Biology and living systems

● The essential characteristic of living cells is homeostasis, the ability to maintain a steady and more-or-less constant chemical balance in a changing environment. Homeostasis is the machinery of chemical controls and feedback cycles that make sure that each molecular species in a cell is produced in the right proportion, not too much and not too little. Without homeostasis, there can be no ordered metabolism and no quasi-stationary equilibrium deserving the name of life.

● The question of how much genetic information can be carried by a population of molecules without exact replication is intimately bound up with the question of the nature of homeostasis. Homeostasis is the preservation of the chemical architecture of a population in spite of variations in local conditions and in the numbers of molecules of various kinds. Genetic information is carried in the architecture and not in the individual components. But we do not know how to define architecture or how to quantify homeostasis.

● The concept of homeostasis can be transferred without difficulty from a molecular context to ecological, economic, and cultural contexts. In each area we have the unexplained fact that complicated homeostatic mechanisms are more prevalent and seem to be more effective than simple ones. This is most spectacularly true in the domain of ecology, where a typical stable community, for example a few acres of woodland or a few square feet of grassland, comprises thousands of diverse species with highly specialized and interdependent functions. But a similar phenomenon is visible in economic life and in cultural evolution.

The open market economy and the culturally open society, notwithstanding all their failures and deficiencies, seem to possess a robustness which centrally planned economies and culturally closed societies [like the ex-Soviet Union] lack.

Dyson,2004

● If the given system is repetitive, physics have general methods to describe it: the methods of thermodynamics and statistical mechanics. If it is instead of a non-repetitive system, we have no idea of how to proceed: all general methods fail and direct, detailed and analytical description is really impossible because of the complexity of the system.

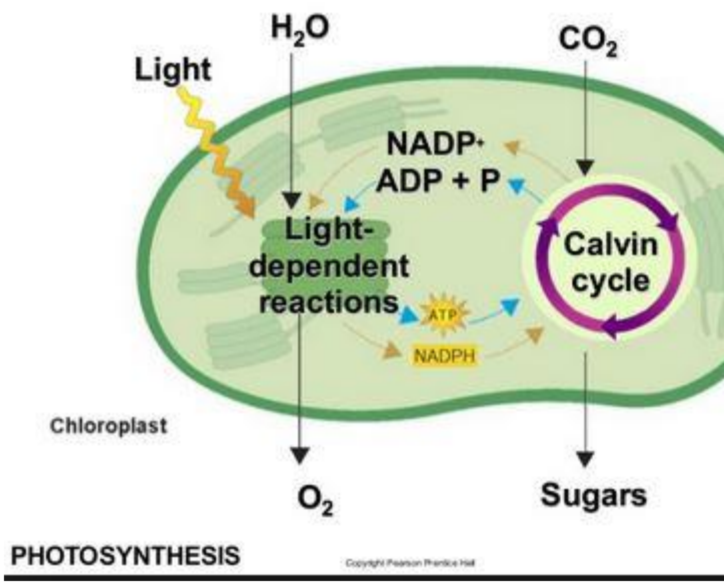
● Who has tried to describe such a system formally by methods similar to statistical mechanics, failed precisely because the schematic approach adopted consisted of eliminating the peculiarity of the individual control loops: this assumption from a Biological point of view, it is by no means a detail in the first approximation negligible, but it is the essence, the focus of the problem.

● A living system is coherent complex system with program.

Monod correctly denies that any *teleological* forces are needed to create life from inanimate matter, but he finds that *teleonomic* purposeful behavior is one of the fundamental characteristics of life, along with what he calls *autonomous morphogenesis* (life is "self-constructing") and *reproductive invariance* (life is "self-replicating").

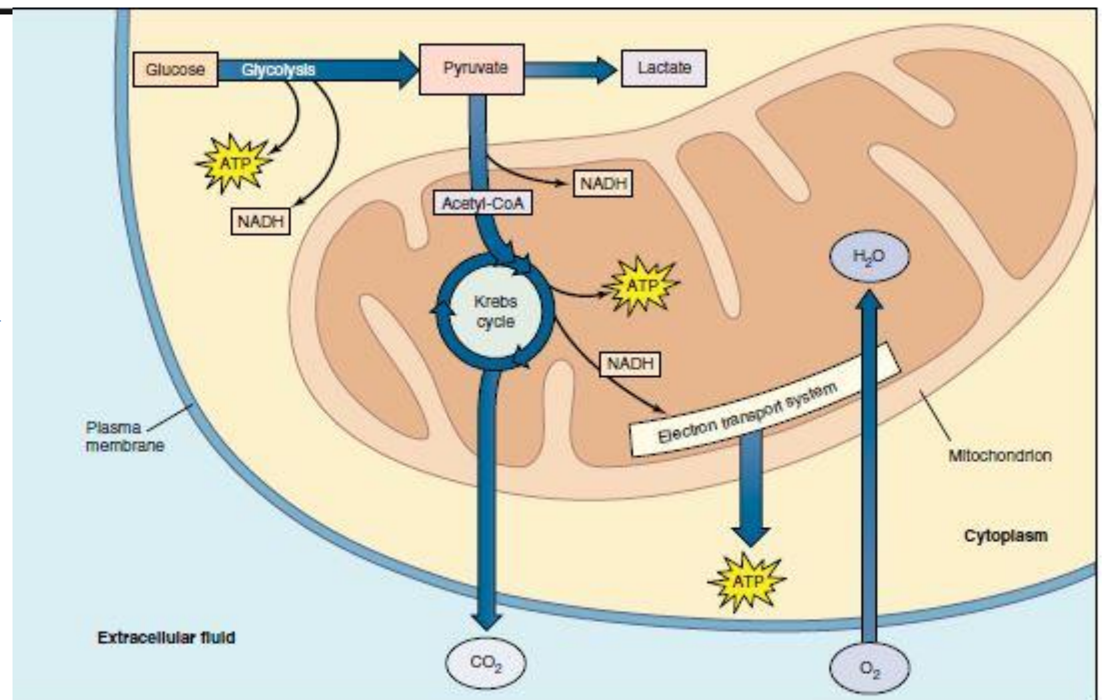
Ageno,1978

Input and output



chloroplast

Mammalian cell



Chemicals

Huge importance of liquid state for life

Surface tension is the elastic tendency of a fluid surface which makes it acquire the least surface area possible.

At liquid-air interfaces, surface tension results from the greater attraction of liquid molecules to each other (due to cohesion) than to the molecules in the air (due to adhesion). The net effect is an inward force at its surface that causes the liquid to behave as if its surface were covered with a stretched elastic membrane.

Main phenomena and law involved in membrane processes:

- osmosis
- concentration partition between different phases
- diffusion (Fick laws)
- redox processes and electrochemical potential (Nernst equation and similar)
- ion pumps (hydrolysis and catalysis)

Protein folding does not occur in isolation but in solution.

Entropic forces

The cells are very crowded: because of their size, small molecules (water and ions) can not get too close to large molecules (proteins, DNA and lipid vesicles): if they went over, they would be incorporated. All large molecules are then surrounded by an exclusion zone: the depletion zone.
If two large molecules adhere to one another, their exclusion zones merge, freeing space for small ones. More space means more microstates available and therefore a greater entropy.

The increase of the order, due to the union of larger molecules, is largely compensated by the disorder that results from greater freedom of movement (resulting in an increase of entropy) of the smaller surrounding molecules . The final result is a force that does not derive from a decrease of energy, but by an increase of entropy. These so strange forces, that can exist only on the molecular scale, are known as ***entropic forces.***

Cells utilize entropic forces for assembling several molecular structures: collagen, actin and microtubule filaments

The hydrophobic force is another example of entropic force.

Hoffmann, 2012

Systems Biology

Systems biology defines and analyzes the interrelationships of all of the elements in a functioning system in order to understand how the system works. In biology, systems approaches aim to:

1. Analyze the thousands of genes/proteins and other molecules comprising the system simultaneously, under different conditions (global analysis vs. local, i.e., one gene/protein);
2. Analyze several levels of complexity: molecules, complexes, modules, networks, cells…
3. Dissect networks: protein–protein interactions, signaling, metabolic and gene regulatory networks;
4. Computationally model/simulate processes;
5. Determine temporal, environment, and genetic/epigenetic changes affect functions.

Definitions

System: Any collection of biological entities (genes, proteins, miRNAs, etc.) that are under study. Systems can contain molecules that can participate in different complexes/networks or modules.

Complexes: Groups of many proteins (and other biomolecules) whose interactions are co-temporal and co-spatial. Complexes form molecular machines with distinct biochemical functions and their compositions and interactions can change genetically/epigenetically, thus determining network and module functions.

Network: Networks are systems of interacting biomolecules (collections of genes, gene products, etc.) with distinct functional outcomes. Networks can consist of single proteins or collections of complexes forming a grid. Interactions can be physical, functional, etc. Network organization is described in terms of links and nodes (see following network slides).

Modules: Collections of genes/proteins or interacting complexes that participate in determining specific cellular functions through network formation. They can arise from different networks or nodal proteins engaged in functional interactions.

Despite all reductionism, determinism and linear approach which try to simplify the problems, some basic principles remain and will remain in the temporal and spatial scale in which we move as living beings in the everyday.

In Systems Biology and living systems: other important elements…

- centrality of information (next to space+time and energy+matter)
- compressibility of info for an algorithmic definition of the complexity (Chaitin)
- compressibility of info for thinking of binomial understanding-compression
- scale-free networks (Barabasi and graph theory)
- non reductionist and non deterministic approach
- entropy and its inversion
- turbulence and phase transition
- edge of chaos and order emerging from disorder
- evolution and natural selection
- Importance of inaccuracies and errors for the adaptability (DNA transcription errors)
- presence of hierarchical levels of complexity
- autopoiesis and life foundations (Varela e Maturana)
- natural and artificial life (intelligence)
- observer's role as complex system he himself (inevitable limitations, relationship observer-observed object, observer's interference on the observation)

cfr. Eletti, 2010

What about robustness and instability?

Each biological complex system (for example a cell) possess a certain extent of dynamical stability: more or complicated different processes run in similar space-time conditions and contribute to the right work. Generally, it has the property of a steady regime of *to resist perturbation* coming from the outside provided it is not too strong. In a rapid and qualitative synthesis we could distinguish some usual types of stability:

(i) if, after removal of the perturbation, the system returns to its previous steady regime, it possesses the *asymptotical* stability;

(ii) if the system adopts a new steady regime close to the previous one, but without returning to the original one, the stability is called *simple*;

(iii) if, on the other hand, the shift caused by the perturbation self-amplifies it-self (of course, after the perturbation end), the steady regime is called *unstable*;

(iv) finally, it can happen that a steady regime is unstable to certain perturbations and stable (asymptotically or simply) to the other: in this case the stability is called *conditional*.

A regime can be stationary without being steady. In statistics, cases of unstable equilibrium are well known, but also in dynamic regimes. *The properties of steady state and stability do not match at all, although there is an instinctive propensity to associate them*, because the vast majority of natural phenomena are at the same time both stationary and stable, *otherwise they would not be observed*.

Reduction or Emergence?

In my opinion, the question is incorrect: both points of view must be applied in science!

► The reduction view

It is the view of most physicists that the properties of big things can be deduced from those of its constituents. With the availability of large scale computation, the reductionist view that any property of a large object can be deduced from that of its constituents has become very powerful. This view of the world, which can be said to have started with Newton, gives a special status to the study of elementary particles. In a sense, it is the most fundamental of all material knowledge. The truth is, we won't know what is there until we get there. There is no substitute for experimental research.

► Emergent phenomena

There is another view, also held by prominent physicists: that it may not be necessary to know the ultimate structure of matter to understand what happens at larger levels: the effect of small scale structure on large objects is limited to the variation of a finite number of parameters. .. Ideas from one area were useful in the other. It looks as though it really doesn't matter what the next level of structure is, to understand what goes on at energies accessible to us now. This approach, pushed most notably by Laughlin and Anderson, is that the theories of elementary particles are also `emergent phenomena' no more fundamental than the theory of superconductivity or of magnetism.

The precise nature of the emerging collective phenomena depends on the mode of interaction between the individual elements and the type of correlation that binds them. Deducing the nature of an emerging phenomenon based solely on the properties of a single object is very difficult, if not impossible.

"... There is no fundamental incompatibility between reductionism and emergence, these are complementary approaches, to use in relation [to the way we want to] study a system." [Licata]