This so-called "Lorenz attractor" is a special form of an attractor as it is a "strange attractor," *i.e.* it exhibits a fractal structure. The state of the system at every point in time can be characterised by its corresponding point on this (rather beautiful) graph. The interesting thing is that even tiniest deviations in the initial conditions will lead the system to points far apart on the attractor, so it is not possible to predict the future behaviour of the system. On the other hand, the system cannot "leave" its attractor (at least not for its parameters and initial values within suitable intervals), so the attractor faithfully describes the system behaviour without the chance of actually predicting it from measurements or the like.

All in all, electronic analog computers are ideal tools to explore the behaviour of chaotic (and other dynamic) systems and modern developments in this field will lead to highly integrated analog computers, which will form hybrid computers when combined with classic digital computers thus bringing the advantages of analog computing to a rather wide audience.

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[2] C. M. Danforth, "Chaos in an Atmosphere Hanging on a Wall," on line: http://mpe.dimacs.rutgers.edu/2013/03/17/chaos-in-an-atmosphere-hanging-on-a-wall/

[3] E. N. Lorenz, "Deterministic Nonperiodic Flow," *Journal of the the Atmospheric Sciences 20*, 1963, 130-141.

[4] For more background information and the history of analog computers, see B. Ulmann, *Analog Computing*, München, De Gruyter Oldenbourg, 2013.

Are There Traces of Megacomputing in Our Universe

Olga Kosheleva and Vladik Kreinovich[1]

The recent successes of quantum computing encouraged many researchers to search for other unconventional physical phenomena that could potentially speed up computations. Several promising schemes have been proposed that will – hopefully – lead to faster computations in the future. Some of these schemes – similarly to quantum computing – involve using events from the micro-world while others involve using large-scale phenomena. If some civilization used micro-world for computations, this will be difficult for us to notice, but if they use mega-scale effects, maybe we can notice these phenomena? In this paper, we analyze what possible traces such megacomputing can leave – and come up with rather surprising conclusions.

Modern computers are fast. By performing billions of computational steps, we can reasonably well predict tomorrow's weather – and when the prediction is not perfect, the problem is usually not with the computers, but with the fact that we do not have enough weather-related sensors in many geographic areas. Onboard computers allow missiles to fly close to the ground at astronomical speeds without hitting the ground. A recent quarantine enables billions of people to be connected by reasonably reliable video-connection, helping many people continue to work, to study, and even to enjoy (remotely) their favorite operas.

But for many practical applications, computers are still too slow. For example, a large part of the US is threatened by destructive tornadoes, and we still do not have a reliable means to predict where a tornado will be moving. As a result, in tornado-prone areas, alarms sound so often – and usually, with no actual tornado coming – that when the actual deadly tornado comes, people do not react to the warning, do not evacuate – and the consequences may be disastrous. Here, we know the equations that would describe the tornado's dynamics – they are largely the same equations that allow us to predict tomorrow's weather. Experiments have shown that by spending the same computation time (several hours) on a supercomputer, we can predict where a tornado will go in the next 15 minutes – but that is too late. This is just one example, there are many other problems like that. Many of such problems are related to organic chemistry and biochemistry. So it is not surprising that, *e.g.* in our university, the main users of high-performance computers are not – as one may think – computer scientists, but folks from the Department of Chemistry and Biochemistry.

How can we make computers faster? Journalists writing about science often express an optimistic belief that human ingenuity will solve all the problems. We are optimistic too, but with computers, we cannot be to optimistic: we are currently reaching the bounds set by fundamental physics. This bound is very simple to explain. According to modern physics, nothing can travel faster that the speed of light – *i.e.* faster than 300 000 km/sec, or 300 000 000 m/sec. How does this affect computations? A usual laptop of which we are typing this article is about 30 cm in diameter, *i.e.* 0.3 m. This means that for a signal to go from one side of the computer to another, we need 0.3/300 000 000 sec, *i.e.* 0.000 000 001 seconds. This may sound like a very small time, but even on the cheapest 4 GigaHerz computer, the processor can perform 4 operations while a signal is still travelling.

To make computers faster, we need to shrink their processing elements even more – this is why we enter the realm of quantum computing.[2] But there is a limit to this shrinkage. Already, a processing element may consist of a few thousand atoms. We can theoretically

shrink more, to the level of a single atom – but then what? Then we are stuck.
So what can we do? In this long-term prospective, quantum physics does not seem to help, so let us look at other possible physical phenomena. It would help if we could find a way to speed up all the processes – that will speed up computations as well. Unfortunately, in modern physics, there is no known way to speed up all the processes – there are only ways to slow them down.
According to Einstein's Special Relativity Theory,[3] processes slow down when we travel with a speed close to the speed of light. Actually, they also slow down when we fly on a plane, but that slow-down is so miniscule that often super-precise clocks can detect it, while for the particles in a particle accelerator (that move practically at speed of light), the time slows down so much that their average decay time increases by orders of magnitude.
According to General Relativity Theory,[4] processes also slow down when we are in a strong gravitational field – *e.g.* near a massive black hole. Yes, they also slow done when a usual gravitational field becomes a little stronger, but this change is also minuscule.

Is the situation hopeless? Good news is that, by the very name of relativity theory, many things are relative. There is no absolute time with respect to which we want computers to be faster, all we want is that the computers be faster with respect to our time. In other words, what we want is to make sure that computers are in one environment, and we are in another environment, and all the processes in the computer-containing environment should be much faster than all the processes in our environment. We cannot achieve this by staying on Earth and placing computers somewhere else – the only thing we would then achieve is that, in comparison to our time, computers will be even slower than they are now. But what we can do is leave computers where they are – and place ourselves in situations where time will go slower. If we manage to slow down our own time by a factor of ten, then the same problem that requires five hours of computation in computer-time will feel like half an hour for us – and this is exactly what we want. In other words, instead of speeding up computers, we can slow down ourselves, our whole civilization. How can we do it? As we mentioned, there are two ways to do it: we can start travelling with a speed close to the speed of light, and/or we can place ourselves in a strong gravitational field. Let us consider these two options one by one, starting with fast travel.[5]
We cannot immediately go from 0 to 300 000 km/sec: we can only survive the acceleration similar to the Earth's gravitational acceleration of 9.81 m/sec^2. So we need to start going slowly. We cannot travel on the same orbit around the Sun – if we start travelling with too high a speed, centrifugal forces will squeeze us, so we need to go further and further away from the Sun. We cannot simply travel away on a straight line – this way, we will reach a high speed, but by that time, we will be so far away from the left-behind computers that communication time will eat up all the advantages. So the only way to reach the desired effect is to make circles which are becoming wider and wider – in other words, to follow a spiral trajectory.

This acceleration requires a lot of energy. Where can we get this energy? We have to get it as we travel, from the interplanetary and then interstellar particles and gases – and other objects. As we follow this spiral trajectory, we will burn whatever we can, leaving practically nothing. So what will remain? What will remain is empty spaces forming a spiral. Sounds familiar? It should: this is exactly how our own Galaxy and many other galaxies look like.
So maybe the spiral shape of our Galaxy is indeed the trace of an ancient megacomputing civilization? But wait, there is more.
As we have mentioned, another way to speed up is to place oneself in a strong gravitational field – *e.g.* near a massive black hole. At first, we can use existing black holes, but what if we want to perform even faster computations? The only way to do that is to make the black hole bigger and bigger – thus increasing its gravitational field and slowing us down even more. So how will be known that a supercivilization used this idea to perform megacomputations? By observing a humongous black hole that our previous astrophysical theories did not explain.
Sounds familiar? It should. According to modern astrophysics, there is indeed a very massive black hole in the center of our Galaxy – and in the centers of many other galaxies. So maybe these black holes are also traces of megacomputing civilizations?
Who knows?

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2 See for instance M. A. Nielsen & I. L. Chuang, *Quantum Computation and Quantum Information*, Cambridge, Cambridge University Press, 2000.
3 See for instance R. Feynman, R. Leighton, and M. Sands, *The Feynman Lectures on Physics*, Boston, Addison Wesley, 2005, and K. S. Thorne & R. D. Blandford, *Modern Classical Physics: Optics, Fluids, Plasmas, Elasticity, Relativity, and Statistical Physics*, Princeton, Princeton University Press, 2017.
4 See *ibidem*.
5 Readers interested in technical details can look into O. Kosheleva & V. Kreinovich, "Relativistic effects can be used to achieve a universal square-root (or even faster) computation speedup," in A. Blass, P. Cegielsky, N. Dershowitz, M. Droste, and B. Finkbeiner (eds.), *Fields of Logic and Computation III*, Springer, to appear.

An example of a spiral galaxy, the Pinwheel Galaxy (also known as Messier 101 or NGC 5457).