) of bee activities. The main challenges of the proposed concept can be defined as follows:

- the solution is addressed to beekeepers to help in their work; any transmission of electricity to far located users should be considered including additional costs, see [9],
- implementation of this idea is strongly connected with number of hives in the apiary; it is rather recommended for bigger farms,
- the area of application the described devices is limited to

- isolated regions as additional option to obtain electricity.
- additional research on balancing energy of honey bee society in the hive is welcome.

Anyway this investigation create opportunity for a discussion on development devices or similar mechanisms based on kinetic energy. It still open consideration about other forms of obtaining energy from insects. Unfortunately, in this case collective intelligence of honey bees has no special meaning but their ability to tolerate something new and tendency to survive in the new conditions confirm adaptation features typical for smart societies. Considering bee colony activities (especially flying swarm) and selection of routes some – they are evidences confirming their orientation on energy lines (see [26] and [27]). One yet another connection between honey bees and flowers: the “electric” signals from flowers can attract foragers – see: [30]

4 Honey bee and sustainability

Keens of honey bees admire the role of their colonies in the nature (mentioned earlier importance of vegetable pollination) and their long history – there are some evidence their presence over 130 million year ago [23]. Thanks to their sense of responsibility for bee existence confirmed during their long history and ability to survive this society cane useful in modern time; brother Adam said: “Listen to the bees and let them guide you”. Accordingly to his saying scientists elaborated bee algorithms based on behaving of foragers during vegetable pollination.

Honey bee algorithms belong to swarm intelligence algorithms in the group of insect based. The idea of the basic version of this algorithm mimics the foraging strategy of honey bees to look for the best solution to an optimisation problem. Each candidate solution is thought of as a food source (flower), and a population (colony) of n agents (bees) is used to search the solution space. Each time an artificial bee visits a flower (lands on a solution), it evaluates its profitability (fitness). Discussion on theoretical aspects, improvements and application of the bees algorithm is presented in [10].

The bees algorithm consists of an initialisation procedure and a main search cycle which is iterated for a given number T of times, or until a solution of acceptable fitness is found. Each search cycle is composed of the separate procedures. The list of steps typical for a simple bee algorithm is presented in Fig. 8.

1. Initialise population with random solutions.
2. Evaluate fitness of the population.
3. While (stopping criteria not met) //Forming new population.
4. Select elite bees.
5. Select sites for neighbourhood search.
6. Recruit bees around selected sites and evaluate fitness.
7. Select the fittest bee from each site.
8. Assign remaining bees to search randomly and evaluate their fitness.
9. End While

Fig. 8. Pseudo code of the bee algorithm
Source: [16]

Initialisation of the algorithm relies on defining a set of parameters like: number of scout bees (playing this following more experienced workers) and number of elite bees (discovering new sources of nectar, water etc.), number of selected regions, number of recruited bees around the regions and stopping criteria.

General idea of this algorithm looks similarly to evolution algorithms (a cycle and certain actions changing population with a defined criteria of fitness evaluation). The main difference refers to inclusion of discovered sources and communication about it to other workers (waggle dance) and applying two kind of searching: local and global. An example of such algorithm used for automatic design of control system for robot manipulators is presented in Fig. 9.

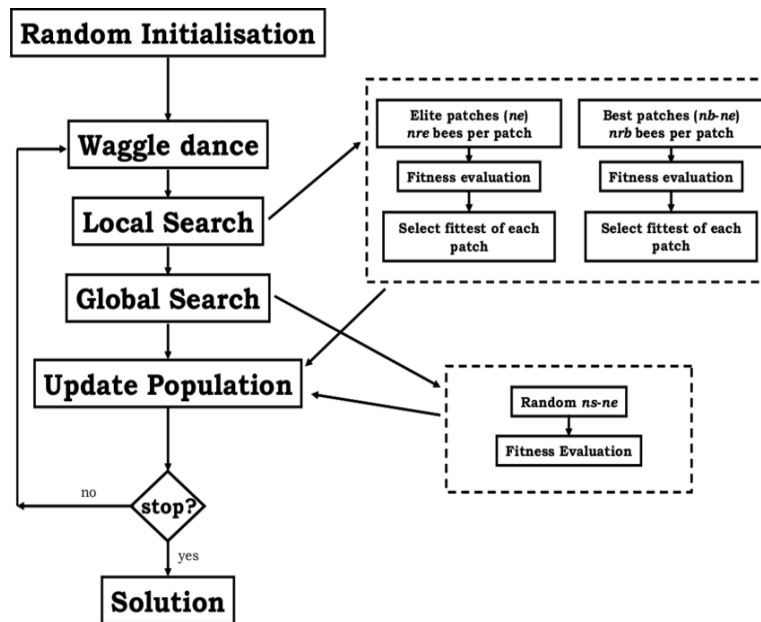


Fig. 9. Flowchart of the bee algorithm.
Source [7]

There are several areas of successful implementation of bee algorithms – power systems seems to be very ambitious challenge for different phases of supporting this industry. Very often the discussed algorithm can be connected with additional methods. Such approach is presented in [3] where Authors decided to include machine learning and neural networks to reactive power optimization. Details are demonstrated in Fig. 10. As previously two sorts of “objects” are employed: workers and scouts both with the defined goal as searching nectar source. According to earlier assumptions workers are oriented on local search while scouts following earlier defined strategies are allocated to global search. The algorithm is based also on knowledge learning through defined Q-value matrix where particular actions are evaluated (reward function) finally generating optimised model useful in Large-Scale Power Systems.

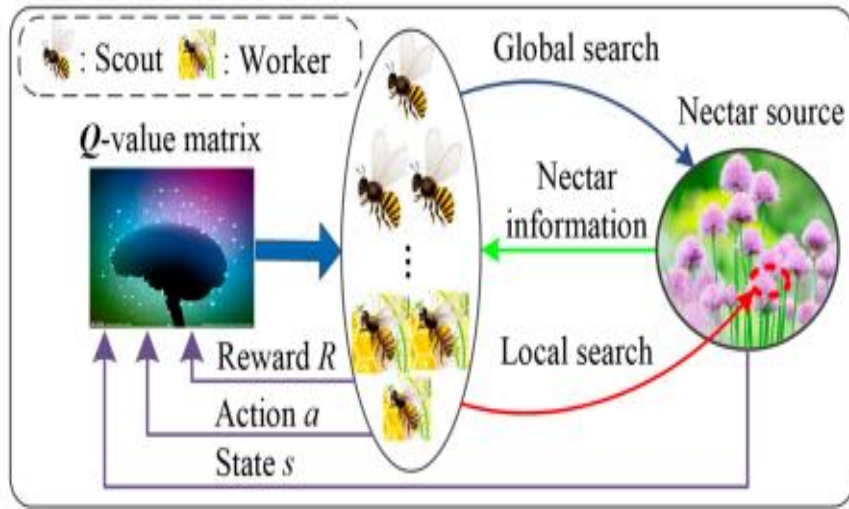


Fig. 10. The concept of bee algorithm for optimization in Power Systems
Source [3]

Additional examples of utilising bee algorithms in the power industry can be found in: [16], [11] and [6]. Different aspects in research of the discovered problem confirm flexibility of these algorithms.

The presented instances of bee algorithms implementation are focused on power industry but there are many others sectors where different variants of bee algorithms have been successfully applied. More synthetic view on the discussed algorithms is showed in Fig. 11.

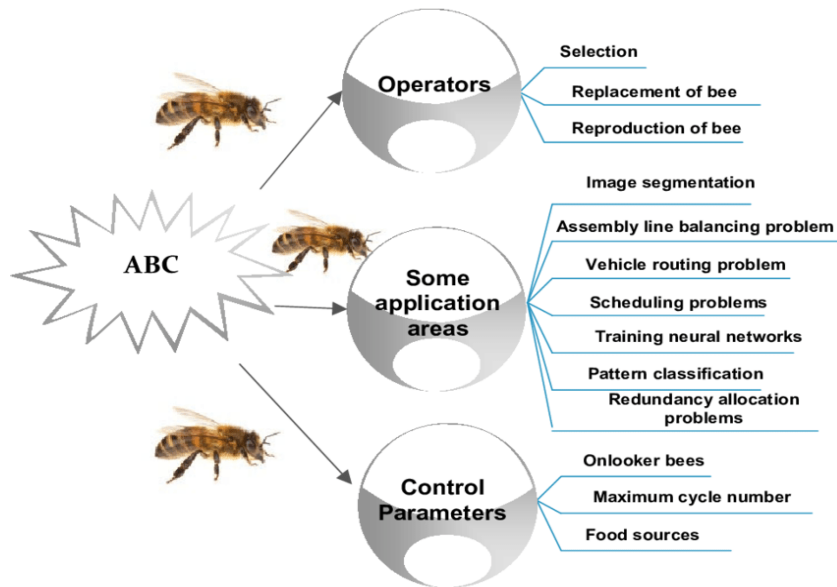


Fig. 11. Artificial Bee Colony (ABC) algorithm
Source [4]

First, *typical areas* where ABC algorithm can be useful; the range of potential application is very wide: starting from supporting computer graphics (image segmentation) through learning tasks (training neural networks) and allocation problems (scheduling and redundancy) up to classification (patterns).

Second, basic *control parameters* essential in experiments are stressed. Apart of number of onlooker bees, food sources and limits in cycles can be determined.

Third, standard *operators* are stressed. The most adequate in ABC algorithm are: selection of bees, replacement some of them and reproduction.

Summing up, applications and variants of bee algorithms (additionally: BeeHive, Bee Colony Optimization, Bee Swarm Optimization, Virtual Bee Algorithm, Marriage Bee Optimization) create opportunities for applying them in different sectors, not only for optimization purposes. This means real impact on sustainable development and stability of systems (compare to [16]).

The problem of meaning bees for achieving sustainable development is discussed in [13]. Main dimensions of supporting SDGs (Sustainable Development Goals) are depicted in Fig. 12.

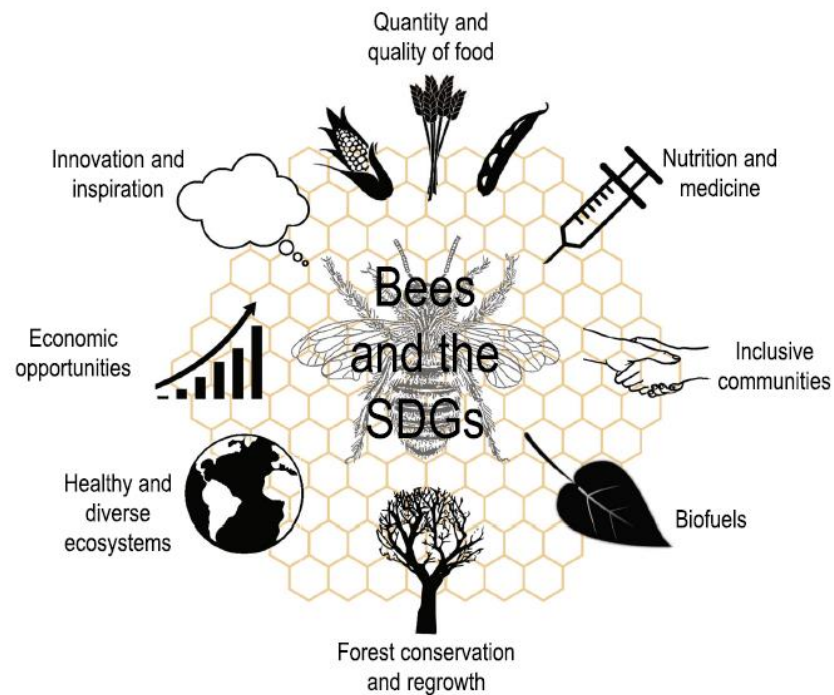


Fig. 12 Bee Colonies and SDGs

Source: [13]

Findings of the Authors in [13] can be formulated as follows:

“ A holistic view of ecosystems including wild and managed bees and humans is necessary to address sustainability challenges. By employing a system approach, we can better understand the interconnections between elements within coupled human–environment systems. We strongly advocate the need for appropriate natural resource management approaches for maintaining sustainable systems as vital for allowing the continued success of bees in their natural role.

We summarise our findings by suggesting eight key thematic priority areas whereby bees can play a crucial role in meeting the SDGs.”

5 Conclusions

Nowadays, people more or less are engaged in saving our world. One of the most important problems is ensuring a balance in nature. The role of honey bees in this process is very significant. Final conclusions are:

1. Honey bee intelligence considered as collective intelligence is crucial in adaptation for changing conditions of colonies life.
2. Ecological aspects of honey bee life are extremely important for their survive but also for keeping a balance in nature.
3. Original approaches referring to looking for alternative sources of energy embrace honey bee society; the presented devices can be useful in supporting in very limited range bee-keepers.
4. Honey bee intelligence was inspiration for the new swarm algorithm. Implementation of different bee algorithms in different areas confirms their universal and flexible character.

Further research can be devoted for presentation experiments and making different types of decisions based on collective intelligence and bees democracy following G.B. Shaw sentence: “Go to the bee, thou poet: consider her ways and be wise” quoting from [17].

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