Int. Journ. of Unconventional Computing, Vol. 13, pp. 187–194
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Information and Computation: The Essence of It All

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Received: April 2, 2017. Accepted: August 19, 2017.

Information is a sequence of symbols representing the answer to a question. *Computation* is the process by which information is transformed in order to produce a desired result. In 2065 humanity has finally realized that the entire Universe, from the infinitely small to the infinitely large, is governed by information and computation. Everything, everywhere, at every moment is an information processing phenomenon. This realization of the fundamental role played by information and computation is having a profound effect on how we view ourselves, each other, and the entire world around us. It is shaping our science, our laws, and every conceivable aspect of our society. Above all, it is changing our life itself in a hugely important and most extraordinary way.

Keywords: Information, computation, it from bit, theory of everything, life, space travel, time travel, I am therefore I compute.

1 INTRODUCTION

> *The physical world is a multiverse, and its structure is determined by how information flows in it.*
> David Deutsch: The Beginning of Infinity. Allen Lane, London (2011)

On the morning of January 15, 2065, my colleague Dr. Alice B., a Computer Science professor, wakes up not feeling too well. As usual in such cases,

and without hesitation or a moment's thought, she proceeds to her den where, standing in front of an interactive screen, she takes a scan of her entire body. What results is not an image of her bones, her muscles, or her organs. Instead, it is a digital file consisting of billions of lines of computer code. The file is instantly transmitted to the office of Alice's physician for processing. For Alice, it is now time to fix some breakfast.

Moments later, Alice receives a call summoning her back to the den. There, she presses the palm of her left hand firmly on the screen for a few seconds. When she returns to the kitchen, Alice is feeling much better. What has just happened?

2 IT FROM BIT

> *Information sits at the core of physics ... every particle, every field of force, even the space-time continuum itself derives its function, its meaning, its very existence entirely ... from answers to yes-or-no questions ... all things physical are information-theoretic in origin.*
> John Archibald Wheeler: Information, physics, quantum: the search for links. In: Zurek, W. (ed.) Complexity, Entropy, and the Physics of Information. Addison-Wesley, Redwood City (1990)

Once upon a time, biologists believed that they understood the world fully: "Know the *cell* and you know life." Then came along the chemists and said "No, it's all chemistry; know the *molecule* and you figure out the whole shebang." Soon the physicists showed up to tell us that everything is really physics: "At the very bottom resides the *atom*, and it explains it all!" Today, in the second half of the twenty-first century, it is clear that the foundational notion is not the cell, the molecule, or the atom, but rather the *bit*. The unit of information is the most fundamental building block of the Universe [5]–[8], [10]. It is the turn of computer scientists to say: "The *bit* is at the heart of it all. Know the *bit* and you can comprehend everything." Not only are we able to fathom the workings of 'nature', but in addition, and for the first time in the history of humankind, we are in charge of our own destiny. We can control aspects of our life and of the world around us, in the face of which we were previously helpless.

3 INFORMATION AND COMPUTATION RULE

> *In a sense Nature has been continually computing the 'next state' of the universe for billions of years; all we have to*

> *do - and actually, all we can do - is 'hitch a ride' on this huge ongoing computation.*
> Tommasso Toffoli: Physics and Computation. International Journal of Theoretical Physics. 21, 165–175 (1982)

Information is the answer to a question. It is represented as a sequence of symbols. *Computation* is the processing of information using a variety of elementary transformations, such as arithmetic and logic operations. In 2065 everybody has accepted that the information-computation pair is at the heart of every phenomenon, be it natural or human instigated. Information and information processing are found to be the foundation of all sciences. From photosynthesis in plants, to the migration of birds and butterflies, all the way to human cognition, every aspect of life is fueled by information and computation [1].

In biology, DNA replication and cell multiplication are seen as instances of text processing. In chemistry, a chemical reaction is simply an exchange of electrons, that is, an exchange of information between two molecules. In physics, the spin of an atom, whether spin up or spin down, is a binary process, the answer to a *yes* or *no* question.

Viewed this way, these phenomena are better understood at their most basic state. The implications are immeasurable. Through the lens of information and computation we are able to read Nature's mind. Most open questions have been answered. Few problems in the material world remain unsolved. Major mysteries of the Universe have been unraveled. All the forces in the realm of physics have been unified. Thanks to information and computation, today we have the long-sought after *theory of everything*.

3.1 The end of death

> *What is special [about living things] is that these molecules are put together in much more complicated patterns than the molecules of non-living things, and this putting together is done by following programs, sets of instructions for how to develop, which the organisms carry around inside themselves. Maybe they do vibrate and throb and pulsate with 'irritability', and glow with 'living' warmth, but these properties all emerge incidentally. What lies at the heart of every living thing is not fire, not warm breath, not a 'spark of life'. It is information, words, instructions. If you want a metaphor, don't think of fires and sparks and breath. Think, instead, of a billion discrete, digital characters carved in tablets of crystal. If you*

> *want to understand life, don't think about vibrant, throbbing gels and oozes, think about information technology.*
> Richard Dawkins: The Blind Watchmaker. W.W. Norton & Company, New York (2015)

By 2065, death has been eliminated from all living creatures. Humans have solved the problem of dying either naturally from old age or as a result of sickness. The process of aging has been obliterated. The cause of disease has been discovered; all diseases in all living things are now eradicated. The end of death has come from using computation to model biological life. This bio-computational view of life changed the world forever. Let me tell you how this came about.

3.2 The cell as a program

A little over one hundred years ago, Francis Crick, James Watson, and Maurice Wilkins received the 1962 Nobel Prize in Physiology or Medicine. The Nobel committee cited them "for their discoveries concerning the molecular structure of nucleic acids and its significance for *information transfer* in living material".

Today we know how to model the behavior of a biological cell as a computer algorithm. In this light, a diseased cell is a program with a flaw. Fix the error in the program and you cure the cell. Computer scientists are good at finding errors in programs. They developed tools to detect and correct errors in biological cells modeled as programs. This insight is having incalculable consequences in 2065. Huge advances in healthcare have been achieved. Contagious diseases have been eradicated. The war on bad bacteria and viruses has been won. It is the end of pain and suffering, the end of disease, and ultimately the end of death.

3.3 The fountain of youth

Aging is now a thing of the past. Previously we aged because the successive copies that our genetic code made of itself were increasingly deteriorating. Today, a digital version of an individual's genetic code is created and the analog version is refreshed from the digital one on a regular basis. Our age is belied by our years, not our biology. Unlike taxes, natural death is no longer necessary or inevitable.

How do we know that we succeeded in solving the problem of natural death, you may ask. The proof, so far, is in the evidence. Over the last 18 months, no age-related or illness-related death has been reported worldwide. The challenge remaining is death from other causes. We are working on it.

3.4 Eternal life

> *Information is not a disembodied abstract entity; it is always tied to a physical representation. It is represented by an engraving on a stone tablet, a spin, a charge, a hole in a punched card, a mark on paper, or some other equivalent. This ties the handling of information to all the possibilities and restrictions of our physical world, its laws of physics and its storehouse of available parts.*
> Rolf Landauer: The physical nature of information. Physics Letters A. **217**, 188–193 (1996)

The elimination of death has had a number of consequences on society, as I am sure you can imagine. Philosophical questions such as "What is the meaning of life?", or "Is there life after death?" seem to make no sense any longer. The vow "Till death do us part" sounds vacuous. Even expressions of the type "This is to die for" or "In my next life" are increasingly losing their significance. Yet, it seems important to recall that these pronouncements are not devoid of meaning only today, they were devoid of meaning, at the most basic level, since life began. For when we "died", we did not "really" die. The information in our body never died. It was transmitted in many different ways to the generation that followed us. It continues to do so today. Information is immortal.

Industries and practices related to death have all but disappeared. Funeral homes, funerals, undertakers, crematoriums, inheritance, last rites, among a host of other customs, are virtually inexistent. Cemeteries, relics of the age of mortality, lay dormant, quieter than ever. The grim reaper is out of a job.

3.5 There are suddenly many more people

Procreation and fertility have a new meaning in a death-free society. For both men and women, they are no longer an age-related matter. People can now procreate forever. This, as you may reasonably suggest, is leading to serious issues.

With the disappearance of death, and the fact that we can now procreate forever, humanity is facing an enormous problem. Human population is increasing exponentially. And so is animal population: For a number of years now, we no longer kill animals for food, given that information and computation has led to the development of delicious synthetic foods. Add to this the movement, by animal rights advocates, demanding that we extend our ability to eliminate natural death to the animal populations.

Scientists, philosophers, sociologists, and many other thinkers have been pondering this problem for some time. We believe we have the answer.

3.6 Reaching for the stars

Here is how we propose to solve the problem of overpopulation and the attendant problems of shortages of food, housing, work, and so on. About 10 years ago we mastered fast space travel. We began exploring the Universe and creating colonies on other celestial objects, the number of which, as far as we can tell in 2065, has no limit. Millions of earthlings embark on voyages every year to settle in a new world. They will continue to go, seeking new adventures, new opportunities, and new knowledge. This will relieve the pressure on our old planet and keep it alive for those who wish to return for old times' sake.

Some happy traditions survive, with a twist. On Earth and in the far reaches of the Universe, buildings, parks, and space-ports are named, plaques are affixed to walls, and statues are erected, all to honor the *living*.

Contrary to previous belief, we now know that we are not unique in the Universe. We have found life on many of these new worlds. On some, we have encountered intelligent life. Here too, information and computation were essential in bringing the different beings to understand one another and work together. Every one of the cultures we met so far uses the binary number system!

It is all the better that we are not alone in the cosmos. This knowledge has liberated humans from hubris and conceit. Information is flowing in both directions and computation is being used to translate this information from one culture to another. Intellectual exchanges are being beneficial to all involved. We introduced extraterrestrials to the Arts and showed them how information processing provides limitless extensions to their creative abilities. They showed us how to grow new limbs.

We are sending our ideas about science, society, politics, philosophy, religion, and all of the human knowledge to other civilizations. What we gain in return is incalculable: Huge technological advances in all fields of endeavor. Most particularly, artificial cognition and parallel computation are making giant strides forward and are developed beyond our most daring ambitions.

3.7 What next?

Access to information is no longer a privilege afforded only to the rich and the powerful. Information and computation are universally recognized as fundamental human rights. Information processing creates the knowledge that helps us achieve peace, prosperity, and the healthy social and natural environment in which we live. Our forests are green, our lakes are clean, and our crops abundant. Poverty, famine, and armed conflicts are things of the past. It is with bewilderment and disbelief that our generation learns about these defunct plagues from books, movies, and great grandparents.

In his audacious book [9], Frank Tipler tells us of a moment in the far future, The Omega Point, in which the laws of physics are used to resurrect

the dead and ensure immortality to all beings. Well, I must admit, though humanity has come a long way thanks to information and computation, we are not yet anywhere close to making Tipler's prediction a reality.

However, there is a way which comes to mind that in some sense may allow us to resurrect the dead: Time travel. By traveling to the past, we may be able to reunite with our parents, grandparents, and more distant ancestors. The visits may be long or short, depending on the technologies that we develop in the future [3]. These time travel technologies will also determine whether it takes *time* to travel to the past, and return from the past to the present, and if so, how much time. Today, we can only dream of the possibility of time travel.

4 CONCLUSION

> *Think of all our knowledge-generating processes, our whole culture and civilization, and all the thought processes in the minds of every individual, and indeed the entire evolving biosphere as well, as being a gigantic computation. The whole thing is executing a self-motivated, self-generating computer program.*
> David Deutsch: The Fabric of Reality. Penguin Books, London (1997)

Alice, now fully recovered, arrives at the University. This morning she is to give a lecture to first-year students on how to prevent Cancer by fixing the error in a cell's program before the affected organism begins multiplying dangerously. As she walks in her building, she reads, as she does every day, a Latin expression inscribed over the entrance. It reminds her of something and, as she does every time, Alice smiles.

Over fifty years ago, a university department in Canada demonstrated incredible prescience in the choice of its motto. The motto of the School of Computing at Queen's University, Alice's home department, is *Sum ergo computo*, which means *I am therefore I compute*. The motto speaks at different levels. At one level, it expresses our identity. The motto says that we are Computer Scientists. Computing is what we do. Our professional reason for being is the theory and practice of Computing. It also says that every aspect of the society in which we live is run by a computer, our homes, our starships, our hospitals, our places of entertainment and education, everything. Just by the simple fact of living in this society, we are always computing.

At a deeper level the motto asserts that "Being is Computing". Computing permeates the Universe and drives it: Every atom, every molecule, every cell, everything, everywhere, at every moment, is performing a computation. *To*

be is *to compute.* Our predecessors predicted then what we now know for sure, thereby demonstrating amazing foresight.

Fifty years ago, it was a good time to be a computer scientist. Today, more than ever, it is great to be a computer scientist! Computational problems thought in 2015 to be unconventional are now standard computations and presently parallel processing is the norm in computing [2], [4]. Our computers, by being smart, simple to use and commonsensical are easily integrated in our lives, and nearly invisible.

Demand for computer scientists continues to grow unabated. The explanation is simple. In its first eighty or so years, computer science was a service discipline, mostly an enabling technology. Today, many disciplines have been subsumed by computer science. In 2065, you cannot practically be a scientist without being also a *computer scientist*.

Never before has there been a more exciting period in the history of computer science. Not only is our field shaping all aspects of today's society from medicine to entertainment, but information and computation are being recognized as fundamental to life itself.

The knowledge that we can live forever is providing answers to many age-old existential questions, while at the same time inducing a host of interesting new ones never before encountered by humanity. Thanks to information and computation, ignorance, anxiety, evil, and fear have no place in our existence. Our relationship with time is more relaxed and less complicated. Confidence, hope, compassion, and kindness are in great supply. Happiness everywhere. Spirits are high, inspiration is plentiful, and creativity boundless. Life is grand.

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