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## 2.1 Introduction

Modern biology has its roots at the work of Gregor Mendel who identified the fundamental rules of hereditary in 1865. The discovery of chromosomes and genes followed later and in 1952 Watson and Crick disclosed the double helix structure of DNA. All living organisms have common characteristics such as replication, nutrition, growing and interaction with their environment. An *organism* is composed of *organs* which perform specific functions. Organs are made of *tissues* which are composed of aggregation of cells that have similar functions. The *cell* is the basic unit of life in all living organisms and it has molecules that have fundamental functions for life. Molecular biology is the study of these molecules in the cell. Two of these molecules called *proteins* and *nucleotides* have fundamental roles to sustain life. Proteins are the key components in everything related to life. DNA is made of nucleotides and parts of DNA called *genes* code for proteins which perform all the fundamental processes for living using biochemical reactions.

Cells synthesize new molecules and break large molecules into smaller ones using complex networks of chemical reactions called *pathways*. Genome is the complete set of DNA of an organism and human genome consists of chromosomes which contain many genes. A gene is the basic physical and functional unit of hereditary that codes for a protein which is a large molecule made from a sequence of amino acids. Three critical molecules of life are deoxyribonucleic acid (DNA), ribonucleic acid (RNA), and proteins. A central paradigm in molecular biology states that biological function is heavily dependent on the biological structure.

In this chapter, we first review the functions performed by the cell and its ingredients. The DNA contained in the nucleus, the proteins, and various other molecules all have important functionalities and we describe these in detail. The central dogma of life is the process of building up a protein from the code in the genes as we will outline. We will also briefly describe biotechnological methods and introduce some of the commonly used databases that store information about DNA, proteins, and other molecules in the cell.

## 2.2 The Cell

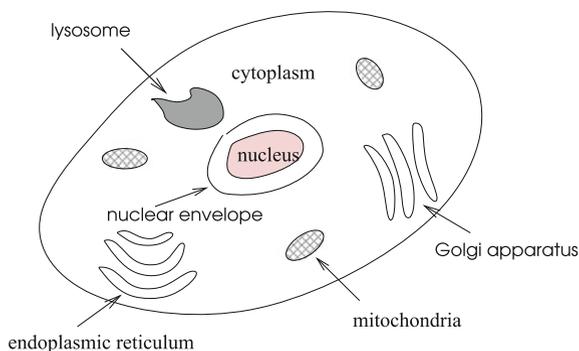
Cells are the fundamental building blocks of all living things. The cell serves as a structural building block to form tissues and organs. Each cell is independent and can live on its own. All cells have a metabolism to take in nutrients and convert them into molecules and energy to be used. Another important property of cells is *replication* in which a cell produces another cell that has the same properties as itself. Cells are composed of approximately 70 % water; 7 % small molecules like amino acids, nucleotides, salts, and lipids, and 23 % macromolecules such as proteins and polysaccharids. A cell consists of molecules in a dense liquid surrounded by a membrane as shown in Fig. 2.1.

The *eukaryotic cells* have nuclei containing the genetic material which is separated from the rest of the cell by a membrane and the *prokaryotic cells* do not have nuclei. Prokaryotes include bacteria and archaea; and plants, animals, and fungi are examples of eukaryotes. The tasks performed by the cells include taking nutrients from food, converting these to energy, and performing various special missions. A cell is composed of many parts each with a different purpose. The following are the important parts of an eukaryotic cell with their functions:

- **Nucleus:** Storage of DNA molecules, and RNA and ribosome synthesis.
- **Endoplasmic reticulum:** Synthesis of lipids and proteins
- **Golgi apparatus:** Distribution of proteins and lipids and posttranslational processing of proteins.
- **Mitochondria:** Generation of energy by oxidizing nutrients.
- **Vesicles:** *Transport vesicles* move molecules such as proteins from endoplasmic reticulum to Golgi apparatus, *Secretory vesicles* have material to be excreted from the cell and *lysosomes* provide cellular digestion.

The nucleus is at the center of the cell and is responsible for vital functions such as cell growth, maturation, division, or death. *Cytoplasm* consists of jellylike fluid which surrounds the nucleus and it contains various other structures. *Endoplasmic*

**Fig. 2.1** Parts of a cell



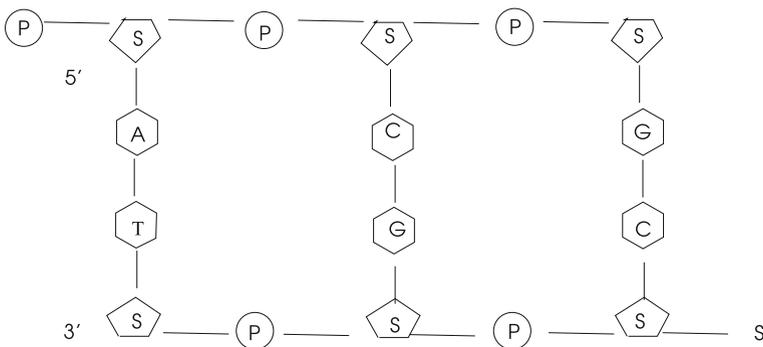
*reticulum* wraps the nucleus, and processes molecules made by the cell and transports them to their destinations. Conversion of energy from food to a form that can be used by the cell is performed by *mitochondria* which have their own genetic material. These components of the cell are shown in Fig. 2.1. The cell contains various other structures than the ones we have outlined here.

Chemically, cell is composed of few elements only. Carbon (C), hydrogen (H), oxygen (O), and nitrogen (N) are the dominant ones with phosphorus (P) and sulfur (S) appearing in less proportions. These elements combine to form molecules in the cell, using covalent bonds in which electrons in their outer orbits are shared between the atoms. A *nucleotide* is one such molecule in the cell which is a chain of three components: a base B, a sugar S, and a phosphoric acid P. The three basic macromolecules in the cell that are essential for life are the DNA, RNA, and proteins.

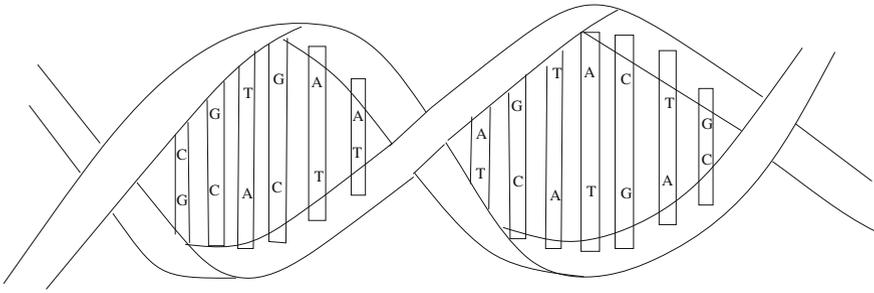
### 2.2.1 DNA

James Watson and Francis Crick discovered the Deoxyribonucleic Acid (DNA) structure in the cell in 1953 using X-ray diffraction patterns which showed that the DNA molecule is long, thin, and has a spiral-like shape [5]. The DNA is contained in the nuclei of eukaryotic cells and is composed of small molecules called *nucleotides*. Each nucleotide consists of a five-carbon sugar, a phosphate group, and a base. The carbon atoms in a sugar molecule are labeled 1' to 5' and using this notation, DNA molecules start at 5' end and finish at 3' end as shown in Fig. 2.2. There are four nucleotides in the DNA which are distinguished by the bases they have: Adenine (A), Cytosine (C), Guanine (G), and Thymine (T). We can therefore think of DNA as a string with a four letter alphabet  $\Sigma = \{A,C,G,T\}$ . Human DNA consists approximately of three billion bases. Nucleotide A pairs only with T, and C pairs only with G, we can say A and T are complementary and so are G and C as shown in Fig. 2.2.

Given the sequence  $S$  of a DNA strand, we can construct the other strand  $S'$  by taking the complement of bases in this strand. If we take the complement of the



**Fig. 2.2** DNA structure



**Fig. 2.3** DNA double helix structure

resulting strand we will obtain the original strand. This process is used and essential for protein production. Physically, DNA consists of two strands held together by hydrogen bonds, arranged in a double helix as shown in Fig. 2.3. The *complement* of a DNA sequence consists of complements of its bases. The DNA therefore consists of two complementary strands which bind to each other tightly providing a stable structure. This structure also provides the means to replicate in which the double DNA helix structure is separated into two strands and each of these strands are then used as templates to synthesize their complements.

The DNA molecule is wrapped around proteins called *histones* into complex-walled structures called *chromosomes* in the nucleus of each cell. The number of chromosomes depends on the type of eukaryote species. Each chromosome consists of two *chromatides* which are coil-shaped structures connected near the middle forming an x-like structure. Chromosomes are kept in the nucleus of a cell in a highly packed and hierarchically organized form. A single set of chromosomes in an organism is called *haploid*, two sets of chromosomes is called *diploid*, and more than two sets is called *polyploid*. Humans are diploid where each chromosome is inherited from a parent to have two chromosomes for each of the 23 chromosome set. The sex chromosome is chromosome number 23 which either has two chromosomes shaped X resulting in a female, or has X and Y resulting in a male. The type of chromosome inherited from father determines the sex of the child in this case.

## 2.2.2 RNA

The ribonucleic acid (RNA) is an important molecule that is used to transfer genetic information. It has a similar structure to DNA but consists of only one strand and does not form a helix structure like DNA. It also has nucleotides which consist of a sugar, phosphate, and a base. The sugar however is a *ribose* instead of deoxyribose and hence the name RNA. Also, DNA base thymine (T) is replaced with uracil (U) in RNA. The fundamental kinds of RNA are the messenger RNA (mRNA), transfer RNA (tRNA), and ribosomal RNA (rRNA) which perform different functions in the cell. RNA provides a flow of information in the cell. First, DNA is copied to mRNA

in the nucleus and the mRNA is then translated to protein in the cytoplasm. During translation, tRNA and rRNA have important functions. The tRNA is responsible for forming the amino acids which make up the protein, as prescribed in the mRNA; and the rRNA molecules are the fundamental building blocks of the ribosomes which carry out translation of mRNA to protein.

### 2.2.3 Genes

A *gene* is the basic unit of hereditary in a living organism determining its character as a whole. A gene physically is a sequence of DNA that codes for an RNA (mRNA, tRNA, or rRNA) and the mRNA codes for a protein. The study of genes is called *genetics*. Gregor Mendel in the 1860s was first to experiment and set principles of passing hereditary information to offsprings.

There are 23 pairs of chromosomes in humans and between 20000–25000 genes are located in these chromosomes. The starting and stopping locations of a gene are identified by specific sequences. The protein coding parts of a gene are called *exons* and the regions between exons with no specific function are called *introns*. Genes have varying lengths and also, exons and introns within a gene have varying lengths. A gene can combine with other genes or can be nested within another gene to yield some functionality, and can be mutated which may change its functionality at varying degrees in some cases leading to diseases. The complete set of genes of an organism is called its *genotype*. Each gene has a specific function in the physiology and morphology of an organism. The physical manifestation or expression of the genotype is the *phenotype* which is the physiology and morphology of an organism cite. A gene may have different varieties called *alleles* resulting in different phenotyping characteristics. Humans are diploid meaning we inherit a chromosome from each parent, therefore we have two alleles of each gene. The genes that code for proteins constitute about 1.5 % of total DNA and the rest contains RNA encoding genes and sequences that are not known to have any function. This part of DNA is called *junk DNA*. There is no relatedness between the size of genome, number of genes, and organism complexity. In fact, some single cell organisms have a larger genome than humans.

### 2.2.4 Proteins

Proteins are large molecules of the cell and they carry out many important functions. For example, they form the antibodies which bind to foreign particles such as viruses and bacteria. As enzymes, they work as catalysts for various chemical reactions; the messenger proteins transmit signals to coordinate biological processes between different cells, tissues, and organs, also they transport small molecules within the cell and the body. Proteins are made from the information contained in genes. A protein consists of a chain of amino acids connected by *peptide bonds*. Since such a bond releases a water molecule, what we have inside a protein is a chain of amino acid

**Table 2.1** Amino acids

Name	Abbrev.	Code	Pol.	Name	Abbrev.	Code	Pol.
Alanine	Ala	A	H	Methionine	Met	M	H
Cysteine	Cys	C	P	Asparagine	Asn	N	P
Aspartic acid	Asp	D	P	Proline	Pro	P	H
Glutamic acid	Glu	E	P	Glutamine	Gln	Q	P
Phenylalanine	Phe	F	H	Arginine	Arg	R	P
Glycine	Gly	G	P	Serine	Ser	S	P
Histidine	His	H	P	Threonine	Thr	T	P
Isoleucine	Ile	I	H	Valine	Val	V	H
Lysine	Lys	K	P	Tryptophan	Trp	W	H
Leucine	Leu	L	H	Tyrosine	Tyr	Y	P

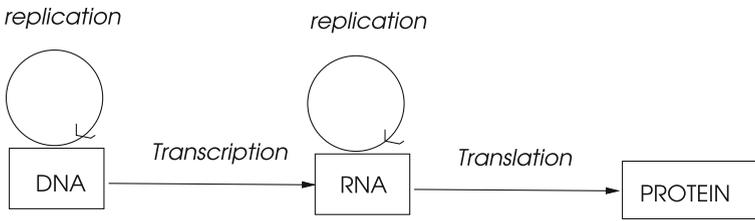
residues. Typically, a protein has about 300 amino acid residues which can reach 5000 in large proteins. The essential 20 amino acids that make up the proteins is shown in Table 2.1 with their abbreviations, codes, and polarities.

Proteins have highly complex structures and can be analyzed at four hierarchical structures. The *primary structure* of a protein is specified by a sequence of amino acids that are linked in a chain and the *secondary structure* is formed by linear regions of amino acids. A *protein domain* is a segment of amino acid sequences in a protein which has independent functions than the rest of the protein. The protein also has a 3D structure called *tertiary structure* which affects its functionality and several protein molecules are arranged in *quaternary structure*. The function of a protein is determined by its four layer structure. A protein has the ability to fold in 3D and its shape formed as such affects its function. Using its 3D shape, it can bind to certain molecules and interact. For example, mad cow disease is believed to be caused by the wrong folding of a protein. For this reason, predicting the folding structure of a protein from its primary sequence and finding the relationship between its 3D structure and its functionality has become one of the main research areas in bioinformatics.

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## 2.3 Central Dogma of Life

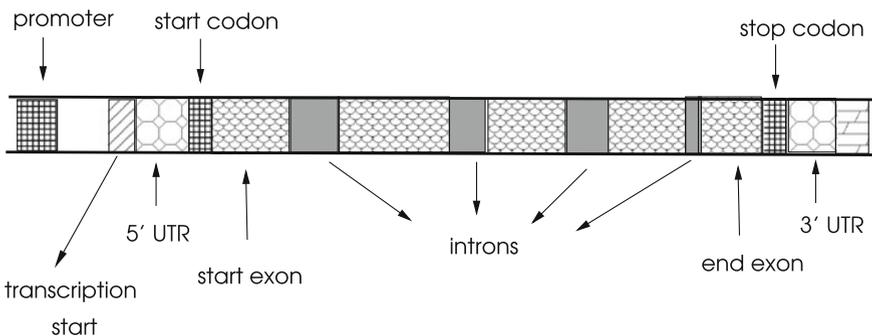
The central dogma of molecular biology and hence life was formulated by F. Crick in 1958 and it describes the flow of information between DNA, RNA, and proteins. This flow can be specified as DNA → mRNA → protein as shown in Fig. 2.4. The forming of mRNA from a DNA strand is called *transcription* and the production of a protein based on the nucleotide sequence of the mRNA is called *translation* as described next.



**Fig. 2.4** Central dogma of life

### 2.3.1 Transcription

In the transcription phase of protein coding, a single stranded RNA molecule called mRNA is produced which is complementary to the DNA strand it is transcribed. The transcription process in eukaryotes takes place in the nucleus. The enzyme called *RNA polymerase* starts transcription by first detecting and binding a *promoter* region of a gene. This special pattern of DNA shown in Fig. 2.5 is used by RNA polymerase to find where to begin transcription. The reverse copy of the gene is then synthesized by this enzyme and a terminating signal sequence in DNA results in the ending of this process after which pre-mRNA which contains exons and introns is released. A post-processing called *splicing* involves removing the introns received from the gene and reconnecting the exons to form the mature and much shorter mRNA which is transferred to cytoplasm for the second phase called *translation*. The complete gene contained in the chromosome is called *genomic DNA* and the sequence with exons only is called *complementary DNA* or cDNA [25].



**Fig. 2.5** Structure of a gene

**Table 2.2** The genetic code

1st L.	2nd Letter				3rd L.
	U	C	A	G	
U	UUU } Phe UUC } UUA } Leu UUG }	UCU } UCC } Ser UCA } UCG }	UAU } Tyr UAC } UAA <b>Stop</b> UAG <b>Stop</b>	UGU } Cys UGC } UGA <b>Stop</b> UGG Trp	U C A G
C	CUU } CUC } Leu CUA } CUG }	CCU } CCC } Pro CCA } CCG }	CAU } His CAC } CAA } Gln CAG }	CGU } CGC } Arg CGA } CGG }	U C A G
A	AUU } AUC } Ile AUA } AUG <b>Met</b>	ACU } ACC } Thr ACA } ACG }	AAU } Asn AAC } AAA } Lys AAG }	AGU } Ser AGC } AGA } Arg AGG }	U C A G
G	GUU } GUC } Val GUA } GUG }	GCU } GCC } Ala GCA } GCG }	GAU } Asp GAC } GAA } Glu GAG }	GGU } GGC } Gly GGA } GGG }	U C A G

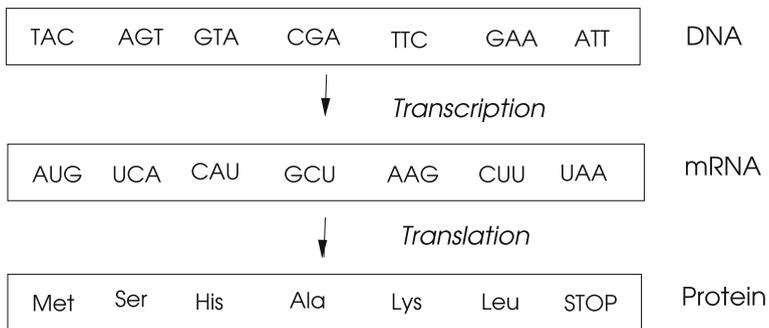
### 2.3.2 The Genetic Code

The genetic code provides the mapping between the sequence of nucleotides and the type of amino acids in proteins. This code is in triplets of nucleotide bases called *codons* where each codon encodes one amino acid. Since there are four nucleotide bases, possible total number of codons is  $4^3 = 64$ . However, proteins are made of 20 amino acids only which means many amino acids are specified by more than one codon. Table 2.2 displays the genetic code.

Such redundancy provides fault tolerance in case of mutations in the nucleotide sequences in DNA or mRNA. For example, a change in the codon UUA may result in UUG in mRNA but the amino acid *leucine* corresponding to each of these sequences is formed in both cases. Similarly, all of the three codons UAA, UAG, and UGA cause termination of the polypeptide sequence and hence a single mutation from A to G or from G to A still causes termination preventing unwanted growth due to mutations. Watson et al. showed that the sequence order of codons in DNA correspond directly to the sequence order of amino acids in proteins [28]. The codon AUG specifies the beginning of a protein amino acid sequence, therefore, the amino acid *methionine* is found as the first amino acid in all proteins.

### 2.3.3 Translation

The translation phase is the process where a mature mRNA is used as a template to form proteins. It is carried out by the large molecules called *ribosomes* which consist of proteins and the ribosomal RNA (rRNA) [5]. A ribosome uses tRNA to



**Fig. 2.6** Construction of a protein

first detect the start codon in the mRNA which is the nucleotide base sequence AUG. The tRNA has three bases called *anticodons* which are complementary to the codons it reads. The amino acids as prescribed by the mRNA are then formed and added to the linear protein structure according to the genetic code. Translation to the protein is concluded by detecting one of the three stop codons. Once a protein is formed, a protein may be transferred to the needed location by the signals in the amino acid sequence. The new protein must fold into a 3D structure before it can function [27]. Figure 2.6 displays the transcription and translation phases of a superficial protein made of six amino acids as prescribed by the mRNA.

### 2.3.4 Mutations

Mutations are changes in genetic code due to a variety of reasons. As an example, a stop codon UAA may be formed instead of an amino acid coding codon UCA (Serine) by a single point mutation of A to C, which will result in a shorter protein that will likely be nonfunctional. An amino acid may be replaced by another one, again by a point mutation such as the forming of CCU (Proline) instead of CAU (Histidine) by the mutation of C to A. These types of mutations may have important or trivial effects depending on the functioning of the mutated amino acid in the protein [5]. Furthermore, a nucleotide may be added or deleted to the sequence, resulting in the shifting of all codons by one nucleotide which will result in a very different sequence.

Mutations can be caused by radiations from various sources such as solar, radioactive materials, X-rays, and UV light. Chemical pollution is also responsible for many cases of mutations and viruses which insert themselves into DNA cause mutations. The inherited mutations are responsible for genetic diseases such as multiple sclerosis and Alzheimer disease. In many cases though, mutations result in better and improved characteristics in an organism such as better eyesight.

## 2.4 Biotechnological Methods

Biotechnology is defined as any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use, as defined by the Convention on Biological Diversity (CBD) [7]. The main biological methods are the *cloning* and *polymerase chain reaction* to amplify it, and *sequencing* to determine the nucleotide sequence in a DNA segment.

### 2.4.1 Cloning

DNA needs to be in sufficient quantities to experiment. DNA *cloning* is a method to amplify the DNA segment which could be very small. In this method, the DNA to be amplified called *insert* is inserted into the genome of an organism which is called the *host* or the *vector*. The host is then allowed to multiply during which the DNA inserted to it also multiplies. The host can then be disposed of, leaving only the amplified DNA segment. The commonly used organisms for cloning DNA are *plasmids*, *cosmids*, *phages*, and *yeast artificial chromosomes* (YACs) [25]. A plasmid is a circular DNA in bacteria and is used for cloning DNA of sizes up to 15 kbp. Phages are viruses and DNA segment inserted in them gets replicated when the virus infects an organism and multiplies itself. In YAC-based cloning, an artificial chromosome of yeast is constructed by the DNA insert sequence and the yeast chromosome control sections. The yeast multiplies its chromosomes including the YAC and hence multiplying the insert. YAC-based cloning can be used for very large segments of a million base pairs [25].

### 2.4.2 Polymerase Chain Reaction

The polymerase chain reaction (PCR) developed by Kary Mullis [3] in 1983, is a biomedical technology used to amplify selected DNA segment over several orders of magnitude. The amplification of DNA is needed for a number of applications including analysis of genes, discovery of DNA motifs, and diagnosis of hereditary diseases. PCR uses *thermal cycling* in which two phases are employed. In the first phase, the DNA is separated into two strands by heat and then, a single strand is enlarged to a double strand by the inclusion of a primer and polymerase processing. DNA polymerase is a type of enzyme that synthesizes new strands of DNA complementary to the target sequence. These two steps are repeated many times resulting in an exponential growth of the initial DNA segment. There are some limitations of PCR processing such as the accumulation of pyrophosphate molecules and the existence of inhibitors of the polymerase in the DNA sample which results in the stopping of the amplification.

### 2.4.3 DNA Sequencing

The sequence order of bases in DNA is needed to find the genetic information. *DNA sequencing* is the process of obtaining the order of nucleotides in DNA. The obtained sequence data can then be used to analyze DNA for various tasks such as finding evolutionary relationships between organisms and treatment of diseases. The exons are the parts of DNA that contain genes to code for proteins and all exons in a genome is called *exome*. Sequencing exomes is known as *whole exome sequencing*. However, research reveals DNA sequences external to the exons also affect protein coding and health state of an individual. In *whole genome sequencing*, the whole genome of an individual is sequenced. The new generation technologies are developed for both of these processes. A number of methods exist for DNA sequencing and we will briefly describe only the few fundamental ones.

The sequencing technology called *Sanger sequencing* named after Frederick Sanger who developed it [23,24], used deoxynucleotide triphosphates (dNTPs) and di-deoxynucleotide triphosphates (ddNTPs) which are essentially nucleotides with minor modifications. The DNA strand is copied using these altered bases and when these are entered into a sequence, they stop the copying process which results in different lengths of short DNA segments. These segments are ordered by size and the nucleotides are read from the shortest to the longest segment. Sanger method is slow and new technologies are developed. The *shotgun* method of sequencing was used to sequence larger DNA segments. The DNA segment is broken into many overlapping short segments and these segments are then cloned. These short segments are selected at random and sequenced in the next step. The final step of this method involves assembling the short segments in the most likely order to determine the sequence of the long segment, using the overlapping data of the short segments.

*Next generation* DNA sequencing methods employ massively parallel processing to overcome the problems of the previous sequencing methods. Three platforms are widely used for this purpose: the Roche/454 FLX [21], the Illumina/Solexa Genome Analyzer [4], and the Ion Torrent: Proton/PGM Sequencing [12]. The Roche/454 FLX uses the *pyrosequencing* method in which the input DNA strand is divided into shorter segments which are amplified by the PCR method. Afterward, multiple reads are sequenced in parallel by detecting optical signals as bases are added. The Illumina sequencing uses a similar method, the input sample fragment is cleaved into short segments and each short segment is amplified by PCR. The fragments are located in a slide which is flooded with nucleotides that are labeled with colors and DNA polymerase. By taking images of the slide and adding bases, and repeating this process, bases at each site can be detected to construct the sequence. The Ion proton sequencing makes use of the fact that addition of a dNTP to a DNA polymer releases an  $H^+$  ion. The preparation of the slide is similar to other two methods and the slide is flooded with dNTPs. Since each  $H^+$  decreases pH, the changes in pH level is used to detect nucleotides [8].

## 2.5 Databases

A database is a collection of structured data and there are hundreds of databases in bioinformatics. Many of these databases are generated by filtering and transforming data from other databases which contain raw data. Some of these databases are privately owned by companies and access is provided with a charge. In most cases however, bioinformatics databases are publicly accessible by anyone. We can classify bioinformatics databases broadly as nucleotide databases which contain DNA/RNA sequences; protein sequence databases with amino acid sequences of proteins, microarray databases storing gene expression data, and pathway databases which provide access to metabolic pathway data.

### 2.5.1 Nucleotide Databases

The major databases for nucleotides are the GenBank [10], the European Molecular Biology Laboratory-European Bioinformatics Institute (EMBL-EBI) database [19], and the DNA Databank of Japan (DDJB) [26]. GenBank is maintained by the National Center for Biotechnology Information (NCBI), U.S. and contains sequences for various organisms including primates, plants, mammals, and bacteria. It is a fundamental nucleic acid database and genomic data is submitted to GenBank from research projects and laboratories. Searches in this database can be performed by keywords or by sequences. The EMBL-EBI database is based on EMBL Nucleotide Sequence Data Library which was the first nucleotide database in the world and receives contributions from projects and authors. EMBL supports text-based retrieval tools including SRS and BLAST and FASTA for sequence-based retrieval [9].

### 2.5.2 Protein Sequence Databases

Protein sequence databases provide storage of protein amino acid sequence information. Two commonly used protein databases are the Protein Identification Resource (PIR) [16,31] and the UniProt [15] containing SwissProt [2]. The PIR contains protein amino acid sequences and structures of proteins to support genomic and proteomic research. It was founded by the National Biomedical Research Foundation (NBRF) for the identification and interpretation of protein sequence information, and the Munich Information Center for Protein Sequences (MIPS) [22] in Germany, and the Japan International Protein Information Database later joined this database. SwissProt protein sequence database was established in 1986 and provided protein functions, their hierarchical structures, and diseases related to proteins. The Universal Protein Resource (UniProt) is formed by the collaboration of EMBL-EBI, Swiss Institute of Bioinformatics (SIB) and PIR in 2003 and SwissProt was incorporated into UniProt. PDBj (Protein Data Bank Japan) is a protein database in Japan providing an archive of macromolecular structures and integrated tools [17].

## 2.6 Human Genome Project

The human genome project (HGP) is an international scientific research project to produce a complete human DNA sequence and identifying genes of human genome as well as other organisms such as mice, bacteria, and flies. This project was planned in 1984, started in 1990 and was finished in 2003. About 20 universities and research centers in United States, Japan, China, France, Germany, and the United Kingdom participated in this project. It aimed to sequence the three billion base pairs in human genome to analyze and search for the genetic causes of diseases to find cure for them, along with analysis of various other problems in molecular biology.

The results of this project are that there are between 20,000–25,000 genes in humans, and the human genome has more repeated DNA segments than other mammalian genomes. The work on results are ongoing but the results started to appear even before the completion of the project. Many companies are offering genetic tests which can show the tendencies of an individual to various illnesses. Comparing human genome with the genomes of other organisms will help our understanding of evolution better. Some ethical, legal, and social issues are questioned as a result of this project. Possible discrimination based on the genetic structure of an individual by the employers is one such concern and may result in unbalance in societies. However, this project has provided data that can be used to find molecular roots of diseases and search for cures.

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## 2.7 Chapter Notes

We have reviewed the basic concepts of molecular biology at introductory level. The processes are evidently much more complex than outlined here. More detailed treatment of this topic can be found [1,20,29,30]. The cell is the basic unit of life in all organisms. The two types of cell are the eukaryotes which are cells with nuclei and prokaryotes which do not have nuclei. Both of these life forms have the genetic material embedded in their DNA. Human DNA consists of a sequence of smaller molecules called nucleotides which are placed in 23 pairs of structures called chromosomes. A sequence in a chromosome that codes for a protein is called a gene. Genes identify amino acid sequences which form the proteins. The central dogma of life consists of two fundamental steps called transcription and translation. During transcription, a complementary copy of a DNA strand is formed and then the introns are extracted to form mRNA which is carried out of nucleus and the ribosomes form the amino acids prescribed using cRNA and tRNA. The three nucleotides that prescribe an amino acid is called a codon and the genetic code provides the mapping from a codon to an amino acid. Proteins also interact with other proteins forming protein–protein interaction (PPI) networks and their function is very much related to their hierarchical structure and also their position in the PPI networks.

We also briefly reviewed the biotechnologies for DNA multiplying, namely cloning and PCR technologies. These techniques are needed to provide sufficient

amount of DNA to experiment in the laboratories. DNA sequencing is the process of obtaining nucleotide sequence of DNA. The databases for DNA and protein sequences contain data obtained by various bioinformatics projects and are presented for public use. DNA microarrays provide snapshots of DNA expression levels of vast number of genes simultaneously and gene expression omnibus (GEO) [11] from NCBI and ArrayExpress [14] from EBI are the two databases for microarray-based gene expression data. There are also pathway databases which provide data for biochemical pathways, reactions, and enzymes. Kyoto Encyclopedia of Genes and Genomes (KEGG) [13, 18] and BioCyc [6] are two such databases.

The computer science point of view can be confined to analysis of two levels of data in bioinformatics: the DNA/RNA and protein sequence data and the data of biological networks such as the PPI networks. Our main focus in this book will be the sequential and distributed algorithms for the analysis of these sequence and network data.

### Exercises

1. For the DNA base sequence  $S = \text{AACGTAGGCTAAT}$ , work out the complementary sequence  $S'$  and then the complementary of the sequence  $S'$ .
2. A superficial gene has the sequence  $\text{CCGTATCAATTGGCATC}$ . Assuming this gene has exons only, work out the amino acid of the protein to be formed.
3. Discuss the functions of three RNA molecules named tRNA, cRNA, and mRNA.
4. A protein consists of the amino acid sequence A-B-N-V. Find three gene sequences that could have resulted in this protein.
5. Why is DNA multiplying needed? Compare the cloning and PCR methods of multiplying DNA in terms of technology used and their performances.

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