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Carrying Pieces of Information in Orgocatalytic Bytes

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Good afternoon. My name is Wanderley dos Santos. I'm a professor of biochemistry at the State University of Maringa, which is in a prosperous region of Southern Brazil. Since earning my PhD, in cell biology I have been working with biochemistry. More precisely, I study allelochemicals, a group of secondary metabolites, which plants use to communicate with its neighbors: to attract pollinators and symbionts or to get rid of pathogens herbivores and plant competitors.

Today, I will talk about how these small compounds are able to store information. Most importantly, I will highlight how these compounds are able to conserve information through a phenomenon known as organocatalysis. Finally, I will explore how these organocatalysts might be related with the origin of life and implications for Code Biology.

When I was a teenager I was a science and technology nerd. I was also interested in literature and after writing a few short stories I decided to write a sci-fi novel. The main character was trying to develop nuclear fusion believing that an unlimited supply of energy would be the ultimate solution to mankind's material troubles. Using a new approach, he would be able to enhance the energy at the reactor several thousand times. His idea succeeded, but instead of ignition he created a rupture in space-time and was taken with part of his team into a distant future. After some adventures he finally found an amazingly wealthy civilization based on a technology much more revolutionary than nuclear fusion.
They had invented a programmable nanostructure able to use materials and energy available in the environment to produce a copy of itself. By following its internal software the structure was able to develop and become any kind of material or complex machine. They called the technology living-material. With such a technology they were able to produce everything: from clothes and houses to computers and heavy machinery. The entire city was made of living-materials. The obvious advantages were that these devices were self-constructed, wear-proof, self-repairing and most important, completely recyclable.

I became so excited with this idea, that over the course of the time, I started to believe that it could be done. So, I graduated in Biological Science and started a post-graduate in cell and molecular biology. Three years ago, I became professor at the same university where I completed my PhD and just last December, I finally received the financial support to explore if my childhood dream could become reality.

Living beings are dissipative structures. This term was coined by Ilya Prigogine to refer to systems which dissipate energy to exist. A machine is similar to a dissipative structure that dissipates the energy of a fuel to produce work. However, it differs by not being self-organized. Maturana and Varela described man-made machines as 'allopoietic', meaning produce other, to contrast with living beings, which they dubbed autopoietic, meaning produce itself. In 1992, Schneider and Kay demonstrated that the emergence of a convection cell increases the rate by which a gradient of temperature is dissipated. When I analyzed their data, I realized that convection cells are also autopoietic systems, since they produce the dissipation that produces it. Then I noticed that similar dissipative feedback mechanisms are also responsible for the organization of fire, vortices and stars. This let me to believe that it is a general mechanism of self-organization.

With this hypothesis in mind, let's direct our attention to prebiotic chemistry. In the process studied by Staley Miller, molecules are excited by an ionizing radiation to produce a gradient of free energy (that is, reactive molecules). This gradient dissipates by chemical reactions producing a wide diversity of organic compounds, including amino acids, sugars and fatty acids. The arising of a dissipative feedback mechanism requires that something produced by the dissipation of the energy, increases the rate by which the energy is dissipated. A chemical reaction can only be accelerated in one of two ways: providing the required activation energy by increasing the temperature or reducing the activation energy with the presence of a catalyst. As pre-biotic reactions are not necessarily exothermic the production of catalysts is the only mechanism able to produce a dissipative system. So I predicted that some organic compounds act as catalysts.

In 2008, I discovered that some small organic molecules are able to catalyze chemical reactions. Moreover, proline, the most studied organocatalyst, is a compound that has been produced in prebiotic conditions. Also, other aminoacids produced in abundance in prebiotic systems has been characterized as working as organocatalysts. The most interesting property of organocatalysts is that they are able to transfer information to their products. Asymmetric organocatalysts may catalyze reactions with high enantiomeric and diastereomeric excess.

Claude Shannon defined the smaller amount of information as a selection between two possibilities (for example choosing 0 between the possibilities of 0 and 1). A series of eight bits produce a byte, which can assume 256 different meanings. An aldohexose presenting 4 chiral centers can produce sixteen different molecules: D-glucose, L-glucose, D-galactose, L-galactose etc. Each stereoisomer presents the same composition, but distinct stereochemical properties. In a catalytic dissipative structure the products perform a function in the system stability. So, if an asymmetric organocatalyst can conserve part of its molecular information in its products, determining its properties, it could have been a primitive way to keep chemical information.

Catalysis never occurs directly in water due to its high polarity. Therefore, organocatalysis occurs only in non-polar environments. However, several researchers have circumvented this limitation by linking a polar organocatalyst (such as proline) to a fatty acid to produce active water soluble micellar organocatalyst. My proposal is to use an organocatalytic micelle to catalyze the chemical linkage of a free organocatalyst to a fatty acid. This will produce an autopoietic system. In a subsequent step, I want to explore the ability of this system to produce diversity using methods of directed evolution. This ability to transfer part of their chemical information to their products makes them candidates to have been the first material capable of carrying genetic information.

Finally, I want to highlight a remarkable result of assuming the existence of molecular information in low molecular weight compounds to code biology. Monomeric compounds carry pieces of information and this information is relevant for its properties. Furthermore, this precise structural information accomplishes a function in the cell or organism. (For example our blood keeps a concentration of glucose, instead of galactose or manose although their free energies are similar). The information to produce a precise structure is somewhat stored in the enzyme pathways, which produce the compound. So, by extension, the information present within the mRNAs and their respective genes are also related with the final functional compound, rather than only with their catalysts. With this reasoning we can deduce that enzymes plays a role of code-adaptors between the genetic information and the information encoded in the metabolites (the metabolic code).