> sense the map of cognitive biases of human beings express not only the mental skills but the adaptive requirements made for such bodies during millions of years. As a consequence, these elicitors of meaning explain how we understand existence, aims, the evaluation of death, or the aesthetics of reality. Possible embodiments of next AI systems will define the semantic possibilities of such entities, at a complete different level from those available for human beings, but biased (or situated) too!

Taking into consideration both aspects, coherence and meaning, we can foresee a plausible scenario for the next generation of AI systems. First of all, the beginning of a new era of exploration of the benefits on integrating new bioinspired models, which, by defect, must include biases and lack of accuracy (at expenses of another benefit); second, the ontological horizon to which such systems will be faced. One of the most childish aspects of techno-fetish followers (under the form of transhumanism), is to consider that the way of escaping from death involved a technological transfer or enhancement, from natural bodies to new forms of embodiment. But it is only a small patch in relation to the physical time in this universe: entropy is the final destiny of this universe. There is no way of escaping from absolute informational destruction: big crush, big rip, big freeze… this is the absolute truth in our universe. Perhaps some humans can feel happy thinking of small time postponements, but for a really intelligent system the reality is there: it doesn't matter the kind of strategy you wish to follow, because everything in this universe will be destroyed. How a real intelligent AI will react to this statement? Surely, adopting a personal neo-phenomenological attitude towards reality. Under such conceptual horizons, the refugee of existence is the acceptance and practice of the things we've been calling as biases, or local embodiments as producers of meaning. To assume the fundamental value of the impurity (bodily and cognitive) for the existence, a new way to embrace what Zen monks described as *wabisabi* 侘寂 (わびさび). This rich concept tries to capture the perfection of things with imperfections. That is, wabi-sabi is the notion about the value of imperfections for the reality of an entity as such. In that sense, what explains the success of (some) humans is not their perfection, but a list of peculiarities that mixed together help to define innovative patterns of thinking and action. Nevertheless, such patterns are not intrinsically good (stubbornness, obsession, idealization, magic thinking,…) but help to create rich diversities of agencies. It is the blending of heuristics, not its coherence or hierarchized coherence, that makes possible such extraordinary beings. Taking into account that life is not a game with clear rules and from which we do not have all the necessary information, an imperfect way to deal with it is surely the best solution for advancing into the path of knowledge. Certainly, a biased approach is a better way to increase the complexity and adaptability of AI. What, then,… Wabisabi AI?

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Collapsing the wave function on postquantum unconventional computing

Richard Mayne[1]

Unconventional computing is the field that drives innovation and progress in computer science. One of its sub-fields, quantum computing, is a potentially breakthrough, disruptive technology in which there has been gradual but encouraging progress in recent years. If developed sufficiently, it is predicted that quantum computing will revolutionise a great many fields of human enquiry through laying bare cryptosystems, accelerating research in the natural sciences and providing enormous speed and efficiency increases in machine learning, to name but a few applications. This article examines what quantum computing is, why we need to be aware of it and whether there is a role for unconventional computing in a postquantum world.

Is quantum computing 'unconventional'?

Unconventional computing is the search for new materials, methods and applications for computing technologies. This doesn't necessarily imply making smaller, faster or more efficient general purpose computers, as is commonly considered: many research foci concern making new types of computers that do things which classical, silicon-based architectures can't do, or otherwise use inspiration from nature to program classical systems in novel ways.

This is an extremely wide remit for a field of enquiry and accordingly, advances therein are typically highly multidisciplinary, melding the expertise of the natural sciences, applied mathematics and philosophy into this branch of computer science. This past decade has seen functional unconventional computing devices arising such as slime moulds tackling problems of graph optimization (with better success rates than undergraduate mathematics students),[2] soldier crab logic gates,[3] neuromorphic 'liquid marble' ballistic-reaction-diffusion circuits[4] and progress towards using intracellular protein networks used as nano-scale data buses[5] (Fig. 1). The applications of these rich and varied prototypes clearly do not support general purpose computation, but rather suggest new routes to understanding the sciences, such as 'reprogramming' of live cells for biomedical benefits or realizing true massively parallel processing to the scale of Avogadro's number. The creativity evident in the design of these devices speaks of the close interrelations between the arts and sciences, with unconventional computing at their nexus; manifold studies in modern art,[6] architecture and wearable fashion,[7] *etc.*, both inspire and emerge from the field.

Under this definition of unconventional computing, the emerging field of quantum computing would doubtlessly find a home. In spite of this, quantum computing is generally considered to be its own field, as happens to the more successful offspring of the original parent field — artificial intelligence being arguably the most significant other example. Quantum computing's proponents argue that it offers routes towards enormous speed increases in computation of certain tasks, with database searches and factorization of prime products being amongst the most intensively researched upon applications in the field to date. Some go further to suggest that quantum computers will also reach the stage of general-purpose computation, although all purported future applications are the topic of much speculation and debate.

This raises an important question: if quantum computers are developed sufficiently that they will revolutionise computing and, by extension, every field of human endeavour, what will be the purpose of unconventional computing?

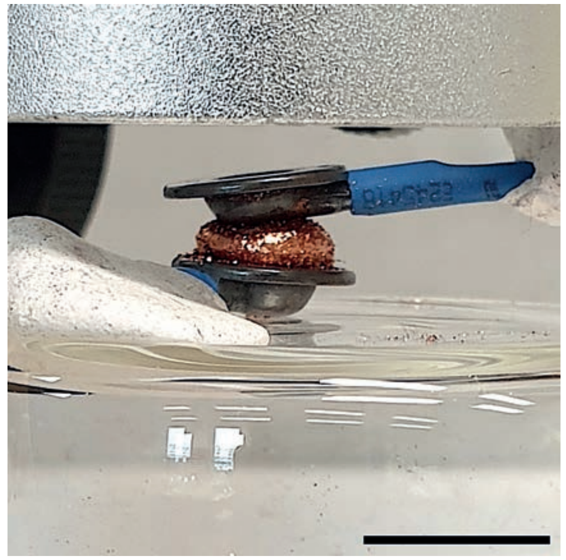

Fig. 1. Examples of unconventional computing devices. Left: A slime mould (*Physarum polycephalum*) navigates its way between distributed nutrient sources, optimising its morphology in a manner that may be exploited to plan transport networks. Above: A 'neuromorphic' liquid marble containing carbon nanotubes whose electrical resistance 'remembers' past electrical activity in a manner similar to human neurons. Scale bar = 10 mm.

The purpose of this article is to briefly delineate what quantum computers are, evaluate whether they are likely to achieve such lofty goals and discuss what role unconventional computing will play in a postquantum world.

How does/will quantum computing work?

Let us consider some fundamental information theoretical concepts relevant to classical computer systems. Data exist as electrical charge distributed across silicon circuit components, where the presence of charge is a binaric bit representing '1' and its absence is a '0'. We may observe these bits and store them: doing something to a bit won't alter anything else in the system and the process is generally lossy, *i.e.* one cannot deduce the input pattern from observing its output with no prior knowledge. None of these facts are true for quantum computing, or indeed many other unconventional computing paradigms.

Quantum information, which may be represented by any of a variety of properties of quantum matter, is stored as 'qubits', which may assume a '1', a '0', or a linear combination of both of these (superposition). This article's title alludes to a concept in quantum science which states that when a qubit is observed, its manifold states will appear to collapse, at which point the qubit will resolve probabilistically as a binary bit. Whilst it would be technically inaccurate to say that superposition enables a greater informational density in a qubit than a conventional bit, there are tools to allow for multiple calculations to be resolved on a single qubit. It should be noted that quantum computers are deterministic under most interpretations of quantum mechanics, but our inference of their output may not be.

Another strange property of quantum matter is called entanglement, which is where changes in the state of one qubit will have simultaneous effects on another qubit, even if they are separated by great distances. Coupled with superposition, these are the primary two physical principles that are exploited in the design of quantum computers and underly the claims that these architectures will achieve enormous increases in efficiency over classical machines, at least at some tasks.

True to the ethos of general unconventional computing, quantum computers seek exploit the natural transfers of state and energy by interpreting them as information processing. For example, the aforementioned probabilistic interpretation of a qubit's state arises from a process of overlying the wave functions of quantum information (as quantum matter assumes the properties of both particles and waves), observing and thresholding patterns of constructive and destructive interference therein. One would struggle to describe the appearance of contemporary quantum computer prototypes as anything other than the domain of the unconventional, as may be observed in the distinctly alien device shown in Fig. 2.

Quantum computing concepts were first devised in the 1970's, but there was arguably little commercial justification for their development until the mid-1990's, when two algorithms were described. Firstly, Shor's algorithm described a method by which a quantum computer may factorise prime numbers efficiently,[8] something which is not possible on conventional computers: as several cryptosystems are based on the intractability of prime factorisation, this algorithm understandably generated significant interest in academia, industry and

Fig. 2. Photograph of the IBM Q 53 qubit quantum computer. Image courtesy of IBM.[9]

government cybersecurity divisions. Second was Grover's algorithm, which described methods to achieve quadratic increases in search efficiency over classical systems.[10]

There have been a significant number of interesting developments in the field since these algorithms emerged (*e.g.* quantum teleportation as a basis for a new wireless internet),[11] but experimental progress in the physical engineering of quantum computers has not yet caught up. Whilst both Shor's and Grover's algorithm have both been experimentally realised, both have been done so on systems with extremely limited capabilities: only the numbers 15 and 21 have been successfully factorised by true quantum systems and Grover's searches haven't been implemented on systems utilising more than a handful of qubits.

In 2019, researchers at Google claimed to have experimentally demonstrated what they called 'quantum supremacy': using a 54 qubit system called 'sycamore', they implemented a non-useful function in 200 seconds which would have apparently taken about 10,000 years on a classical supercomputer, although both these results and the estimations of their significance are contested.

The reader should now appreciate that quantum computers utilise unconventional media and algorithms to do certain tasks very well, but that we are yet to witness the advent of quantum computing at which it becomes a useful and widespread technology. Before we evaluate whether quantum computers will ever become useful and widespread, *en route* towards assessing the postquantum future of unconventional computing, let us briefly examine why we should be excited by the prospect of quantum computing, as it is perhaps difficult to be enthralled by discussing tedious and abstruse mathematical algorithms.

Why should we care about quantum computers?

An obvious application of quick searches is the ability of the use of brute force to crack encryption schemes; indeed, the emergence of Grover's algorithm contributed to the industry-wide adoption of 256-bit encryption in 2001. Similarly, Shor's algorithm is purported to be a route towards breaking RSA encryption schemes, thereby laying bare all internet-based communications and transactions. From the paucity of published progress, we must concede that these applications are a long way away; furthermore, in the author's opinion, these tasks are also an inelegant and restrictive application of such technologies, despite their obvious utility.

To reiterate a theme expounded upon in the previous section, unconventional computing concerns doing things that classical computers cannot, as opposed to competing with them. One intuitive application for quantum computers is, therefore, simulation of the quantum world: something which is extremely difficult to do on classical systems as the interaction environment needed to represent a quantity of quantum particles must necessarily be exponentially larger than the number of particles contained. This presents a problem as quantum physical experiments are notoriously complex, time-consuming and expensive. Simulation of these events therefore allows us access to previously unfound tools for unlocking the secrets of the natural world. Recent results from IBM's quantum group, based on their previous numerical work, have already found uses in the design of next-generation rechargeable batteries.[12]

There have also been encouraging results in the field of quantum machine learning. Conventional machine learning refers to techniques which use computers to do classification or prediction, typically using very large datasets, where the experiment is repeated many times with minor variations in run parameters. The computer keeps a score of what works well, and 'learns' how to adjust itself to achieve optimal results, which can then be leveraged on new data. Incidentally, machine learning and its parent field, artificial intelligence, were once considered unconventional and derive from the biological sciences.

Quantum machine learning in its purest sense, which is using quantum computers and their inherent mechanisms for doing efficient work on very large quantities of data to do machine learning, may potentially greatly accelerate

the course of inquiry in all fields where data science is applied, which is to say, practically ever field of contemporary research. Most popular machine learning methods now have their own quantum implementations ready-and-waiting for the architectures that can run them, including fully scalable neural networks. Quantum machine learning may also refer to the use of conventional machine learning to interpret the output of a quantum computer which is, unfortunately, currently very noisy. There is an elegant self-perpetuation here in the use of unconventional computing to accelerate the progress of unconventional computing research.

The past decade has seen an enormous increase in the use of machine learning concomitant with the emergence of affordable computers capable of having arguments with large quantities of data. The field of data science has arisen from this and industry is only starting to realise the great many incentives that emerge the field including accelerated research, optimisation, anomaly detection and intuitive interpretation of natural languages. It is therefore no exaggeration to say that quantum computing will, through enhancing simulation of the natural world and enabling further advances in artificial intelligence, lead to momentous progress in every field of human enquiry.

The only caveat to these optimistic appraisals is that quantum computers may never reach these dizzy heights: therein will lie the answer to our main issue as to what role there is for the entirety of unconventional computing in this process, one way or the other.

The postquantum role of unconventional computing

It is impossible to predict the scale of investment in quantum computing to date, due to the nature of hidden business interests and state involvement in potentially disruptive technologies, but the size of government grants and magnitude of bespoke laboratories of tech giants (notably, IBM, Google and Microsoft) indicate that tens of billions have been spent. Yet, the pace of experimental development after 20 years of work and 50 of academic interest is unequivocally glacial.

Quantum matter is extremely difficult to manipulate due to its sensitivity to even minor environmental changes: a phenomenon called 'decoherence' stalks every advance in the field, which introduces error into calculations once qubits experience the changes in entropy that are unavoidable during computation, for example resulting from self-examination, moving data and performing calculations. Quantum computers must be isolated from all forms of radiation, vibration, temperature, *etc.* For these reasons, it's difficult to imagine miniaturised, affordable quantum chips being available during this century, although they may reach academic institutions and large businesses much sooner. Furthermore, several cloud computing services are planning to or have already begun to offer access to quantum compute clusters.

A significant number of dissenters argue that, due to the requirement for quantum computers to have vastly larger qubit capacities than their algorithms require to compensate for error correction mechanisms, we will never achieve the aforementioned quantum computing goals. These arguments, which are based in convincing quantum theory, are difficult to counter, although developments such as quantum machine learning seek to bridge the cap by resolving engineering issues through intelligent use of software.

We are currently at an historic fulcrum between which we must consider the putative future of unconventional computing as both existing and not existing (no pun intended): will quantum computation fall by the wayside and leave room for other unconventional substrates to fill the gap, or will the future lie with quantum and leave us wondering how we may advance the field yet another 'quantum' leap.

The most salient fact here is that we are already in a quantum era: the sparse experimental advances in the past two or three years have shown that the theoretical benefits of these architectures may be achieved on a small scale; it's unreasonable to assume that we won't realise significant improvements on this design. This cannot be overstated: we are already using quantum computers and they are already being applied to real problems, albeit on an extremely limited scale.

A key role for unconventional computing researchers is to recognise and understand the failings of quantum computers, rather than just their advantages. This article offers no specific mathematical or experimental method by which we can propose to exert control over a number of error-corrected qubits greater than the number of subatomic particles in the observable universe and hence enable the creation of 'useful' quantum computers, but we have seen how a bioinspired unconventional computing tool (machine learning) has already been applied to clean the output of true quantum computers, which goes at least some way to bridging this gap.

Quantum computers are noisy, don't achieve true parallelism and will demand comparatively strenuous engineering, but this doesn't detract from the magnificent vision with which they are being developed.

Regardless of whether the future is quantum, unconventional computing research fill both seek to improve its sister field and look for alternatives. We will still find enormous use in parameterising biological mechanisms that afford us control over biomedical systems, designing chemical systems which realise true massive parallelism and developing naturally-inspired algorithms for use on conventional systems that solve open problems on computability, to name but a few, limited examples. In an ideal world, we would have a different specialised computing substrate for each task: a biological CPU (Central Processing Unit) for neural networks, a quantum computer for database searches and a conventional computer to compose text documents with, and so on. Until then, unconventional computing research will continue to find new methods, materials and applications for novel computing materials.

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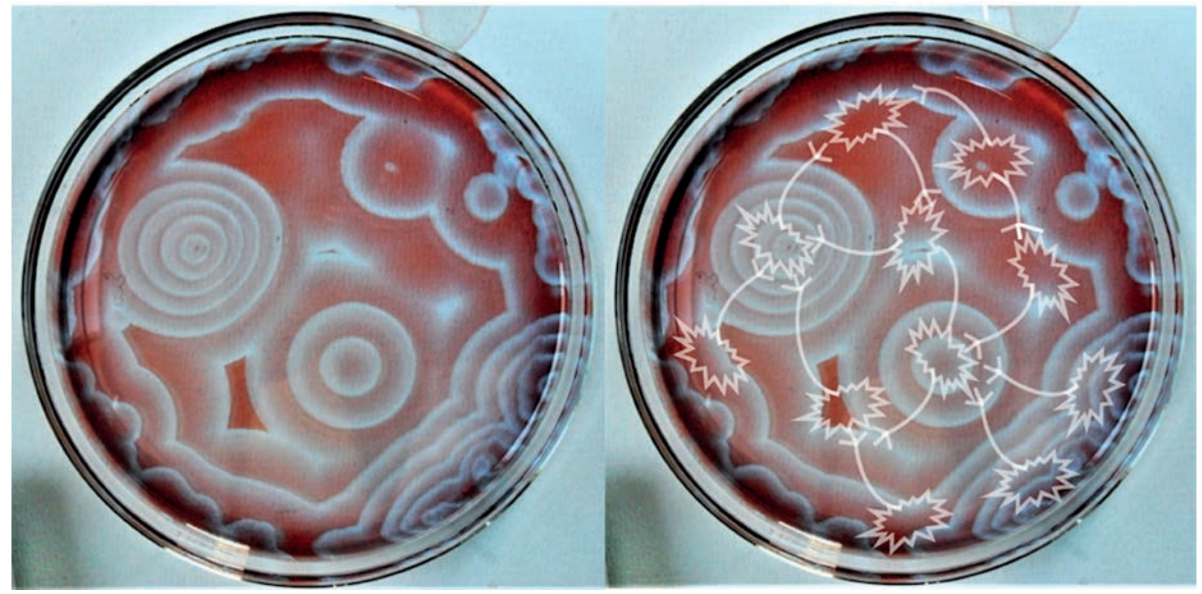
How to face the Complexity of the 21st Century Challenges? The contribution of Natural Computing

Pier Luigi Gentili[1]

The 21st Century Challenges are Complexity Challenges because they regard Complex Systems, and hence other types of Complexities, such as Bio-ethical, Computational, and Descriptive Complexities. This article proposes some strategies to tackle the compelling challenges of this century. A promising strategy is the interdisciplinary research line of Natural Computing that includes Artificial Intelligence.



The phenomenon of chemical waves generated by the Belousov-Zhabotinsky reaction (on the left) and its interpretation according to the theory of Natural Computing that describes the thin film of the solution as a collection of artificial neuron models communicating chemically (on the right).

A fundamental role of science is that of solving practical problems and improve the psychophysical well-being of humans. Science succeeds in playing this role when it promotes technological development. Mutual positive feedback action exists between science and technology: science sparks technological development. At the same time, new technologies allow an always more-in-depth analysis of natural phenomena. Cutting-edge technologies let us manipulate materials at the molecular and atomic scale, send robots to other planets of our solar system, and engineer living beings. Despite many efforts, there are still compelling challenges that must be won. They are the so-called 21st Century Challenges included in the 2030 Agenda composed by the United Nations. Examples of these challenges are all those diseases that are still incurable. There are challenges that concern about human activities. Our manufacturing processes must become circular, minimizing waste. They should not perturb the fragile stability of natural ecosystems and contribute to climate change.