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Time: The Final Frontier

SELIM G. AKL

School of Computing and Department of Mathematics and Statistics,
Queen's University, Kingston, Ontario, Canada K7L 3N6
E-mail: akl@cs.queensu.ca

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In 2121 humans finally took control of the last aspect of their lives in the face of which they had so far remained helpless. I am speaking of time. Time, which had always dominated and regulated our day to day existence, is no longer our master. Today, we can travel backward in time and we can travel forward in time. We can go to the past and visit our ancestors. We can go to the future and meet our descendents. Time has lost its grip on our destiny. Free from time's tyranny we can do amazing things. The range of possibilities is unfathomable. The consequences are far reaching. Information and computation are the richer.

Keywords: Time, time travel, arrows of time, time machine, paradoxes of time travel, closed timelike curve, universality, nonuniversality.

1 INTRODUCTION

I saw Eternity the other night,
Like a great Ring of pure and endless light,
All calm, as it was bright;
And round beneath it, Time in hours, days, years,
Driv'n by the spheres
Like a vast shadow mov'd; In which the world
And all her train were hurl'd.
Henry Vaughan: The World. In: Nicholson, D.H.S., Lee, A.H.E. (eds.) The Oxford Book of English Mystical Verse. The Clarendon Press, Oxford (1917)

In the 1960s, the science fiction television series *Star Trek* began with the words "Space: The final frontier", spoken by the captain of the spaceship *Enterprise*. The show recounted the intergalactic voyages of the spaceship and its occupants, in the far distant future. Eventually, fast and safe space travel became a reality in 2065 when humans, having eliminated death, needed to address the threat of overpopulation on Earth. Human colonies on various celestial bodies became a reality nearly fifty years ago. Space is no longer a problem; we have crossed that frontier. Today, in 2121, humans have stood up to address the true final challenge: Taking control of time.

2 TIME

> *All things transform into one another, ... following the necessity ... and according to the order of time.*
> Anaximander: As quoted by Simplicius (c. 610 BCE - c. 546 BCE)

Time is a strange and mysterious thing [6, 8, 10]. It controls every moment of our lives. Yet we cannot see it, nor can we touch it. We have to resort to the motions of the planets in order to measure it.

Nobody knows what time is. Not the physicists, not the philosophers. Much less the writers: "Time flows like a river", "Time flies like an arrow". The French poet Lamartine begged time to suspend its flight, but to no avail; time marched on. Consider the following quotes:

> *Unless hours were cups of sack, and minutes capons, and clocks the tongues of bawds, and dials the signs of leaping houses, and the blessed sun himself a fair hot wench in flame-colour'd taffeta, I see no reason why thou shouldst be so superfluous to inquire the nature of time.*
> William Shakespeare: Henry IV. Part I, Act I, Scene 2 (c. 1597)

> *Absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external, and by another name is called duration. Relative, apparent, and common time, is some sensible and external measure of duration by the means of motion, which is commonly used instead of true time; such as an hour, a day, a month, a year.*
> Isaac Newton: Mathematical Principles of Natural Philosophy (1687)

Folklore is replete with statements about time; for example:

1. It has been said that while space is the relationship between different things, time is a relationship between a thing and itself.
2. It has been said that we cannot perceive time because our two-dimensional retina can only see a three-dimensional world.
3. It has been said that time does not exist, time is but an illusion.
4. It has been said that those who will control time will be the masters of the Universe.
5. Albert Einstein spoke of the relativity of time. It is rumored that he said: "One hour with a nice girl is like a minute, one minute sitting on a hot stove feels like an hour".
6. And by the way, if anybody tells you: "Time is on your side", don't believe them. Time is insidious and evil. Ever wondered why it is called the *"deadline"*?

Time, according to the Random House Dictionary, is the most frequently used noun in the English language: Time to eat, time to sleep, departure time, arrival time, prime time, time is of the essence, once upon a time, take your time, don't have enough time, good time, bad time, high time, in no time, time is money, time of your life, running time, down time, extra time, in time, on time, at the time, about time, over time, spare time, a matter of time, time out, signs of the times, time will tell . . . And what about: *TIME* square, *TIME* magazine, *TIME* sculpture . . .

From the clepsydra, the first timer device invented in Alexandria in 270 BCE, to the clock of the long now of the twenty-first century, we have been obsessed with, and oppressed by, time. Today we are time's slaves no more. Through time travel we have liberated ourselves from the shackles of time.

3 TIME TRAVEL

> *Common sense may rule out such excursions – but the laws of physics do not.*
> David Deutsch, Michael Lockwood: The quantum physics of time travel. Scientific American. **270**, 50–56 (1994)

Historically, you may remember, there have been objections to time travel. These included a number of so-called "arrows of time" that suggest that time moves in one direction only:

1. Thermodynamics (entropy cannot be reversed),

2. Cosmology (the Universe is expanding),
3. Electromagnetics (electromagnetic waves are unidirectional), and
4. Quantum physics (decoherence cannot be undone).

There were also a handful of theoretical proposals for building so-called "time machines" which required the use of seemingly impossible devices, such as:

1. Infinitely long rotating cylinders,
2. Rotating black holes,
3. Wormholes,
4. Negative matter,
5. Negative energy,
6. Cosmic strings,
7. Warp drives traveling faster than the speed of light,

among others, all of which faced serious engineering obstacles, as you may guess.

People loved to invent and talk about "paradoxes of time travel":

1. The grandfather paradox (changing the past to make the present impossible),
2. The information paradox (information comes from the future to make the same information possible in the future),
3. The bilker's paradox (changing the present to make the future impossible),
4. The sexual paradox (fathering oneself, a biological impossibility),

and many more [5, 7, 9].

Today time travel is a reality. We can travel to the past and we can travel to the future. The technology is fairly simple. In 2065, we had used *information* to unify all the forces of nature. We had a theory of everything. The rest was easy. Reversibility is fundamental to quantum theory. The curvature of space is inherent to the general theory of relativity. Closed timelike curves (CTCs) became a reality. Traveling through time and space logically followed.

Time travel is having a profound effect on human knowledge. It has revolutionized all branches of humanities and sciences. Philosophy, Religion, Information Theory, History, Anthropology, Physics, Cosmology, Biology, Paleontology, Geology, and of course, Computing are no longer what they used to be one hundred years ago.

3.1 Remembrances of things past

It is utterly beyond our power to measure the changes of things by time ... time is an abstraction at which we arrive by means of the changes of things; made because we are not restricted to any one definite measure, all being interconnected.
Ernst Mach: The Science of Mechanics (1883)

Because of time travel to the past we now know how events of the past *really* happened. We can tell with certainty how the dinosaurs became extinct. We can describe precisely how the pyramids of Egypt were built and how the ancient people of Rapa Nui erected their gigantic moai. We witnessed the early days of the great religions. We have captured multidimensional multisensorial recordings of these historic events; they are shown today in schools.

For the purposes of this paper, however, the effect on Computer Science is the one of interest. Travel to the past has allowed universality in computation to be restored.

In 2005, S.G. Akl had proved that universality in computation is a myth [1, 3]. Previously, since Turing's work in the 1930s, it was believed that there exists a universal computer, that is, a computer capable of performing, through simulation, any computation that another computer performs. Akl demonstrated that this is only true for *standard computations*. There were, he pointed out, computations considered *unconventional* in the first decades of the twenty-first century. These computations would prove that no computer can be universal.

Let me remind you at this time that a Universal Computer is, by definition, a computer that is fixed once and for all. It cannot be changed in any way once its specification are defined. In particular, it cannot be augmented to fit a given computational problem. For example, it cannot be made faster by adding processing units to it.

In order to prove that the concept of a Universal Computer cannot be realized, Akl proceeded to exhibit computable functions F that cannot be computed on any machine U that is capable of only a finite and fixed number of operations per step. He showed that this remained true even if, when attempting to compute function F, computer U:

1. Is endowed with an infinite memory,
2. Is able to communicate with the outside world, and
3. Is given an infinite amount of time.

Examples of computations in which such functions F appeared were ones involving:

1. Time-varying variables
2. Time-varying computational complexity
3. Rank-varying computational complexity
4. Interacting variables
5. Uncertain time constraints
6. Mathematical constraints.

Akl's argument went like this. Suppose, for example, that the state of a system with n time-varying variables $x_0(t), x_1(t), \ldots, x_{n-1}(t)$, where n is an arbitrarily large variable, is to be captured at a moment $t = t_0$. No Universal Computer U capable of $m < n$ operations per step (where a step takes one time unit to be executed) can perform this computation. For it can certainly read m variables in one time unit at $t = t_0$. Meanwhile, however, the remaining $n - m$ variables of the system will have changed by then, that is, at $t = t_0 + 1$, thus eliminating the possibility of reading their values at $t = t_0$. It should be noted that assuming that the Universal Computer is capable of n operations per time unit is of no help, for the number of variables of the system can always be set to a value larger than the fixed number of operations of which the (purported) Universal Computer is capable of executing in one time unit. The only Universal Computer capable of performing these unconventional computations successfully would be U_∞, that is one capable of an infinite number of operations per time unit.

Akl showed that time travel, if it were achieved, would be able to save the day. Time travel would allow us to perform the above computations successfully. It would allow U to solve problems that are otherwise only solvable on U_∞. For example, for the problem just described, the idea is to allow U to travel back in time to the moment t_0, as many times as necessary, to pick up the values $x_i(t_0)$ that it is missing. This works for all computations listed above. All, that is, except for one [2].

Akl proved that time travel, despite being an extraordinary ally, still failed to solve the counterexample to universality which involves variables obeying a mathematical constraint.

For illustration, consider a rewriting system. From an initial string ab, in some formal language consisting of the two symbols a and b, it is required to generate the string $(ab)^n$, for an even integer n larger than 1. The rewrite rules to be used are:

$$\begin{aligned} a &\rightarrow ab \\ b &\rightarrow ab. \end{aligned}$$

Thus, for $n = 4$, the target string is $ababab$. Throughout the computation, no intermediate string should have two adjacent identical characters. Here we

note that applying any *one* of the two rules at a time causes the computation to fail (for example, if ab is changed to abb, by the first rewrite rule, or to aab by the second).

A computer capable of applying one rewrite rule per time unit cannot solve this problem successfully. If augmented by one processing unit, it will succeed, but then it is not universal by definition. Starting with a computer capable of applying two rewrite rules per time unit is not a solution either, for it could be presented with a problem requiring that three or more rewrite rules be applied simultaneously for a successful termination. This escalation proved that no computer is universal. Even with time travel, the process was hopeless. A computer that travels to the past after one rewrite rule has been applied, will arrive to one of two situations:

1. Either it will find a string that violates the condition because one rewrite rule was applied and the computation has already failed,
2. Or it will find a string on which no rewrite rule has been applied, that is, a return to the initial condition that defeated the computer in the first place.

Today we know how to solve this problem on a Universal Computer. All we need is to equip the universal computer with the ability to time travel to a past *where it meets a younger version of itself*. If a computer can travel to the past and meet a younger version of itself, then there are two computers in the past and they can work in parallel to solve a problem that requires that two rewrite rules be applied simultaneously. More generally, the computer can travel to the past repeatedly, as many times as necessary, in order to encounter additional versions of its younger self, and solve a problem that requires that several rewrite rules be applied simultaneously.

3.2 The future will tell

> *Now he has departed this strange world a little ahead of me. That signifies nothing. For us believing physicists, the distinction between past, present, and future is only a stubbornly persistent illusion.*
> Albert Einstein: In a letter of condolences (1955)

Time travel to the future also had an effect on human knowledge. In Computing we can now easily solve problems previously thought to be intractable. A computer equipped with a CTC is able to travel to the future and send itself (back in time, to the present) solutions to problems that are otherwise computationally impossible to solve using conventional means, even in 2121.

4 CONCLUSION

The fundamental things apply
As time goes by.
Herman Hupfeld: As time goes by. Everybody's Welcome. Broadway musical, New York (1931)

Computation is so fast these days, it is unbelievable. Banks of trillions of tiny superluminal processors can solve problems, regardless of how computationally demanding, at the blink of an eye. Theoretical computer science, whose decline began one hundred years ago, has now witnessed its total demise. Due to their perceived lack of relevance, theory courses in computer science departments are no longer being taught. Undeservedly, they have joined other justifiably extinct subjects (such as Calculus and the like).

Recently, we witnessed an unusual occurrence. For the first time ever, a unique event took place, namely, an information exchange and a human swap, between two people across two epochs, through time itself. It happened as follows.

Dr. Alice B., a retired Professor Emerita of Computer Science traveled back in time to a world facing a serious problem in 2055. The inhabitants of Earth had begun to achieve noticeable progress in the eradication of aging, disease, and ultimately death [4]. Upon arrival in the past, Alice meets her younger self who tells her that, unfortunately, this incredible achievement is threatening the old planet with overpopulation and its ugly consequences: Shortages of food, resources, work, and so on. Something needs to be done soon to prevent an impending catastrophe. Springing to action, Alice (senior) teaches the people of Earth how to accomplish fast travel in space to other planets, other constellations, and other galaxies. Humanity's natural curiosity and thirst for knowledge and adventure results in huge migrations to new worlds and overcrowding is no longer a problem on Earth.

Alice (senior) remained on Earth in order to train scientists and engineers and oversee the success of her space migration project. Meanwhile, Alice (junior) traveled to the future to teach us in 2121 the lost art of the design and analysis of computer algorithms!

REFERENCES

[1] Akl, S.G.: The myth of universal computation. In: Trobec, R., Zinterhof, P., Vajteršic, M., Uhl, A. (eds.) Parallel Numerics, pp. 211–236. University of Salzburg, Salzburg, Austria and Jožef Stefan Institute, Ljubljana, Slovenia (2005).

[2] Akl, S.G.: Time travel: A new hypercomputational paradigm. *International Journal of Unconventional Computing*, **6**, 329–351 (2010).

[3] Akl, S.G.: Nonuniversality in computation: Fifteen misconceptions rectified. In: Adamatzky, A. (ed.) Advances in Unconventional Computing, pp. 1–31. Springer, Cham, Switzerland (2017).

[4] Akl. S.G.: Information and computation: The essence of it all. In: Adamatzky, A. (ed.) Computing 2065. Springer International Publishing, Cham, Switzerland (2017).

[5] Carroll, S.: From Eternity to Here. Penguin, New York (2010).

[6] Falk, D.: In Search of Time. McClelland & Stewart, Toronto (2008).

[7] Le Poidevin, R.: Travels in Four Dimensions. Oxford University Press, New York (2003).

[8] Lockwood, M.: The Labyrinth of Time. Oxford University Press, New York (2005).

[9] Nahin, P.J.: Time Machines. Springer-Verlag, New York (1999).

[10] Pickover, C.A.: Time. Oxford University Press, New York (1999).