

Intelligent Systems, Control and Automation:  
Science and Engineering 90

Spyros G. Tzafestas

# Energy, Information, Feedback, Adaptation, and Self-organization

The Fundamental Elements of  
Life and Society

 Springer

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Spyros G. Tzafestas

# Energy, Information, Feedback, Adaptation, and Self-organization

The Fundamental Elements of Life  
and Society

 Springer

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# Preface

*Society is well governed when its people obey the magistrates,  
and the magistrates obey the law.*

Solon

*I cannot teach anybody anything. I can only make them think.*

Socrates

*Science is the creator of prosperity.*

Plato

*Freedom is the sure possession of those alone who have the  
courage to defend it.*

Pericles

*Wealth consists not in having great possessions, but in having  
few wants.*

Epicurus

The aim of this book is to provide a comprehensive conceptual account of the five fundamental elements of life and society, viz., energy, information, feedback, adaptation, and self-organization. These elements inherently support any living organism, human society, or man-made system.

*Energy* is the cornerstone of everything. *Information* is included in the “program” (organized plan) of any living organism, to function over time, which is implemented by the DNA that encodes the genes and is transferred from generation to generation. It is one of the main factors of the progress of modern society which is characterized as the “*information society*”. *Feedback* (control) is a “must” for any kind of system, biological, natural, or technological, to be stable and operate according to its purpose. *Adaptation* is the capability of living organisms, species, and societies to adapt to changes that occur in their environment so as to fit to it. It

is the principle that lies behind the natural selection and evolution. *Self-organization* has many interpretations, the predominant of which is the “tendency” of natural systems to become more organized by their own, and shows more structure or order or pattern without the help or intervention of any external agent. This means that spontaneous emergence of global complex structure occurs out of local interactions.

All the above aspects of life and society have been of principal concern to humans over time, and a plethora of concepts and scientific or technological methodologies were developed and studied. The topics addressed in this book are the subject matter in a vast number of sources in the literature and the web. The book gives a collective and cohesive presentation of the fundamental issues, concepts, principles, and methods drawn from the literature, including modern applications and short historical notes of each field. The presentation is kept at a level sufficient for a clear understanding of the concepts and principles by the general scientific reader. In many cases, viz., thermodynamics, communication systems, information theory, and feedback control, the discussion includes the basic mathematical analysis aspects in some more detail which are deemed to be necessary and useful for the nonprofessionals. Unavoidably, the material provided in the book does not exhaust all the results and views available in the literature. However, it is considered to be over sufficient for disseminating the fundamental concepts and issues. The views and opinions/quotations on the delicate aspects of life and society, presented in the book, are those coined and published by the referenced authors. No attempt was made to modify or speculate them in any way.

The writing of this book was inspired by the need of a concise, cohesive, and complete presentation of the five life-and-society fundamental elements (pillars): energy, information, feedback, adaptation, and self-organization in a unique volume. Surely, besides the general reader, this book will be valuable as a source for introductory or complementary material in relevant science and engineering academic programs.

The book involves 13 chapters. Chapter 1 provides an introduction to the book presenting the background concepts of life and society, and outlining the five fundamental elements of life and society considered in the book.

Chapters 2 and 3 are devoted to the *energy*. Chapter 2 presents the basic issues of energy (historical landmarks, types, sources, and environmental impact), and Chap. 3 is devoted to thermodynamics (basic concepts, laws of thermodynamics, entropy, exergy, branches of thermodynamics, and entropy interpretations).

Chapters 4 and 5 are concerned with the *information* element. Chapter 4 introduces the concept of information and reviews the communication systems and information theory. Chapter 5 discusses information science, information technology, and information systems in enterprises and organizations.

Chapters 6 and 7 are devoted to the *feedback element*. Chapter 6 presents the concept of feedback and control, the history of its study, and the methods for linear and nonlinear control systems analysis and design developed between about 1935 and 1950 (classical control). Chapter 7 reviews the modern control techniques which are based on the state-space model, namely, Lyapunov stability,

state-feedback (eigenvalue/model matching) control, and optimal control (deterministic and stochastic). The classes of adaptive, predictive, robust, nonlinear, and intelligent control are also discussed.

Chapter 8 is concerned with the *adaptation* in biology and society including the related scientific fields of complexity and complex adaptive systems.

Chapter 9 is devoted to the final fundamental element studied in the book, i.e., the *self-organization* of natural and societal systems. The four self-organization mechanisms observed in nature are first reviewed, and the concept of self-organized criticality (edge of chaos) is then discussed. The role of *cybernetics* in the study of self-organization is also examined.

Chapters 10 through 13 are concerned with the role and impact of the five fundamental elements studied in the book on life and society discussing major issues and a variety of examples. Chapter 10 discusses the fundamental role that energy plays in life and society, starting with an examination of the three basic biochemical pathways of energy in life (photosynthesis, respiration, and metabolism) and going to the energy flow in ecosystems. The evolution of energy resources, the thermoeconomy, and the saving of energy in the human society are then investigated.

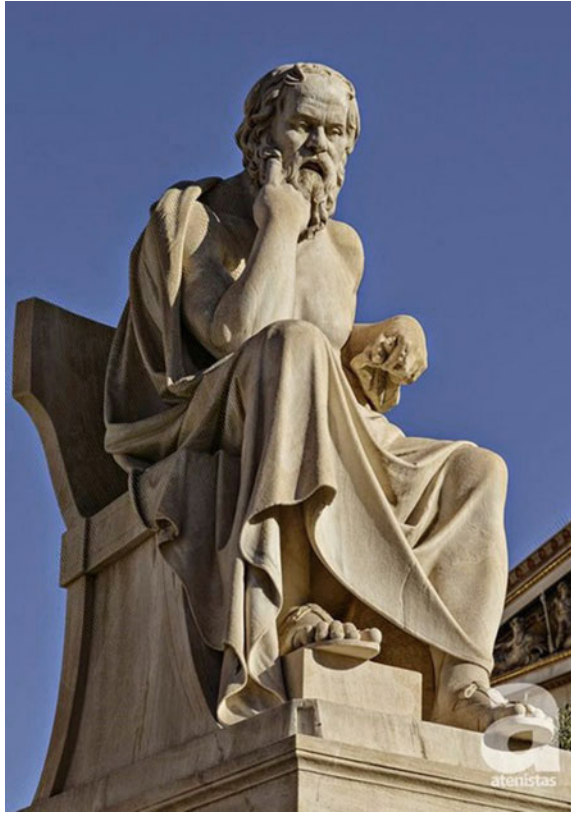
Chapter 11 deals with a number of issues that refer to the role of information in life and society. These include the substantiative and transmission roles of information in biology, and the information technology applications in modern society, such as office automation, power generation /distribution, computer-assisted manufacturing, robotics, business/e-commerce, education, medicine, and transportation.

Chapter 12 reviews the role and impact of feedback in both living organisms and societal systems. Representative examples that best show the operation of negative and positive feedback in biology and society are provided. These include temperature, water, sugar, and hydrogen ion (pH) regulation, autocatalytic (autoreproduction) reactions, enzyme operation, cardiovascular-respiratory system, process control, manufacturing control, air flight and traffic control, robot control, management control, and economic control systems.

Finally, Chap. 13 provides a number of adaptation and self-organization examples and applications in life and society. These examples are adaptations of animals, ecosystems, climate change, immune systems, social-ecological systems, capital /stock market, general society system, knowledge management, and man-made self-organizing systems.

In overall, the book provides a cohesive and complete picture of the five fundamental elements: energy, information, feedback, adaptation, and self-organization, and the role they play in sustained life and society, including selected modern applications.





Only one thing I know, that I know nothing.

Only Absolute Truth is that there are No Absolute Truths.

**Socrates, Athens, 470-399 B.C.**

Footnote: *Statue of Socrates in front of Athens Academy*

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# Chapter 1

## Life and Human Society: The Five Fundamental Elements

*The goal of life is living in agreement with nature.*

Zeno of Elea (490–435 B.C.)

*The good life is one inspired by love and guided by knowledge.*

Bertrand Russel

**Abstract** The aim of this chapter is to provide fundamental material about life and society (definition, evolution, etc.), starting with a brief presentation of cell biology, DNA/RNA, protein synthesis, and a list of the principal discoveries about DNA and RNA. The meaning of “society” is discussed, followed by the evolution of life on Earth, and the evolution of human society (physical, vital, and mental stages). The common fundamental elements (pillars) of life and society that are studied in this book, namely: energy, information, feedback, adaptation, and self-organization, are briefly introduced. As a supplement, the chapter includes a short outline of some purely societal fundamental elements that are encountered in humanity studies. These elements are: (i) pillars of democracy, (ii) pillars of fulfilled living, and (iii) pillars of sustainable development.

**Keywords** Life · Society · Molecular biology · Cell biology · Life domains  
Energy · Information · Feedback · Adaptation · Self-organization  
Evolution of life · History of life · Evolution of human society  
Human development · DNA · Life-program · Pillars of democracy  
Pillars of fulfilled living · pillars of sustainable development

### 1.1 Introduction

This chapter serves as an introduction to the book by providing some background concepts about life and society, specifically their definitions and evolution. These concepts will help the reader to go smoothly to the five particular “*elements*” or “*pillars*” of life and society studied in the book. The term “*pillar*” is used in several frameworks of life and society, some of which will be discussed in Sect. 1.5. Koshland has used the term “pillar” for the definition of ‘life’ [1]. According to

Webster (1913) the term “pillar” literally means “a firm, upright, insulated support for a superstructure; a pier, column, or post; also, a column or shaft not supporting a superstructure, as one erected for a monument or an ornament” [2, 3]. “Figuratively, that which resembles a pillar in appearance, character or office; a supporter or mainstay” (as: the Pillars of Hercules; a pillar of the state, etc.) or “anything tall and thin approximating the shape of a column or tower”. In science, pillar may be called “a fundamental principle or practice”.

The questions “*what is life*” and “*what is society*” were of primary concern to humankind throughout the centuries of historical record and have been studied by philosophers, scientists, biologists, sociologists, archaeologists, geographers, etc. Today we have better informed and more developed views of what is life and how it evolved since the formation of Earth 4.5 billion years ago. We know that human societies are essentially “*adaptive systems*” the elements of which, “*human populations*”, strive to satisfy their varied needs and wishes. History has shown that these needs and wishes have been accomplished either by maintaining existing ways of doing things or by developing and adopting new, innovative ways. In all cases, the parts that failed to adapt were eliminated from the system, while those that succeeded survived. This is exactly the “*principle of survival of the fittest*” which holds in all biological and sociological processes.

The structure of the chapter is as follows. Section 1.2 deals with the question “*what is life*”. It starts with a brief presentation of cell biology, DNA, and protein synthesis. Then it lists the main discoveries about DNA and RNA, and provides the definition of life coined by *Daniel Koshland*. Section 1.3 is concerned with the meaning of society (*Richard Jenkins’* and *Richard Alston’s* views). Section 1.4 outlines the evolution of life (prokaryotes, eukaryotes, etc.) and society (physical, vital, and mental stages). It also includes a discussion of *human development* (requirements, components, economic models) and *human development index*. Section 1.5 describes briefly the fundamental elements of some societal aspects, other than the five elements that are the subject matter of the book, namely: democracy, fulfilled living, and sustainable development. Finally, Sect. 1.6 discusses the scope of the book and places the five pillars: energy, information, feedback, adaptation, and self-organization, in their proper position which is in the “intersection” of the “*biological*” and “*societal*” sets of pillars [1–118].

## 1.2 What Is Life?

### 1.2.1 General Issues

The reply to this question appears to be simple: “A living organism is an organized entity which is able to grow and sustain itself through metabolic processes (absorption of energy), to respond to stimuli, to protect itself from external attacks or injuries, and to be reproduced”. This is a very primitive definition of life not

capturing all the facets of life. Actually, many biologists have the opinion that there still does not exist a clear, definite, and complete definition of life. One of the reasons seems to be the existence of *viruses* and other *microscopic entities*. Many biologists suggest that viruses are complex organic molecules, but others consider viruses as the simplest form of life. No one knows with certainty how life began. But we know for certain that all life on Earth involves strings of **DNA** (**D**eoxyribo**N**ucleic **A**cid) that are long chains of self-replicating molecules which encode information (*genes*) and implement the so-called *life-program*. We also know that life (except of viruses) is constructed by cells, i.e., tiny containers which contain the DNA and other chemical compounds that make up the cells. The early life forms were single cells. To understand what life is and later supply an apparently complete list of *features* (or *pillars*) that define life, we first give a short review of *cell-biology* (biological cell) [4–11].

### 1.2.2 The Living Cell

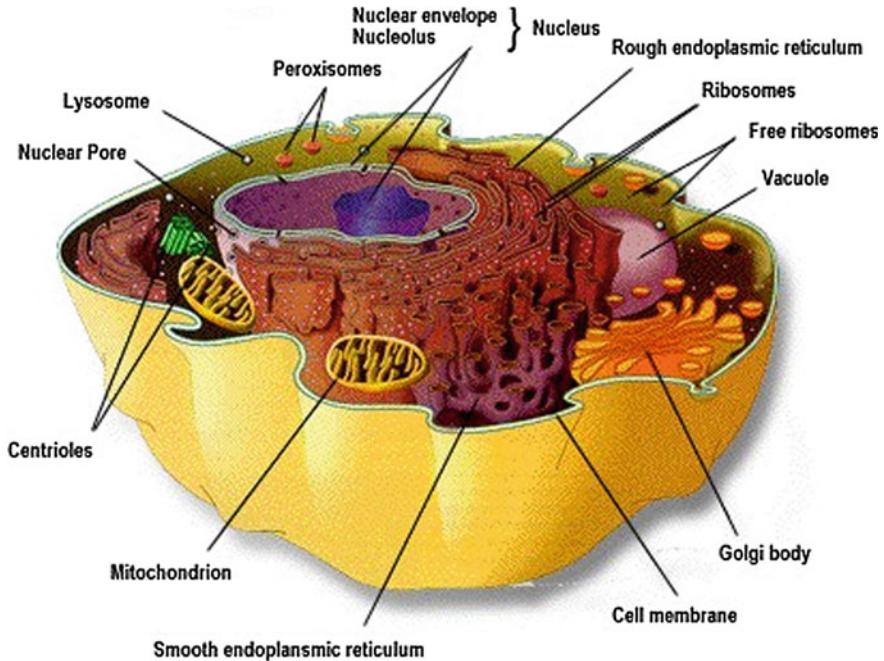
A *living organism* may be composed of a single biological cell (*single-cell organisms*) or of many cells (*multiple-cell organisms*). The biological cell can sustain its functionality through a set of *organelles* (which are “*miniature*” machines) that each have a special function. Some of them in case of the animal cells are the following Fig. 1.1 Analogous organelles exist in the plant cell (<http://waynesword.palomar.edu/lmexer1a.htm>).<sup>1</sup>

**Cell membrane or plasma membrane** This is the external layer of a cell that has a structural and protective role affecting how molecules enter or exit the cell.

- **Nucleus** This is the “*brain*” of the cell that contains the genetic information about the processes taking place in an organism. It is surrounded by the *nuclear membrane*.
- **Nucleolus** This resides inside the nucleus and is the organelle where ribosomal RNA is produced.
- **Cytoplasm** This is the fluid that surrounds the contents of a cell.
- **Mitochondrion** This is an organelle that participates in respiration (i.e., in the energy release and storage; it is also called “*powerhouse*” of the cell).
- **Ribosomes** These are packets of **RNA** (**R**ibo**N**ucleic **A**cid) and protein. They are the site of protein synthesis. Messenger RNA from the nucleus moves systematically along the ribosome where transfer RNA adds individual amino-acid molecules to the lengthening protein chain.
- **Lysosomes** These are sacs filled in with digestive enzymes.

---

<sup>1</sup>(\*) The term “biology” comes from the Greek “**Βίος**” (bios = life) and “**λόγος**” (logos = speech/study), (\*\*\*) All web sources and references were collected during the writing of the book. Since then, some of the urls may not be valid due to change or removal.



**Fig. 1.1** Schematic of eukaryote animal cell with the basic organelles. *Source* [http://www.odcc.ca/projects/2004/mcgo4s0/public\\_html/t1/animalcell3.jpg](http://www.odcc.ca/projects/2004/mcgo4s0/public_html/t1/animalcell3.jpg) (The reader is informed that Web figures and references were collected at the time of writing the book. Since then, some of them may not be valid due to change or removal by their creators, and so they may no longer be available)

- **Golgi body/complex** They are involved in the production of glycoprotein.
- **Vacuole** Cavities filled with food being digested and waste material to go out of the cell.
- **Centrosome** A small body located near the nucleus, also called “the microtubule organizer center”. It is the organelle where microtubules are made during cell division (mitosis).
- **Endoplasmic reticulum (ER)** A useful organelle, differentiated into rough ER and smooth ER, which is involved in the synthesis of protein.

The cell (or plasma) membrane, which is a semi-permeable structure composed by proteins and fat (*phospholipid*) molecules, acts as a circumferential barrier and allows only selected compounds to get in and out of a cell. The transportation of *ions* via the cell membrane into the cell is performed in three ways: *active transport* (based on concentration gradient), *passive transport* (diffusion via a carrier), and *simple diffusion* (such as *osmosis of water*). The uptake of materials from the external environment of the cell is called *absorption*, and the ejection of material is called *secretion*. A full animal-cell picture with labels is provided by *Russell Kightley Media* [21].

The cells are specialized to each perform a distinct function within an organism. Thus we have, for example:

- **Skin cells** They function as waterproof and pathogen protection from the cell's exterior environment.
- **Nerve cells** These cells, also called *neurons*, are electrically excitable cells that function within the nervous system for message transmission to and from the central nervous system.
- **Muscle cells** These cells have an elastic capability and enable flexible movement (as in our muscles).
- **White blood cells** They activate suitable digestive enzymes that break down pathogens to the molecular level, thus eliminating them.

Biological cells have the capability to break down complex molecules into simple molecules, which can then be used as building elements of other complex molecules. This is done via *pinocytosis* (e.g., drinking bacteria after breaking down them into drinkable form) or *phagocytosis* (in which the original material is eaten, after it has been broken down into a suitable form).

### 1.2.3 DNA, Nucleotides, and Protein Formation

The type, structure, and functioning of cells are determined by *chromosomes* (from the Greek words *chroma* = color and *soma* = body) which reside in the cell nucleus. These chromosomes are made from DNA bonded to various proteins in the nucleus of eukaryotic cells or as a circular strand of DNA in the cytoplasm of prokaryotes and in the mitochondrion (and chloroplast) of some eukaryotes. The DNA specifies all the features of an organism, containing all the genetic material that makes what a living being is. This material (information) is transferred from generation to generation in a species, determining the offsprings' characteristics. The building blocks of DNA are the *nucleotides* which appear as four different types, namely: *adenine* (**A**), *guanine* (**G**), *thymine* (**T**), and *cytosine* (**C**). Our genome contains billions of these nucleotides in all possible permutations, located in adjacent pairs along the *double-helix* arrangement of DNA. Actually, there are two groups of bases, namely, *purines* and *pyrimidines*. Purines (adenine and guanine) have a two-ring structure, whereas pyrimidines (thymine and cytosine) have a single-ring structure. *Complementary* (or *permissible*) bases are bases that pair together in a DNA molecule. These base pairs are:

- Thymine and adenine (**TA**)
- Guanine and cytosine (**GC**)

Thymine and cytosine cannot make a base pair, and similarly adenine and guanine cannot form a base pair.



While **DNA** resides mainly in the nucleus, the nucleic acid polymer **RNA** (*Ribonucleic acid*) is found mainly in the cytoplasm, despite the fact that it is usually synthesized in the nucleus. DNA contains the genetic codes to make RNA, and RNA contains the codes for the primary sequences of amino acids to make proteins.

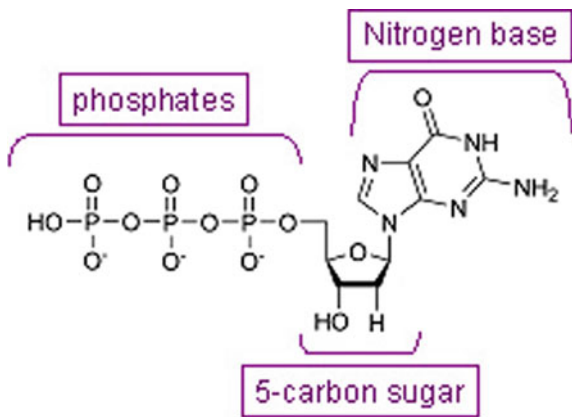
The backbone of the polymer is a repeating chain of sugar-phosphate-sugar-phosphate, etc. The pentose sugar of DNA is a *deoxyribose* sugar, whereas RNA contains a *ribose* sugar. Both DNA and RNA contain a phosphate group and a nitrogenous base as shown in Fig. 1.2.

The pentose is a five-membered, puckered ring. Attached to the ring is the phosphate group (which is a phosphorous atom with four covalently attached oxygen atoms) and the nitrogenous base. Pictures of DNA and RNA models are provided in <http://www.dreamstime.com/stock-images-structure-dna-rna-molecule-vector-image28618424><http://www.dreamstime.com/stock-images-structure-dna-rna-molecule-vector-image28618424>

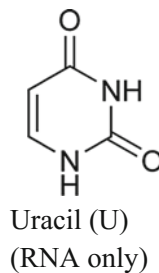
In the RNA model, we have an extra-OH of the pentose sugar, and the *uracil* base (**U**) is used instead of the thymine base (**T**) used in DNA (Fig. 1.3).

The cells—which have finite life spans—pass their genetic information to new cells replicating *exactly* the DNA to be transferred to offsprings. To this end, a

**Fig. 1.2** Structure of connected pentose sugar, phosphate group, and nitrogenous base in DNA and RNA



**Fig. 1.3** Uracil base (a single-ring pyrimidine)



supply of suitable *enzymes* that stimulate the reaction process is available, together with a pool of the required nucleotides. The actual DNA acts as an *exact template*. The energy needed for this transfer is provided by **ATP (Adenosine Triphosphate)** molecules (see Chap. 10).

Actually, the replication of the double-helix DNA involves two strands of DNA, each one of which produces a copy of itself. The replicated DNA has only half of the original material from its parent (i.e., it is *semi-conservative*). Therefore the two copies produced have the full (exact) DNA material contained in the two strands of the DNA involved in the replication. This is the way genetic information is transferred from cell to cell and from parent to offspring.

The sequence of the nucleotides is used to create *amino acids*, the chains of which are shaped so as to make a protein. An amino-acid molecule consists of the basic *amino group* ( $\text{NH}_2$ ), the *acidic carboxylic group* ( $\text{COOH}$ ), a *hydrogen atom* (**H**), and an *organic side group* (**R**) attached to the carbon atom. Thus, an amino acid has the structure  $\text{NH}_2\text{CHR}\text{COOH}$ . Actually, there exist more than a hundred amino acids in nature, each of them differing in the R group. Twenty of them participate in protein synthesis and are differentiated into *essential* and *non-essential* amino acids. *Essential* (or indispensable) amino acids cannot be created in the body and can only be acquired via food. *Non-essential* (or dispensable) amino acids are synthesized in the body. These twenty amino acids are the following:

- **Essential** Histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine.
- **Non-essential** Alanine, arginine, aspartic acid, asparagine, cysteine, glutamic acid, glutamine, glycine, proline, serine, and tyrosine.

The structure of proteins spans four levels of complexity, namely:

- *Primary structure* (the sequence of amino acids).
- *Secondary structure* (local folding sustained via short-distance interactions; hydrogen bonds).
- *Tertiary structure* (additional folding sustained via more distant interactions between alpha helices and pleated sheets).
- *Quaternary structure* (sustained by interchain interactions of more than one acid chain).

Although the sequence must determine the structure, we cannot yet predict the full structure accurately from a sequence. Structures are stable and relatively rigid. Today, there are about 4000 known protein structures determined by X-ray crystallography and 2-D NMR studies. The above four-level structure of proteins is depicted in Fig. 1.4.

The synthesis of proteins takes place in the *ribosomes* residing in the cell's cytoplasm, whereas the genetic information lies in the nucleus. Thus, the genetic information has to pass to these ribosomes. This transfer is performed by **mRNA**

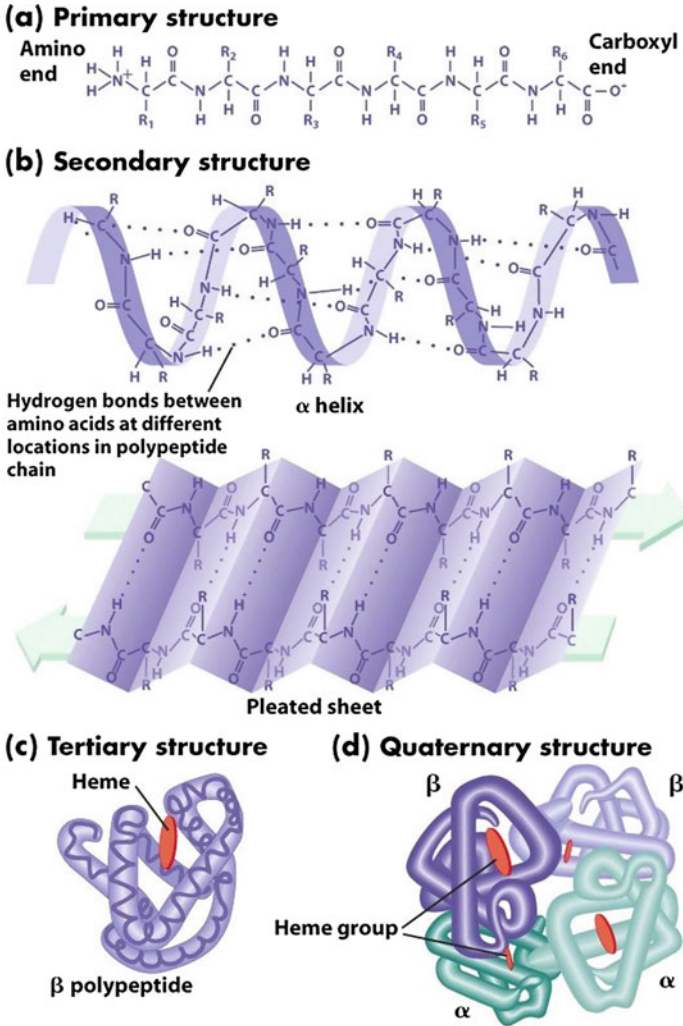


Fig. 1.4 The four-complexity levels of proteins (source [18])

(messenger ribonucleic acid), which is analogous to DNA, differing only in two aspects.

- In mRNA, the thymine bases are replaced by a base called *uracil* (U).
- The deoxyribose sugar of DNA is substituted by ribose sugar.  
The transfer is performed in the following sequence:
- Inside the cell's nucleus, genes (DNA) are transcribed into RNA. To this end, the double-helix structure of DNA uncoils for mRNA to replicate, like the DNA, the genetic sequence of which corresponds to the protein under synthesis.

- This RNA produces a mature mRNA through post-transcription modification and control.
- The mRNA is transported out of the nucleus and travels through the cytoplasm until it reaches a ribosome where it is translated into protein. Since ribosomes don't understand the mRNA code, they use their *translator*, i.e., the *transfer RNAs* (**tRNAs**). The RNAs decode the message and assemble the desired amino acids in the specified sequence to form the protein which is released into the cytoplasm for further transport and processing.

The above scheme for *protein synthesis* (known as “*dogma of molecular biology*”) is pictorially illustrated in Fig. 1.5.

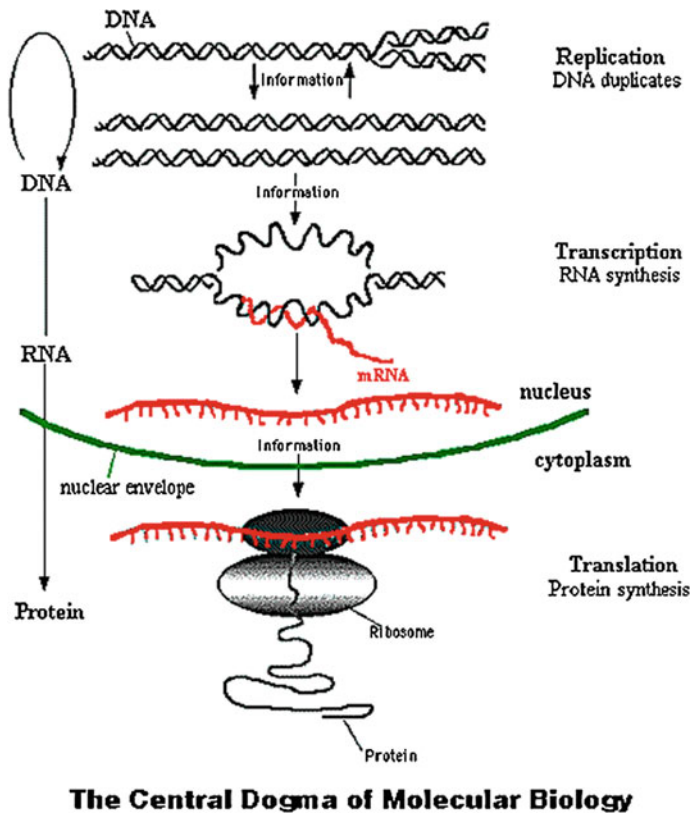


Fig. 1.5 Synthesis of protein (source [9])

### 1.2.4 Historical Landmarks of DNA and RNA Discoveries

Until the 1800s, it was believed that life arose more or less spontaneously, but in 1864 *Louis Pasteur* disproved spontaneous generation. He demonstrated that, when any micro-organisms residing in a liquid are killed through boiling, the liquid becomes *sterile* (nothing grows afterwards). After *Pasteur*, the principal historical landmarks of the “RNA world” are here listed chronologically [12]. The complete historical evolution of DNA and RNA discoveries and studies can be found in [13–17].

- 1924: *Alexander Ivanovich Oparin* attributes the origin coming of the simplest single-cell life to simple organic molecules residing in the early Earth’s atmosphere that was substantially different from our present atmosphere—there was no free oxygen, but there was abundant hydrogen, ammonia, methane, carbon dioxide, water, and nitrogen).
- 1953: *James Watson* and *Francis Crick* publish their results on the structure of DNA. They received a joint Nobel Prize for these results in 1962.
- 1961: *Marshall Nirenberg* and colleagues discover that messenger RNA, composed completely of the base uracil, can be translated into the amino acid phenylalanine.
- 1968: *Francis Crick* and *Leslie Orgel* argue that the first information molecule was RNA.
- 1972: *Harry Noller* suggests that ribosomal RNA plays a role in the translation of mRNA into protein.
- 1986: *Walter Gilbert* uses the term “RNA world” for the time during which RNA was the main information and catalytic molecule. *Thomas Cech* presents his discovery of *self-splicing* (catalytic RNA). In 1989, he shares a Nobel Prize with *Sidney Altman* for the catalytic RNA discovery. *Kary Mullis* presents a procedure for rapid copying of DNA and RNA sequences (*polymerase chain reaction*). He was awarded a Nobel Prize for this in 1993.
- 1989: *Gerald Joyce* starts his work on simulating RNA evolution via the “polymerase chain reaction”. *Jack Szostak’s* lab provides evidence for self-replicating RNA.
- 1992: *Harry Noller’s* lab provides experimental evidence for the involvement of ribosomal RNA in protein synthesis.
- 1993: *Gerald Joyce* presents test-tube experimental processes for RNA evolution.
- 1994: *Charles Wilson* (while working in *Szostak’s* labs) creates RNA molecules that are able to perform simple cellular reactions more efficiently than the proteins, which perform it in cells.

Complete presentations of “*molecular cell biology*” are provided in [19, 20], where both *genomics* (the complete DNA sequences of many organisms), and *proteomics* (all possible shapes and functions that proteins employ) are studied. The principal topics considered include:

- The dynamic cell
- Nucleic acids and genetic code

- From gene to protein
- Protein structure and function
- Genetic analysis
- DNA replication, repair, and recombination
- RNA processing and post-transcriptional control
- The mechanism of translation
- Gene control in development
- Cell-to-cell signaling: hormones and receptors
- Genome analysis
- Epigenetics and monoallelic gene expression
- Medical molecular biology.

A useful site with biology images, videos, and cell-interactive animation is provided by *Cells Alive Com* in [22].

### 1.2.5 Koshland's Definition of Life

With the background on molecular and cell biology provided in Sects. 1.2.2–1.2.4, we can now proceed and examine the seven fundamental elements (pillars) that define life as presented by the molecular biologist *Daniel Koshland* (2002) [1], where the term “pillars” is used to mean “*the essential principles (thermodynamic and kinetic) that enable a living system to operate and propagate*”. These seven pillars, although essential to the distinct mechanisms by which the life's principles are implemented on Earth, may be complemented by other pillars, as well that may explain better the mechanisms of life so far known or other mechanisms to be discovered in the future for other forms of life or for life elsewhere [1]. Koshland's seven pillars defining life are the following:

- Program
- Improvisation
- Compartmentalization
- Energy
- Regeneration
- Adaptability
- Seclusion,

Which can be represented by a Temple, called as a whole by the acronym **PICERAS**. A brief description of the pillars follows Fig. 1.6.

**Program** Koshland states that “*program* is the organized plan that describes both the ingredients themselves and the kinetics of the interactions among ingredients as the living system persists through time”. These interactions and processes involve the metabolic reactions that enable a living organism to function over time. Each program of a living system on Earth is implemented by the DNA which encodes the