TELEPORTATION[1]

Alberto Rojo

"A large pepperoni pizza and two diet cokes please"
"Sure madam. Ordinary delivery or teleportation?"
"Just ordinary please. My teleporter is not behaving well."

The scene is illusory, in a hypothetical future where an improbable technology, teletransport, is of everyday usage. Improbable but—as we will see—not impossible. Those who saw *The Fly* (in its two versions) or remember Captain Kirk commanding "energize" would recognize the idea: a body disappears and reappears somewhere else. It is the theme in *Jumper*, directed by Doug Liman, in which David (Hayden Christensen), the superhero of the movie, suffers a captivating genetic anomaly: by only thinking he can instantaneously transport himself from one place to another.

Although the reviews were poor, I got interested in the movie, on the one hand because some scenes were filmed in Gallup Park, located at walking distance from my house in Ann Arbor. But mostly after reading an article in the *New York Times* about a preview at MIT followed by a discussion among students, Liman, Christensen and two physicists, Eduard Farhi and Max Tegmark, experts in the physics allegedly relevant to the plot. At the show, Warren Betts was also present, the pub-

[1] Translated by the author from the original published in *Diario Critica de Argentina.*

licist behind the project, who confessed his enthusiasm with the idea after a physicist from Caltech told him that teletransport was a reality in the enigmatic world of quantum mechanics.

The predictable outcome of the meeting was that teletransport, in its current version, has little to do with the movie. There was, however, agreement among the physicists that good fictions are invitations to the scientific imagination and to reflect on the true impossibility of certain fantastic proposals. An essay that captivated me as a teenager came to mind, "Incredible contraction," in which Isaac Asimov scrutinizes the scientific imprecisions of the movie *Fantastic Voyage*. A diplomat is about to be murdered. In order to save him, a submarine is contracted to microscopic size and injected in his bloodstream with a crew that includes Rachel Welch. Through an amusing analysis, Asimov shows the impossibility of such contraction, among other things because the submarine would be subject to the erratic bombardment of atoms of sizes comparable to the submarine itself. With teletransport the situation is different: it an improbability rather than an impossibility, insinuating a communicating pathway below the divide that separates science and fiction.

Technology invites us to extrapolate realities. If I am capable of sending a Fax or scanning a photograph and "teletransport" it by mail almost instantaneously would the day come in which we could do the same thing with a person or a slice of pizza? Let's look at this with some detail. When we send a Fax, what we are sending is a copy, a facsimile and we keep the original. With teletransport, such as it occurs in *Jumper* or in other science fiction variations, the intention is to teletransport the original. The "transporter," such as seen in some episodes of *Star Trek*, would be a kind of scanner in which the original disappears and is converted into energy. This energy is sent, in some way, somewhere else, where it is reconstructed into matter to make an identical copy, atom by atom, of the original. And here a number of objections emerge.

The first, under the brightest marquee of Physics: $E = mc^2$.

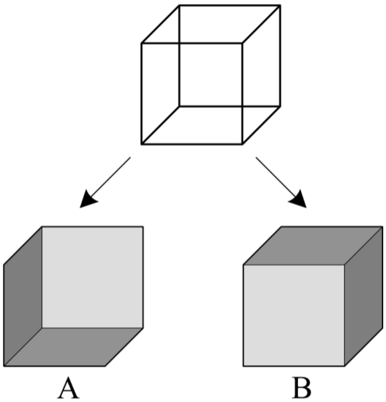
In this case, what the formula is saying is that to convert a 70 Kg human being into energy an equivalent of thousands of hydrogen bombs would be liberated (less than a gram converted into energy destroyed Hiroshima). In other words, this version of teletransport does not seem practical.

The second alternative is to transport the information of the precise atomic configuration of a human being and design a method to reconstruct him somewhere else. This method is vulnerable to two objections. The first is quantitative and the second fundamental. In his book *The Physics of Star Trek*, Lawrence Krauss estimated the number of 100 thousand gigabyte hard disks necessary to code a human being. He obtained a stack of a hundred light years in height. Many readers objected his estimate but without lowering the number to something practical. The second objection has to do with the so called quantum mechanics: at the microscopic level, it is impossible to extract information about the atomic states without altering their state. But the most interesting part of this story is that, in 1993, a group of theoretical physicists from IBM found a quantum shortcut such that by "destroying" the original information it is possible to teletransport the complete information for *one* microscopic particle. The limitation of teletransport would be quantitative and not fundamental.

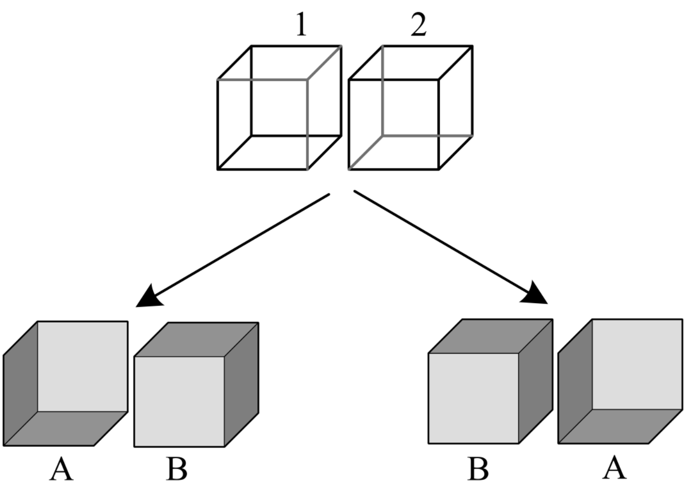
Assume a future in which the complete information of Caroline X is sent almost instantaneously from Wall Street to Times Square, where it is reconstructed atom by atom to its original configuration. Is it the same Caroline X or a mere reproduction? Is the whole identity of Caroline X contained in her atoms? Before writing this article, I exchanged e-mail messages with Juan Pablo Paz, an expert in quantum information. He told me an anecdote that took place in a seminar by Asher Peres, one of the authors of the famous IBM paper. Someone from the audience asked about the prospects of teletransporting the soul on top of the body. "We *only* teletransport the soul," Asher replied, "we simply transport the body." What Asher was implying is that quantum teleportation involves the sending of information and not matter. In our example, that information would be used to reconstruct Caroline X with atoms different from the ones that constituted her in Wall Street. Our identity is the order in the configuration of matter that constitutes us and not in the matter itself.

In the Greek legend, after killing the Minotaur, Theseus returns to Athens in a ship that the Athenians preserved long after his death. As the ship deteriorated, they replaced its parts so that it showed no outward change. After some time, each component of the ship was different from the original. Was it the same ship? asked the philosophers. For some, the ship's identity was in its form; for others in its matter—whose etymology is precisely in "wood." If we think of a ship in which each atom was replaced, in current language we would say that the identity is in its form. Our body, like Theseus' ship, is a structure of cells that are replaced and discarded. We create a new skin every two weeks, a liver every sixteen months and our skeleton is renewed every ten years. Although with neurons the subject is controversial, it is conceivable that when we die we are reproductions of ourselves when young.

The question of identity is more than philosophical; it is a cornerstone of quantum mechanics: elementary particles, the constituents of atoms, are absolutely indistinguishable one from the other. Each Carbon atom of yours is identical to mine; each electron lacks individuality. Even more, in the quantum world each microscopic particle is not only indistinguishable form the rest but also indistinguishable from itself. An electron within an atom exists *simultaneously* in infinite places close to the atomic nucleus, and those infinite twins are constituted in one when they are detected, when they are measured. A rendering of this enigmatic property in the following allegory, in which, instead of infinite locations for an electron, a cube is, simultaneously, in two possible states, A and B.



After a while, our mind "locks into" one of the two perspectives of the cube, A or B. That locking in corresponds, roughly, to the detection, to the transition between multiplicity (two in this case) to a well defined state. Now consider two cubes in such a way that while before the measurement we ignore the perspective of each cube, we know that they have opposite perspectives:



Before the measurement, cubes 1 and 2 are "entangled"; they are simultaneously in the two possibilities, in its two identities, but one opposed to the other. If we measure the state of one cube, we immediately know the state of the other. Quantum entanglement is a concept without an equivalent in our everyday experience, and distinguishes quantum and classical Physics. In Newtonian Physics, there is no entanglement, each cube is *either* in A *or* in B, not in both perspectives at the same time.

The first quantum teleportation experiment, realized in 1997, resorts to entanglement to teleport, not a cube but a photon, an atom of light that, like the cube, can be in two "perspectives" mutually exclusive: the polarization of light.

Let us say that we want to teletransport a cube (a photon) that is in Wall Street, sending the information of its state to Times Square. The cube (let us call it X) in Wall Street is in a superposition of A and B, let us say, 30% of A and 70% of B. But we ignore the information of those percentages; if we attempt to measure them, the cube would suddenly be in *either* A *or* B and we would destroy the information. The way out is to resort to two more cubes, let's call them W and T. The first step is to entangle them, like in the case of the cubes we just discussed, and *transport* (not teletransport) cube T to Times Square, preserving its entanglement with W. It might sound magical, but it is possible to generate entangled photons at large distances. In an experiment done in Viena in 2004, entangled photons a distance of 600 meters apart were used. They were connected by an optical fiber fed through a public sewer system tunnel connecting labs on opposite sides of the River Danube. The second step is to entangle cube X with W, both on Wall Street. As a result of this new entanglement, the state of the cube in Times Square changes instantaneously. In the third step, an observer makes a measurement on the entangled state of X and W, both on Wall Street and communicates the result by cell phone to the observer in Times Square. In this process, the state of X gets destroyed, but with this information the observer in Times Square is ready to operate on T, *without measuring it,* for example, rotating it through its axis. After that, the cube in Times Square is in *exactly* the same quantum state as the original X: teleportation is complete.

Can this be extended to the enormous amount of atoms of Caroline X or to a slice of pizza? In order to teleport a pizza according to the IBM method, we first need to have the necessary atoms at home, and those atoms have to be entangled with their corresponding ones at the restaurant: very improbable. In 2001 the Air Force commissioned to Warp Drive Metrics a modest budget ($25,000) to study the potential application of teleportation. The conclusion was negative.

However, the interest in quantum entanglement is of fundamental interest to other potential practical applications of quantum mechanics. But for the time being, ordinary delivery, and from Wall Street to Times Square, the subway.