THE BEAUTY OF NATURE INSPIRED COMPUTATION

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Melody Lee was selected as the winner of the 2022 *Broad Street Scientific* Essay Contest. Her award included the opportunity to interview Dr. Amay Bandodkar, Assistant Professor in the Electrical & Computer Engineering Department at North Carolina State University.

Nature is an inescapable construct. A careful investigation of what nature has inspired reveals a complex network of intertwined stories between mankind and nature. According to an overview of The History of Mankind, by Professor Friedrich Ratzel, such tales are said to consist of "the rise of civilisation, and the development of language, religion, science and art, and family and social customs" (Ratzel, 1899). While this description skims over the precise role nature has played, it is clear humans have evolved with the times under the hand of environmental circumstances over the course of thousands of years (Seymour, 2016).

Technology, on the other hand, is a more recent invention of civilized society – a manmade advancement seemingly far removed from nature. In the last century or so, high-level calculations using computers have become possible through the leaps and bounds made in technological advancements. Computations have transitioned from use of the abacus, to Babbage's Analytical Engine, and then to modern computers (Encyclopædia Britannica, n.d.). Since then, processing capacities have increased exponentially, a pattern noted in the 1960's by Gordon E. Moore, alongside his namesake law (Moore, 1965). Despite these advancements, the solutions to certain problems we as a part of the human population seek to solve continue to elude researchers.

The continual evasion of a definite solution (in the form of algorithms) is due in part to several reasons. On the one hand, it is rather difficult to solve certain problems without a brute-force algorithm of some sort. As a result, the estimated time required for computation grows to unmanageable lengths, often exceeding several hundred thousand human lifetimes. Such problems are classified as NP-complete or NP-hard problems, in reference to the amount of time required relative to the size of the input data (Hochba, 1997).

Many of the problems that fall under this class are also a type of optimization problem, meant to maximize or minimize some set of results. Take, for example, a set of points where the distances between each point are defined as some positive, nonzero values. The dilemma is as follows: how could one best visit every single point in this set, such that the total distance traveled is minimized?

Known as the Traveling Salesman problem, iterations of the dilemma are applicable to logistical operations that fall under many human industries (including door-to-door marketing and communications). The ideal method for finding the perfect solution generally involves attempting every possible travel route, which is nearly impossible to finish in a logical interval of time, even with the help of supercomputers. Consequently, others have sought to utilize approximations to get close, but generally inexact, solutions (Karlin, Klein, & Gharan, 2021).

This is where nature steps in. It is clear that nature has been a driving force in human society. So, naturally, what follows is this question: what precisely has nature inspired in this world of computational science, specifically? The response is a series of beautiful algorithms aimed at mimicking patterns seen in the natural world (Fister, *et al.*, 2013).

To briefly illustrate its significance as a source of inspiration, one could argue that nature is inclined to optimize the situation regardless. After all, following billions of years of evolution and subjugation to the laws of nature, the most efficient or least energy consuming processes are more likely to prevail (Smith, 1978). In the case of biological constructs, ineffective solutions to problems encountered on the regular (including those relating to motor skills and instincts) could potentially be a cause for die-offs in the face of hardship (Smith, 1978). As for examples of nature enacting an optimal result, simply consider a ball of water in zero gravity, where the water tends to minimize the surface area.

Consider, now, the paths of ants on the lookout for food. The world is quite broad, even for humans whose strides are at least several times the length of that of these small insects. Consequently, ants must travel from destination to destination in search for resources without a significant loss in time (which corresponds to minimizing the distance traveled). In order to remedy the difficulties that may go along with this, ants will lay down pheromones as natural traffic cones to direct other ants and, more importantly, leave a record of places they have visited (Chalissery, *et al.*, 2019). In the case one ant encounters a pleasant surprise somewhere along their path, they may use these pheromones to indicate to other ants to help them bring back what they have found to the colony (Chalissery, *et al.*, 2019). This simple, yet elegant, method of "remembering" the paths proves to be quite effective in illustrating travel.

We thus arrive back again at the Traveling Salesman problem. A brute force solution for this problem would be the equivalent of an ant leaving the colony, choosing a path to walk, visiting all destinations, and then walking all the way back, retrying again and again with a different path each time in order to find the best path. Even for an entire colony of ants, it would not make any sense to request every individual ant go out in an attempt to test a series of paths over and over.

The resultant solution to cut down on the work lies in the use of pheromones, the computational equivalent of which involves the storage of the "result" for some subsection of the path in the memory. This dynamic storage of what information has already been gathered (and what paths have been traversed) cuts down significantly on the running time of the algorithm and, therefore, presents a much better solution than sheer brute force (Sudholt & Thyssen, 2011).

This solution, therefore, is beautiful in the sense that it takes from nature and converts these elements into points of data – mere numerical entities with a sudden flair of character. Perhaps, then, it follows that other algorithms, too, have sought to use data to mimic the mannerisms of natural phenomena, a tactic not confined to merely the biological world.

Namely, in recent decades, the spotlight on the quantum community has grown. On the one hand, researchers have proposed the plausibility of utilizing quantized particles – called qubits– and their probability-based characteristics to perform calculations (Katwala, 2020). The advantage these types of quantum computers have has been coined "quantum speedup", in reference to the ability to compute a similar result to a problem at a rate several times that of typical, classical computers (Rønnow, *et al.*, 2014).

However, one may argue this is the equivalent of hiring an army of ants to walk every path known to man – a plausible prospect, but preferably avoided if possible. Likewise, the maintenance of a significant number of qubits in low temperature, isolated conditions so as to avoid decoherence (loss of information) is consuming on all fronts (Pakin, 2019).

Furthermore, it is yet unproven as to whether or not quantum supremacy is definite, and therefore it follows that alternatives are being sought after. The typical routes for computation (using the binary-based computers) have taken these quantum characteristics as inspiration, and nature strikes yet again. Indeed, quantum-inspired classical algorithms made waves in the computing field, as they challenged what were previously believed to be "untouchable" capabilities of quantum computers (Tang, 2019). Take, for instance, the quantum-inspired algorithm developed by Ewin Tang; unlike the ant-based algorithm, it was centered around the development of a recommendation system. However, unlike other existing algorithms, it managed to dramatically cut down on the running time needed to formulate a result by mimicking the properties of qubits (Tang, 2019).

The applications of these nature-inspired systems, in both optimization and general large-scale data processing, makes these algorithms valuable in the context of an ever expanding world. Traffic control, infrastructural development, or even entertainment recommendation systems all pose as areas with undiscovered solutions nature has the potential to infiltrate.

Of course, these are only several of the many possibilities out there. As no one yet knows the secrets of the universe, further investigation into the patterns and phenomena that manifest themselves in nature is a worthy investment. Perhaps the areas of computation and natural science are not quite as far apart as believed. Who knows? Perhaps their pairing may one day go as far as save the world from strife.

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