ing and classifying when an existing entity or system is a living being and when it is not.

This raises a sticky problem: how do I know when a being is living? What are my criteria? Throughout the history of biology many criteria have been proposed. They all have drawbacks. For instance, some have proposed as a criterion chemical composition, or the capacity to move, or reproduction, or even some combination of those criteria, that is, a list of properties. But how do we know when the list is complete? For instance, if we build a machine capable of reproducing itself, but it is made of iron and plastic and not of molecules, is it living?

We wish to give an answer to this question in a way radically different from the traditional listing of properties. This will simplify the problem tremendously. To understand this change in perspective, we have to be aware that merely asking the question of how to recognize a living being indicates that we have an idea, even if implicitly, of its *organization*. It is this idea that will determine whether we accept or reject the answer given to us. To prevent this implicit idea from entrapping and blinding us, we must be aware of it when we consider the answer that follows.

What is the makeup or organization of anything? It is both very simple and potentially complicated. "Organization" signifies those relations that must be present in order for something to exist. For me to judge that this object is a chair, I have to recognize a certain relationship between the parts I call legs, back, and seat, in such a way that sitting down is made possible. That it is made of wood and nails, or plastic and screws, has nothing at all to do with my classifying it as a chair.

This situation, in which we recognize implicitly or explicitly the organization of an object when we indicate it or distinguish it, is universal in the sense that it is something we do constantly as a basic cognitive act, which consists no more and no less than in generating classes of any type. Thus, the class of "chairs" is defined by the relations required for me to classify something as a chair. The class of "good deeds" is defined by the criteria that I establish and that must apply between the actions done and their consequences for considering them good.

It is easy to point to a certain organization by naming the objects that make up a class; however, it can be complex and hard to describe exactly and explicitly the relations that make up that organization. Thus, as regards "chairs" as a class, it may be easy to describe the organization of a "chair"; however, it is not so with the class of "good deeds," unless there is a considerable amount of cultural agreement.

AUTOPOIETIC (LIVING) ORGANIZATION:

organized as a network of processes of production (transformation and destruction) of components which: (i) continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it as a concrete unity in the space in which …the components…exist

Autopoiesis and Cognition, 78

When we speak of living beings, we presuppose something in common between them; otherwise we wouldn't put them in the same class we designate with the name "living." What has not been said, however, is: what is that organization that defines them as a class? Our proposition is that living beings are characterized in that, literally, they are continually self-producing. We indicate this process when we call the organization that defines them an *autopoietic organization*. Basically, this organization comes from certain relations that we shall outline and view more easily on the cellular level.

First, the molecular components of a cellular autopoietic unity must be dynamically related in a network of ongoing interactions. Today we know many of the specific chemical transformations in this network, and the biochemist collectively terms them "cell metabolism."

Now, what is distinctive about this cellular dynamics compared with any other collection of molecular transformations in natural processes? Interestingly, this cell metabolism produces components which make up the network of transformations that produced them. Some of these components form a boundary, a limit to this network of transformations. In morphologic terms, the structure that makes this cleavage in space possible is called a membrane. Now, this membranous boundary is not a product of cell metabolism in the way that fabric is the product of a

The Origin of Organic Molecules

In a discussion of the origin of organic molecules comparable to those found in living beings (such as nucleotidic bases, amino acids, or protein chains), there is often the temptation to think that there is little likelihood of their spontaneous appearance and that some guiding force is required in the entire process. From what we have outlined, this is not so. Each one of the stages described arises as an inevitable consequence of the previous one. Even today, taking a sample of the primitive atmosphere and energizing it adequately would produce organic molecules similar in complexity to those found in living beings. Even today, sufficiently compressing a gaseous hydrogen mass would produce thermonuclear reactions in it that give rise to atomic elements not present before. The history that we have been outlining is one of sequences that invariably follow one after the other, and a result would be surprising only to a person unfamiliar with the complete historical sequence.

A classic piece of evidence that there is no discontinuity in this transformation by stages was given in an experiment that Miller did in 1953 (see Fig. 11).* Miller's idea is simple: put inside a laboratory bottle an imitation of the primitive atmosphere as to composition and energy radiations. Apply an electric discharge to a mixture of ammonia, methane, hydrogen and water vapor. The results of the molecular transformations are collected by circulating water inside the bottle, and the substances that remain dissolved there are analyzed. To the surprise of the entire scientific community, Miller was able to produce abundant molecules typical of modern cellular organisms, such as the amino acids alanine and aspartic acid, and other organic molecules such as urea and succinic acid.

*S. L. Miller, *Science* 117 (1953):528.

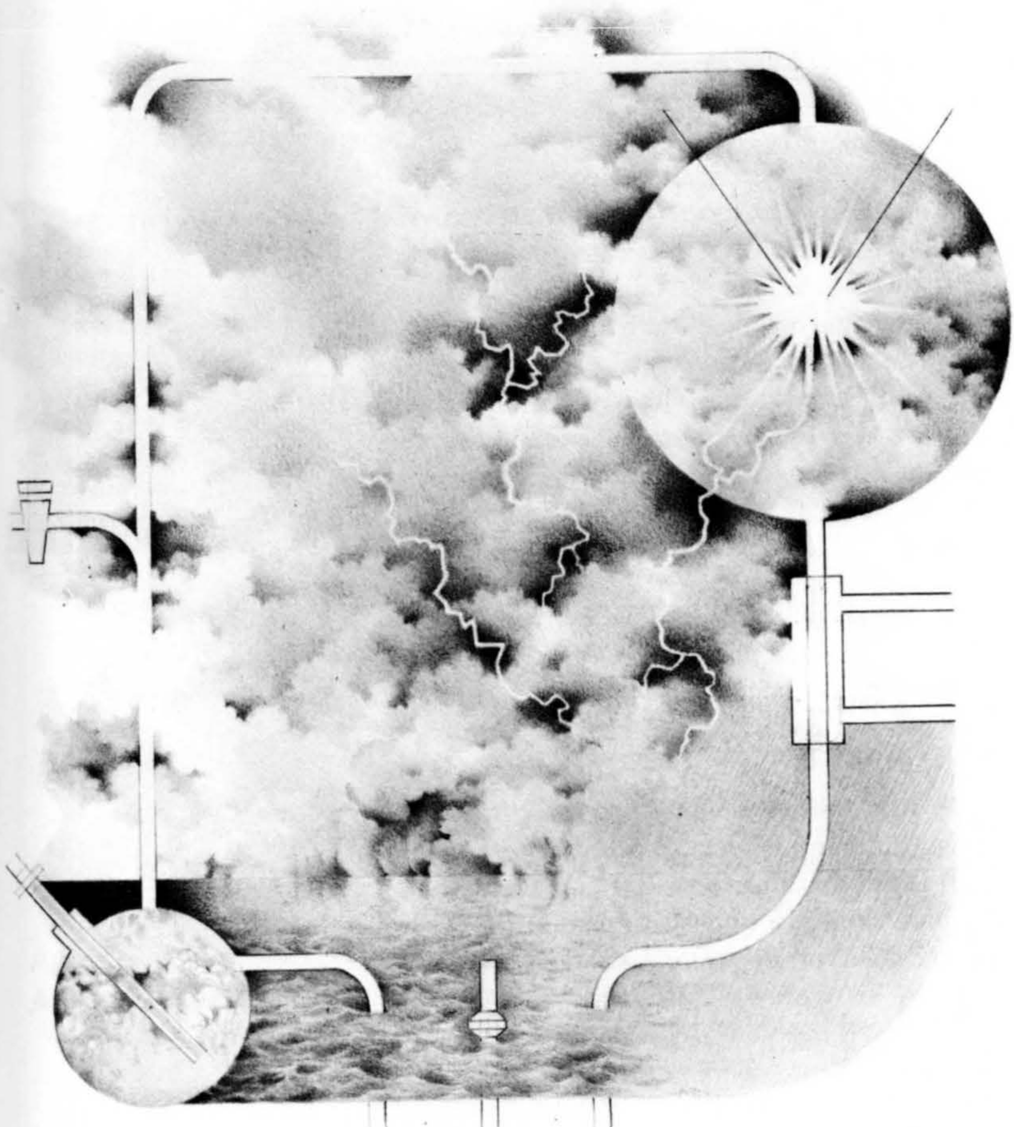
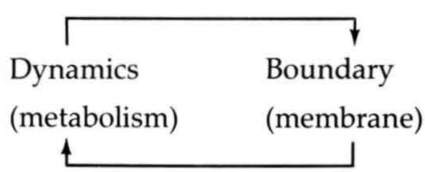


Fig. 11. Miller's experiment as a metaphor of what occurred in the primitive atmosphere.

fabric-making machine. The reason is that this membrane not only limits the extension of the transformation network that produced its own components but it participates in this network. If it did not have this spatial arrangement, cell metabolism would disintegrate in a molecular mess that would spread out all over and would not constitute a discrete unity such as a cell.

What we have, then, is a unique situation as regards relations of chemical transformations: on the one hand, we see a network of dynamic transformations that produces its own components and that is essential for a boundary; on the other hand, we see a boundary that is essential for the operation of the network of transformations which produced it as a unity:



Note that these are not sequential processes, but two different aspects of a unitary phenomenon. It is not that first there is a boundary, then a dynamics, then a boundary, and so forth. We are describing a type of phenomenon in which the possibility of distinguishing one thing from a whole (something you can see under the microscope, for instance) depends on the integrity of the processes that make it possible. Interrupt (at some point) the cellular metabolic network and you will find that after a while you don't have any more unity to talk about! The most striking feature of an autopoietic system is that it pulls itself up by its own bootstraps and becomes distinct

Organization and Structure

Organization denotes those relations that must exist among the components of a system for it to be a member of a specific class. *Structure* denotes the components and relations that actually constitute a particular unity and make its organization real.

Thus, for instance, in a toilet the organization of the system of water-level regulation consists in the relations between an apparatus capable of detecting the water level and another apparatus capable of stopping the inflow of water. The toilet unit embodies a mixed system of plastic and metal comprising a float and a bypass valve. This specific structure, however, could be modified by replacing the plastic with wood, without changing the fact that there would still be a toilet organization.

from its environment through its own dynamics, in such a way that both things are inseparable.

Living beings are characterized by their autopoietic organization. They differ from each other in their structure, but they are alike in their organization.

Autonomy and Autopoiesis

By realizing what characterizes living beings in their autopoietic organization, we can unify a whole lot of empirical data about their biochemistry and cellular functioning. The concept of autopoiesis, therefore, does not contradict these data. Rather, it is supported by them; it explicitly proposes that such data be interpreted from a specific point of view which stresses that living beings are *autonomous* unities.

We use the word "autonomy" in its current sense; that is, a system is autonomous if it can specify its own laws, what is proper to it. We are *not* proposing that living beings are the only autonomous entities. Certainly they are not. But one of the most evident features of a living being is its autonomy. We *are* proposing that the mechanism that makes living beings autonomous systems is autopoiesis. This characterizes them as autonomous systems.

The question about autonomy is as old as the question about the living. It is only contemporary biologists who feel uncomfortable over the question of how to understand the autonomy of the living. From our standpoint, however, this question is a guideline to understanding the autonomy of living beings: to understand them, we must understand the organization that defines them as unities. Being aware that living beings are autonomous unities helps to show how their autonomy—usually seen as mysterious and elusive—becomes explicit, for we realize that what defines them as unities is their autopoietic organization, and it is in this autopoietic organization that they become real and specify themselves at the same time.

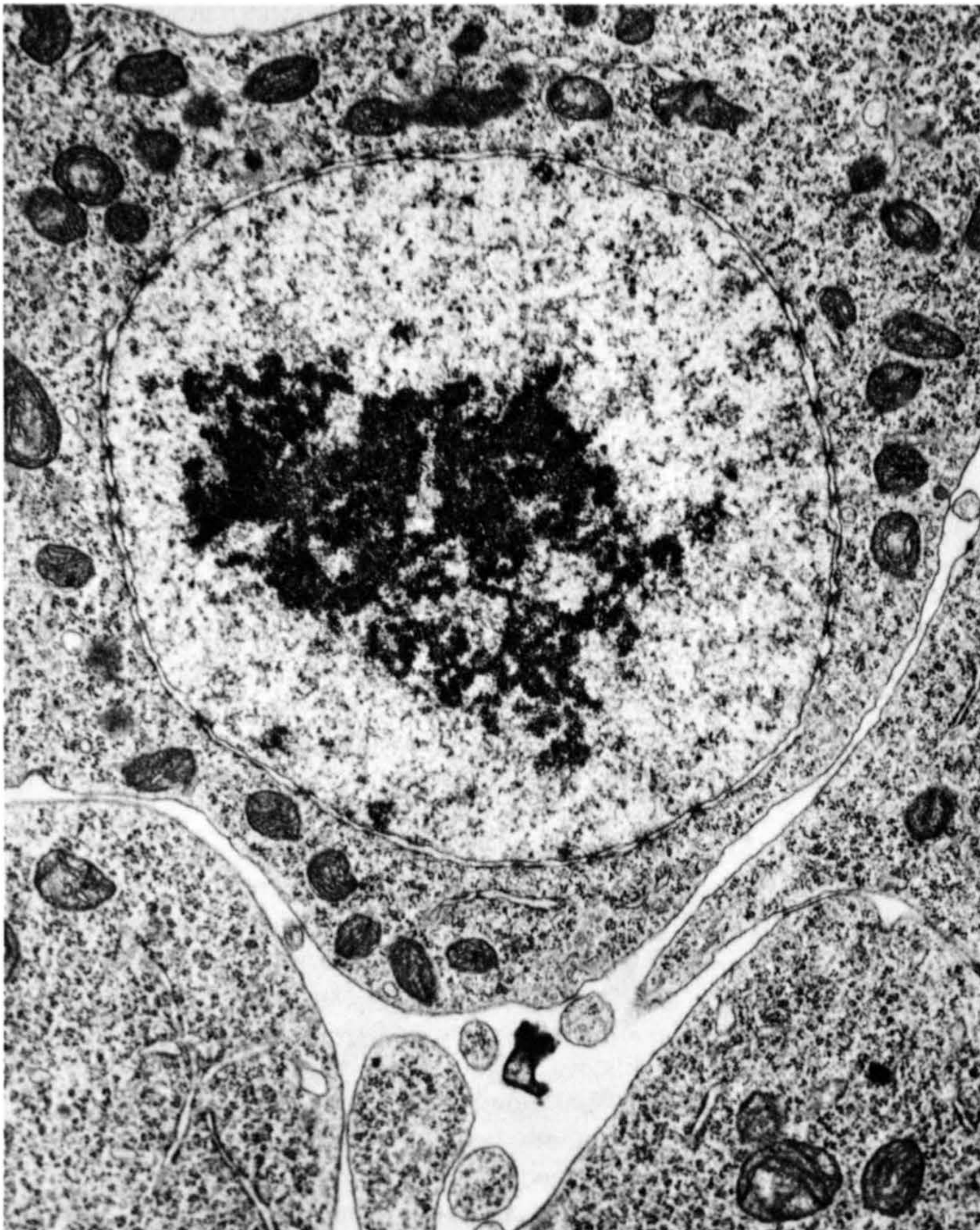
Our intention, therefore, is to proceed scientifically: if we cannot provide a list that characterizes a living being, why not propose a system that generates all the phenomena proper to a living being? The evidence that an autopoietic unity has exactly all these features becomes evident in the light of what we know about the interdependence between metabolism and cellular structure.

That living beings have an organization, of course, is proper not only to them but also to everything we can analyze as a system. What is distinctive about them, however, is that their organization is such that their only product is themselves, with no separation between producer and product. The being and doing of an autopoieic unity are inseparable, and this is their specific mode of organization.

Like any organization, autopoietic organization can be attained by many different types of components. We have to realize, however, that as regards the molecular origin of terrestrial living beings, only certain molecular species probably possessed the characteristics required for autopoietic unities, thus initiating the structural history to which we ourselves belong. For instance, it was necessary to have molecules capable of forming membranes sufficiently stable and plastic to be, in turn, effective barriers, and to have changing properties for the diffusion of molecules and ions over long periods of time with respect to molecular speeds. Molecules from silicon layers, for instance, are too rigid for them to participate in dynamic unities (cells) in an ongoing and fast molecular interchange with the medium.

It was only at that point in the Earth's history when conditions were right for the forming of organic molecules such as proteins, which have enormous complexity and pliancy, that conditions were right also for the forming of autopoietic unities. In fact, we can assume that when all these sufficient conditions were present in the Earth's history, autopoietic systems formed inevitably.

That moment is the point we can refer to as the moment when life began. This does not mean that it happened in one instance and in one place only; nor can we specify a date for it. All the available evidence leads us to believe that once conditions were ripe for the origin of living systems, they



Cells and Their Membranes

The cell membrane plays a more sizable and varied role than that of a simple line of spatial demarcation for a number of chemical transformations, because it participates therein like other cellular components. This takes place under circumstances in which the cell interior has a rich architecture of large molecular blocks, through which pass many organic species in continuous exchange, and the membrane is operationally part of that interior. This is true both for the membranes which limit the cellular spaces that adjoin the exterior medium and for those membranes which limit each one of the different internal spaces of the cell (see accompanying figures).

This interior architecture and cell dynamics are complementary features of cellular autopoiesis.

originated many times; that is, many autopoietic unities with many structural variants emerged in many places on the Earth over a period of perhaps many millions of years.

The emergence of autopoietic unities on the face of the Earth is a landmark in the history of our solar system. We have to understand this well. The formation of a unity always determines a number of phenomena associated with the features that define it; we may thus say that each class of unities specifies a particular phenomenology. Thus, autopoietic unities specify biological phenomenology as the phenomenology proper of those unities with features distinct from physical phenomenology. This is so, not because autopoietic unities go against any aspect of physical phenomenology—since their molecular components must fulfill all physical laws—but because the phenomena they generate in functioning as autopoietic unities depend on their organization and the way this organization comes about, and not on the physical nature of their components (which only determine their space of existence).

Fig. 12. An electron micrograph of a cell specimen from a leech, showing membranes and intracellular components (magnified approximately 20,000 times).

Thus, if a cell interacts with molecule X and incorporates it in its processes, what takes place as a