Research Article

Study of Codon Degeneracy Based on Similarity Measure

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ABSTRACT

In genetics, Codon degeneracy is a salient feature which refers to a single amino acid being encoded by more than one codon. According to a study, Degeneracy of genetic code helps an organism to prosper on earth. Each amino acid is encoded by triplet codes of four possible (Guanine (G), Adenine (A), Cytosine (C), or Thymine (T/U)) bases. The genetic codon degeneracy occurs mainly due to the variance in third position e.g. the amino acids Glycine is encoded by four codons GGU, GGC, GGA, GGG differ only in third base. Taking part of more than one tri nucleotides sequence out of 64 triplets to encode one amino acids lead to the concept of Degeneracy. In this manuscript we formulate a new classifying technique with the help of cosine similarities to explain the degeneracy. Further we have done a comparison of our method with an existing classification technique. The consequences of our results open a new paradigm to study the genetics from a new mathematical perspective. The disassortative nature of codons networks may help us to understand the flow of genetic information in the evolution process of amino acids.

Keywords: Degeneracy, Similarity Measures, Impression.

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INTRODUCTION

In molecular biology, transcription and translation are two processes through which transformation of genetic information from DNA to mRNA takes place. DNA has four nucleotide bases namely Adenine (A), Thymine (T), Guanine (G) and Cytosine (C), whereas RNA has A, G, C and Uracil (U) instead of T. A combination of three adjoined nucleotides (triplet) of four nucleotide bases form an amino acid.[1] For the first time, George Gamow named a set of three adjoined nucleotides (triplet) as codon. 20 different types of amino acids which are formed by the different combinations of 61 codons play the pivotal role in protein synthesis in a living organism. Either minimum of 3 codons or maximum of 6 codons form an amino acid. The mechanism of different codon codes for the same amino acid is called codon degeneracy. In broader senesce, Degeneracy can be described as a property that elements of different structures carry out the same results. Different codons match to the same amino acid are recognized as synonymous codons. In this paper, we are trying to address the codon degeneracy using a mathematical tool.

Several attempts have been made to describe the codon degeneracy, few of them are[1-7] etc. Since the inception of Genetic Code Table[8] actual reason of degeneracy still remains a mystery. Sengupta *et al.*, classified 64 codons into three different classes namely transitional, weak and strong based on their strength in codon degeneracy.[9] This classification was based on position and their nucleotides in a codon. In a study, Gonzalez *et al.*, proposed a new interpretation of degeneracy based only on symmetry principle.[10] Unifying mathematical framework, they depicts degeneracy with integer number representation systems. Based on symmetrical properties

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of codons T. Negadi[11] has proposed degeneracy of genetic code into distinct multiplet structures. Revisiting the study of degeneracy of genetic codon Jayanta Kumar Das *et al.*[12] introduced a new parameter "impression" to classify 20 amino acids. In their classification it has been noticed that amino acids having different degeneracy clubs into same cluster. Though in the recent few years study of genetic code gets new prospects incorporating mathematics yet a lot of avenues are still open to explore. The study of genetic code is still a subject of more or less rigorous exploration from mathematical standpoint. So, looking into these facts in our proposed work we define similarity measurement among the codons which give rise to clustering of amino acids. Further while comparing our results it is observed that the amino acid heaving same degeneracy gives the same similarity measurements. So, our clustering technique is more significant than the previous methods. Grouping different amino acids heaving same degeneracy paves the path for a potent analysis.

The rest of the paper is organized as follows. In Section 2, we discuss basics of degeneracy, Lagerkvist's hypothesis, Impression and similarities measures. Section 3, includes the main results of our paper followed by a comparison of our method with impression. Section 4 incorporates the concluding remarks.

Preliminaries

In this section we recall the degeneracy property of amino acids followed by Lagerkvist's hypothesis, Impression and similarities measures.

Degeneracy

The Standard Genetic Code table clearly reveals that out of 64 codons 61 codons plays the role of forming 20 amino acids and rest of the three codons does not have any significant role in forming amino acids. Which indicates multiple codons encoded for the same amino acids and this phenomenon is called the degeneracy.[13] The redundant codons are called synonymous codons. For ready reference redundant codons are arranged in some specific groups as shown in Table 1. Based on numbers of codons involved in forming a corresponding amino acid, degeneracy of genetic codons is divided into distinct multiplet structure[11] From the Table 1, it is observed that nine amino acids are corresponding to groups of two codons, called twofold degenerated. Five amino acids are corresponding to groups of four codons called fourfold degenerated, and three amino acids are corresponding to groups of six codons. One amino acid is corresponding to groups of by three codons, and only two amino acids are corresponding to single codons. For example, Alanine (A) and Valine (V) are encoded by four codons called fourfold degeneracy. It has been found that some organisms have been surviving more prosperously due to degeneracy of genetic codes. It may be due to the fact that while point mutation takes place if the mutation leads to a synonymous codon then effectiveness of the mutation will not affect the functionality of the protein.

Since the emergence of the degeneracy phenomena it has been challenging many biologists to find out the reasons behind this. Crick 1968 explained this phenomena and he suggested that first two codon positions were responsible in forming synonymous codons.[8] It is worth mentioning that genetic codon redundancy has a significant role in the mutation process. Because while substituting one nucleotide to another in the degenerated codon position gives the same amino

Table 1: Standard Genetic Code table.

	U	C	A	G	
U	UUU } Phe (F)	UCU	UAU } Tyr(Y)	UGU } Cys(C)	U
	UUC } (F)	UCC } Ser (S)	UAC }	UGC }	C
	UUA } Leu (L)	UCA } (S)	UAA } Stop codon	UGA } StopCodon	A
	UUG } (L)	UCG	UAG }	UGG } Try(W)	G
C	CUU	CCU	CAU } His(H)	CGU	U
	CUC } Leu (L)	CCC } Pro (P)	CAC }	CGC } Arg (R)	C
	CUA } (L)	CCA } (P)	CAA } Gln(Q)	CGA } (R)	A
	CUG	CCG	CAG }	CGG	G
A	AUU	ACU	AAU } Asn(N)	AGU } Ser(S)	U
	AUC } Iso (I)	ACC } Thr (T)	AAC }	AGC }	C
	AUA } (I)	ACA } (T)	AAA } Lys(L)	AGA } Arg(R)	A
	AUG } Met(M)	ACG	AAG }	AGG }	G
G	GUU	GCU	GAU } Asp(D)	GGU }	U
	GUC } Val (V)	GCC } Ala (A)	GAC }	GGC } Gly(G)	C
	GUA } (V)	GCA } (A)	GAA } Glu(E)	GGA	A
	GUG	GCG	GAG }	GGG	G

acids. For example in fourfold degenerate codon point mutation is insignificant at the third position.

Lagerkvist's Hypothesis

Followed by Crick 1968,[8] Lagerkvist 1978[14,15] formulated a new hypothesis which is known as hypothesis "Two out of three". In this hypothesis Lagerkvist stated that:

- If the first two base pair of codon-anticodon binds with six hydrogen bonds then the third positioned codon base becomes insignificant.
- If first two base pairs of codon-anticodon binds with four hydrogen bonds then the characteristic of the third codon base i.e., purine or pyrimidine will have a determining role towards the forming of different amino acids.
- If two first base pairs binds with 5 hydrogen bonds then rule 1 and rule 2 is relevant when the second codon base is pyrimidine and purine respectively.

It is worth mentioning that Crick hypothesis[8] was revolutionary in the field of genetics to study the degeneracy property of amino acids. Crick hypothesis suggested that Wobble position determines why multiple codons can encode a single amino acid. The Wobble Hypothesis proposed by Francis Crick, states that the 3rd base in an mRNA codon can pair with 1st base of a tRNA anticodon which is a non-Watson-Crick base pairing. But the Crick hypothesis has come into questions when it was significantly failed to describe the molecular mechanism of the G-U pair formation. Later integrating H- bonding perspective of first two codon nucleotides into Crick hypothesis Lagerkvist proposed a hypothesis "two out of three"; which is later known as Lagerkvist hypothesis. Later, Lagerkvist's rules were seen in the genetic code table suggested by Rumer.[16]

Impression

Impression is a parameter to study the underlying theme of degeneracy. Introducing impression to study the underlying theme of degeneracy Das *et al*.,[12,17] made a paradigm shift in the field of computational biology. Based on molecular weights on amino acids they have assigned rank of the amino acids as some ternary number and finally they have calculated impression factor for individual amino acids. This impression factor leads them to incorporate mathematics to define the degeneracy of amino acids. They classified twenty amino acids into four groups based on parameter impression.

Impression of amino acids (*IP*) is calculated as -

$$IP\{X_1, X_2, X_3\} = \{I_1, I_2, I_3\} \quad (1)$$

Where, $X_1, X_2, X_3 \in \{0, 1, 2\}$ are ternary number and and $I_1 = |X_1 - X_2|$, $I_2 = |X_2 - X_3|$ and $I_3 = |X_3 - X_1|$.

Similarity Measures

Similarity measures are used to determine how two data objects are alike. Generally it ranges between zero (0) to one (1). Similarity of two data object is defined as 1 if they are alike and 0 otherwise. Cosine similarity is one of the most broadly used similarity measure. Cosine similarity of two vectors A and B is defined as –

$$\sin(A,B) = \frac{AB}{\|A\| \cdot \|B\|} = \frac{\sum_i^n A_i B_i}{\sqrt{\sum_i^n A_i^2}\sqrt{\sum_i^n B_i^2}} \quad (2)$$

Where,

$$A = \{A_1, A_2 \ldots A_N\} \in R^n; \quad B = \{B_1, B_2 \ldots B_N\} \in R^n$$

Cosine similarity is not affected by the magnitude of vectors. This is why cosine similarity is more preferable than the Euclidian distance while evaluating relationship among various features is the same. Cosine similarity is more affected by the orientation of vectors that than the exact position of the vector.

A New Interpretation of Genetic Codon Degeneracy

Over the few years several researches have been carried out to describe the degeneracy of the genetic code. But still the development in this field is in the neonatal stage. The work that has been carried out here is a part of incorporating mathematical perspective to describe the degeneracy. In an approach to unifying mathematical framework Bora *et al*.,[18] has assigned some weight on each base positions of a codon depending on positional impact, appearance of pyrimidine and purine in the second and third base position and Hydrogen bonding influence of codon bases as given by Lagerkvist's hypothesis to define a distance among the amino acids.

For ready reference, consider the following example. Details of the method of giving weight on each base position of codons are discussed by Bora *et al*., 2020.[18]

Examples

- Alanine(A) encoded by GCU, the first two codon base position of GCU binds with six hydrogen bonds so Bora *et al*.,[18] allocated weights on three codon base position as (2, 2, 0).
- Amino acids Asparagine (N) encoded by AAU, Lysine (K) encoded byAAA, the first two codon base position of AAU and AAA binds with four

hydrogen bonds further chemical sorts of third codon base positions are Pyrimidine and Purine respectively so Bora *et al.*, 2020[18] assigned weights on three codon base position as (2, 2, 0.5) and (2, 2, 1) respectively.

- Amino Acids Cysteine (C) encoded by UGU, Glutamine E encoded byGAA, the first two codon base position of UGU and GAA binds with five hydrogen bond and chemical sorts of second codon base positions is Purine so Bora *et al.*, 2020[18] allocate weights on three codon base position as (2, 2 + 1, 0.5) and (2, 2 + 1, 1) respectively.
- Amino Acid Valine (V) encoded by GUU, the first two codon base position of GUU share five hydrogen bonds and chemical sorts of third codon base positions is Pyrimidine so Bora *et al.*, 2020[19] allocated weights on three codon base position as (2, 2 + 0.5, 0).

Based on the weight defined by the Bora *et al.*, 2020[18] in this paper we have made a similarity measurement among the codons which give rise to interpret degeneracy in a new paradigm. Similarity measurement asses the degree of similarity among set of given data. As we know that synonymous codons are similar in a sense that synonymous codons give the same acid. Use of cosine similarity is justified by the fact that cosine similarity concern where duplication matters.

Using equation number 2 we have measured the similarity among 61 codons out of 64 codons, as the rest of three codons are start and stop codons and they have not significant contribution in amino acids formation. The similarity measurement among 61 codons give us a 61 by 61 matrix where adjacency values of the matrix reflect the degree of similarity among codons as shown in Table 2, 3, 4 and Table 5. Table 2 is formed from the first 29 rows and 30 columns of the 61 by 61 matrix. Table 3 is formed from the next 32 rows and from the first 30 columns of the 61 by 61 matrix. Table 4 is formed from the first 30th rows and 31 columns starting from column number 31 of the 61 by 61 matrix and finally Table 5 is formed from 32 rows starting from row number 30 and 31 columns starting from column number 31 of the 61 by 61 matrix. This gives rise to interpret degeneracy in a new paradigm.

In the matrix we have some $1 \times n$ blocks (n = 2,3,4,6) where all the elements are (degree of similarities) same. From the said $1 \times n$ block of the 61×61 matrix one can easily derive that the codons correspond to n columns are synonymous codons.

If we correspond m synonymous codon with n synonymous codons (n = 2,3,4,6) then we have m n block of the matrix where all the elements (degree of similarities) are same.

The element 1 in this matrix represents the highest degree of similarities among the corresponding codons. This is justified because those corresponding codons encode the same amino acid. In some $m \times n$ block where (m = 2,3,4,6) and (n = 2,3,4,6) of this matrix we also

Table 2: Degree of Similarity of Codons.

	UUU	UUC	UUA	UUG	CUU	CUC	CUA	CUG	AUU	AUC	AUA	AUG	GUU	GUC	GUA	GUG	UCU	UCC	UCA	UCG	CCU	CCA	CCA	CCG	ACU	ACC	ACA	ACG	GCU	GCC
UUU	1	1	0.9995289	0.9995289	0.9995289	0.9995289	0.9995289	0.9995289	0.9998912	0.9998912	0.9998912	0.9973633	0.9954479	0.9954479	0.9954479	0.9954479	0.9954065	0.9954065	0.9954065	0.9954065	0.9971746	0.9971746	0.9971746	0.9971746	0.995389	0.995389	0.995389	0.995389	0.9971746	0.99717465
UUC	1	1	0.9995289	0.9995289	0.9995289	0.9995289	0.9995289	0.9995289	0.9998912	0.9998912	0.9998912	0.9973633	0.9954479	0.9954479	0.9954479	0.9954479	0.9954065	0.9954065	0.9954065	0.9954065	0.9971746	0.9971746	0.9971746	0.9971746	0.995389	0.995389	0.995389	0.995389	0.9971746	0.99717465
UUA	0.9995289	0.9995289	1	1	1	1	1	1	0.999362	0.999362	0.999362	0.9966078	0.9966917	0.9966917	0.9966917	0.9966917	0.9971125	0.9971125	0.9971125	0.9971125	0.9970004	0.9970004	0.9970004	0.9970004	0.9966625	0.9966625	0.9966625	0.9966625	0.9970004	0.99700037
UUG	0.9995289	0.9995289	1	1	1	1	1	1	0.999362	0.999362	0.999362	0.9966078	0.9966917	0.9966917	0.9966917	0.9966917	0.9971125	0.9971125	0.9971125	0.9971125	0.9970004	0.9970004	0.9970004	0.9970004	0.9966625	0.9966625	0.9966625	0.9966625	0.9970004	0.99700037
CUU	0.9995289	0.9995289	1	1	1	1	1	1	0.999362	0.999362	0.999362	0.9966078	0.9966917	0.9966917	0.9966917	0.9966917	0.9971125	0.9971125	0.9971125	0.9971125	0.9970004	0.9970004	0.9970004	0.9970004	0.9966625	0.9966625	0.9966625	0.9966625	0.9970004	0.99700037
CUC	0.9995289	0.9995289	1	1	1	1	1	1	0.999362	0.999362	0.999362	0.9966078	0.9966917	0.9966917	0.9966917	0.9966917	0.9971125	0.9971125	0.9971125	0.9971125	0.9970004	0.9970004	0.9970004	0.9970004	0.9966625	0.9966625	0.9966625	0.9966625	0.9970004	0.99700037
CUA	0.9995289	0.9995289	1	1	1	1	1	1	0.999362	0.999362	0.999362	0.9966078	0.9966917	0.9966917	0.9966917	0.9966917	0.9971125	0.9971125	0.9971125	0.9971125	0.9970004	0.9970004	0.9970004	0.9970004	0.9966625	0.9966625	0.9966625	0.9966625	0.9970004	0.99700037
CUG	0.9995289	0.9995289	1	1	1	1	1	1	0.999362	0.999362	0.999362	0.9966078	0.9966917	0.9966917	0.9966917	0.9966917	0.9971125	0.9971125	0.9971125	0.9971125	0.9970004	0.9970004	0.9970004	0.9970004	0.9966625	0.9966625	0.9966625	0.9966625	0.9970004	0.99700037
AUU	0.9998912	0.9998912	0.999362	0.999362	0.999362	0.999362	0.999362	0.999362	1	1	1	0.9983253	0.9941037	0.9941037	0.9941037	0.9941037	0.9942223	0.9942223	0.9942223	0.9942223	0.995958	0.995958	0.995958	0.995958	0.9940422	0.9940422	0.9940422	0.9940422	0.995958	0.99595799
AUC	0.9998912	0.9998912	0.999362	0.999362	0.999362	0.999362	0.999362	0.999362	1	1	1	0.9983253	0.9941037	0.9941037	0.9941037	0.9941037	0.9942223	0.9942223	0.9942223	0.9942223	0.995958	0.995958	0.995958	0.995958	0.9940422	0.9940422	0.9940422	0.9940422	0.995958	0.99595799
AUA	0.9998912	0.9998912	0.999362	0.999362	0.999362	0.999362	0.999362	0.999362	1	1	1	0.9983253	0.9941037	0.9941037	0.9941037	0.9941037	0.9942223	0.9942223	0.9942223	0.9942223	0.995958	0.995958	0.995958	0.995958	0.9940422	0.9940422	0.9940422	0.9940422	0.995958	0.99595799
AUG	0.9973633	0.9973633	0.9966078	0.9966078	0.9966078	0.9966078	0.9966078	0.9966078	0.9983253	0.9983253	0.9983253	1	0.9867434	0.9867434	0.9867434	0.9867434	0.9874894	0.9874894	0.9874894	0.9874894	0.989094	0.989094	0.989094	0.989094	0.9866716	0.9866716	0.9866716	0.9866716	0.989094	0.98909397
GUU	0.9954479	0.9954479	0.9966917	0.9966917	0.9966917	0.9966917	0.9966917	0.9966917	0.9941037	0.9941037	0.9941037	0.9867434	1	1	1	1	0.9998036	0.9998036	0.9998036	0.9998036	0.9989286	0.9989286	0.9989286	0.9989286	0.99978	0.99978	0.99978	0.99978	0.9989286	0.99892863
GUC	0.9954479	0.9954479	0.9966917	0.9966917	0.9966917	0.9966917	0.9966917	0.9966917	0.9941037	0.9941037	0.9941037	0.9867434	1	1	1	1	0.9998036	0.9998036	0.9998036	0.9998036	0.9989286	0.9989286	0.9989286	0.9989286	0.99978	0.99978	0.99978	0.99978	0.9989286	0.99892863
GUA	0.9954479	0.9954479	0.9966917	0.9966917	0.9966917	0.9966917	0.9966917	0.9966917	0.9941037	0.9941037	0.9941037	0.9867434	1	1	1	1	0.9998036	0.9998036	0.9998036	0.9998036	0.9989286	0.9989286	0.9989286	0.9989286	0.99978	0.99978	0.99978	0.99978	0.9989286	0.99892863
GUG	0.9954479	0.9954479	0.9966917	0.9966917	0.9966917	0.9966917	0.9966917	0.9966917	0.9941037	0.9941037	0.9941037	0.9867434	1	1	1	1	0.9998036	0.9998036	0.9998036	0.9998036	0.9989286	0.9989286	0.9989286	0.9989286	0.99978	0.99978	0.99978	0.99978	0.9989286	0.99892863
UCU	0.9954065	0.9954065	0.9971125	0.9971125	0.9971125	0.9971125	0.9971125	0.9971125	0.9942223	0.9942223	0.9942223	0.9874894	0.9998036	0.9998036	0.9998036	0.9998036	1	1	1	1	0.9980723	0.9980723	0.9980723	0.9980723	0.9998169	0.9998169	0.9998169	0.9998169	0.9980723	0.9980723
UCC	0.9954065	0.9954065	0.9971125	0.9971125	0.9971125	0.9971125	0.9971125	0.9971125	0.9942223	0.9942223	0.9942223	0.9874894	0.9998036	0.9998036	0.9998036	0.9998036	1	1	1	1	0.9980723	0.9980723	0.9980723	0.9980723	0.9998169	0.9998169	0.9998169	0.9998169	0.9980723	0.9980723
UCA	0.9954065	0.9954065	0.9971125	0.9971125	0.9971125	0.9971125	0.9971125	0.9971125	0.9942223	0.9942223	0.9942223	0.9874894	0.9998036	0.9998036	0.9998036	0.9998036	1	1	1	1	0.9980723	0.9980723	0.9980723	0.9980723	0.9998169	0.9998169	0.9998169	0.9998169	0.9980723	0.9980723
UCG	0.9954065	0.9954065	0.9971125	0.9971125	0.9971125	0.9971125	0.9971125	0.9971125	0.9942223	0.9942223	0.9942223	0.9874894	0.9998036	0.9998036	0.9998036	0.9998036	1	1	1	1	0.9980723	0.9980723	0.9980723	0.9980723	0.9998169	0.9998169	0.9998169	0.9998169	0.9980723	0.9980723
CCU	0.9971746	0.9971746	0.9970004	0.9970004	0.9970004	0.9970004	0.9970004	0.9970004	0.995958	0.995958	0.995958	0.989094	0.9989286	0.9989286	0.9989286	0.9989286	0.9980723	0.9980723	0.9980723	0.9980723	1	1	1	1	0.9988833	0.9988833	0.9988833	0.9988833	0.99871	0.99871
CCA	0.9971746	0.9971746	0.9970004	0.9970004	0.9970004	0.9970004	0.9970004	0.9970004	0.995958	0.995958	0.995958	0.989094	0.9989286	0.9989286	0.9989286	0.9989286	0.9980723	0.9980723	0.9980723	0.9980723	1	1	1	1	0.9988833	0.9988833	0.9988833	0.9988833	0.99871	0.99871
CCA	0.9971746	0.9971746	0.9970004	0.9970004	0.9970004	0.9970004	0.9970004	0.9970004	0.995958	0.995958	0.995958	0.989094	0.9989286	0.9989286	0.9989286	0.9989286	0.9980723	0.9980723	0.9980723	0.9980723	1	1	1	1	0.9988833	0.9988833	0.9988833	0.9988833	0.99871	0.99871
CCG	0.9971746	0.9971746	0.9970004	0.9970004	0.9970004	0.9970004	0.9970004	0.9970004	0.995958	0.995958	0.995958	0.989094	0.9989286	0.9989286	0.9989286	0.9989286	0.9980723	0.9980723	0.9980723	0.9980723	1	1	1	1	0.9988833	0.9988833	0.9988833	0.9988833	0.99871	0.99871
ACU	0.995389	0.995389	0.9966625	0.9966625	0.9966625	0.9966625	0.9966625	0.9966625	0.9940422	0.9940422	0.9940422	0.9866716	0.99978	0.99978	0.99978	0.99978	0.9998169	0.9998169	0.9998169	0.9998169	0.9988833	0.9988833	0.9988833	0.9988833	1	1	1	1	0.9988833	0.99888335
ACC	0.995389	0.995389	0.9966625	0.9966625	0.9966625	0.9966625	0.9966625	0.9966625	0.9940422	0.9940422	0.9940422	0.9866716	0.99978	0.99978	0.99978	0.99978	0.9998169	0.9998169	0.9998169	0.9998169	0.9988833	0.9988833	0.9988833	0.9988833	1	1	1	1	0.9988833	0.99888335
ACA	0.995389	0.995389	0.9966625	0.9966625	0.9966625	0.9966625	0.9966625	0.9966625	0.9940422	0.9940422	0.9940422	0.9866716	0.99978	0.99978	0.99978	0.99978	0.9998169	0.9998169	0.9998169	0.9998169	0.9988833	0.9988833	0.9988833	0.9988833	1	1	1	1	0.9988833	0.99888335
ACG	0.995389	0.995389	0.9966625	0.9966625	0.9966625	0.9966625	0.9966625	0.9966625	0.9940422	0.9940422	0.9940422	0.9866716	0.99978	0.99978	0.99978	0.99978	0.9998169	0.9998169	0.9998169	0.9998169	0.9988833	0.9988833	0.9988833	0.9988833	1	1	1	1	0.9988833	0.99888335
GCU	0.9971746	0.9971746	0.9970004	0.9970004	0.9970004	0.9970004	0.9970004	0.9970004	0.995958	0.995958	0.995958	0.989094	0.9989286	0.9989286	0.9989286	0.9989286	0.9980723	0.9980723	0.9980723	0.9980723	0.99871	0.99871	0.99871	0.99871	0.9988833	0.9988833	0.9988833	0.9988833	1	1

Table 3: Degree of Similarity of Codons.

1	1	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	0.991833	0.991833	0.991833	0.991833
0.9971746	0.9971746	1	1	0.9961033	0.9961033	0.9956553	0.9956553	0.99781	0.99781	0.9973633	0.9973633	0.9961033	0.9961033	0.9956553	0.9956553	0.9961683	0.9961683	0.9956553	0.9989432	0.9989432	0.9989432	0.9989432	0.9954065	0.9954065	0.9989432	0.9989432	0.9971746	0.9971746	0.9971746	0.9971746
0.9971746	0.9971746	1	1	0.9961033	0.9961033	0.9956553	0.9956553	1	1	0.9973633	0.9973633	0.9961033	0.9961033	0.9956553	0.9956553	0.9961683	0.9961683	0.9956553	0.9989432	0.9989432	0.9989432	0.9989432	0.9954065	0.9954065	0.9989432	0.9989432	0.9971746	0.9971746	0.9971746	0.9971746
0.9951054	0.9951054	0.9961033	0.9961033	1	1	0.9978581	0.9978581	0.9961033	0.9961033	0.991722	0.991722	0.99801	0.99801	0.9978581	0.9978581	0.995178	0.995178	0.9978581	0.9982868	0.9982868	0.9982868	0.9982868	0.998552	0.998552	0.9982868	0.9982868	0.9951054	0.9951054	0.9951054	0.9951054
0.9951054	0.9951054	0.9961033	0.9961033	1	1	0.9978581	0.9978581	0.9961033	0.9961033	0.991722	0.991722	0.99801	0.99801	0.9978581	0.9978581	0.9999965	0.9999965	0.9978581	0.9982868	0.9982868	0.9982868	0.9982868	0.998552	0.998552	0.9982868	0.9982868	0.9951054	0.9951054	0.9951054	0.9951054
0.9897433	0.9897433	0.9956553	0.9956553	0.9978581	0.9978581	1	1	0.9956553	0.9956553	0.9960238	0.9960238	0.9978581	0.9978581	0.99844	0.99844	0.9980284	0.9980284	0.998691	0.9954023	0.9954023	0.9954023	0.9954023	0.9932512	0.9932512	0.9954023	0.9954023	0.9897433	0.9897433	0.9897433	0.9897433
0.9897433	0.9897433	0.9956553	0.9956553	0.9978581	0.9978581	1	1	0.9956553	0.9956553	0.9960238	0.9960238	0.9978581	0.9978581	0.99844	0.99844	0.9980284	0.9980284	0.998691	0.9954023	0.9954023	0.9954023	0.9954023	0.9932512	0.9932512	0.9954023	0.9954023	0.9897433	0.9897433	0.9897433	0.9897433
0.9971746	0.9971746	0.99781	0.99781	0.9961033	0.9961033	0.9956553	0.9956553	1	1	0.9973633	0.9973633	0.9961033	0.9961033	0.9956553	0.9956553	0.9961683	0.9961683	0.9956553	0.9989432	0.9989432	0.9989432	0.9989432	0.9954065	0.9954065	0.9989432	0.9989432	0.9971746	0.9971746	0.9971746	0.9971746
0.9971746	0.9971746	0.99781	0.99781	0.9961033	0.9961033	0.9956553	0.9956553	1	1	0.9973633	0.9973633	0.9961033	0.9961033	0.9956553	0.9956553	0.9961683	0.9961683	0.9956553	0.9989432	0.9989432	0.9989432	0.9989432	0.9954065	0.9954065	0.9989432	0.9989432	0.9971746	0.9971746	0.9971746	0.9971746
0.989094	0.989094	0.9973633	0.9973633	0.991722	0.991722	0.9960238	0.9960238	0.9973633	0.9973633	1	1	0.991722	0.991722	0.9960238	0.9960238	0.9919795	0.9919795	0.9960238	0.9936476	0.9936476	0.9936476	0.9936476	0.9874894	0.9874894	0.9936476	0.9936476	0.989094	0.989094	0.989094	0.989094
0.989094	0.989094	0.9973633	0.9973633	0.991722	0.991722	0.9960238	0.9960238	0.9973633	0.9973633	1	1	0.991722	0.991722	0.9960238	0.9960238	0.9919795	0.9919795	0.9960238	0.9936476	0.9936476	0.9936476	0.9936476	0.9874894	0.9874894	0.9936476	0.9936476	0.989094	0.989094	0.989094	0.989094
0.9951054	0.9951054	0.9961033	0.9961033	0.99801	0.99801	0.9978581	0.9978581	0.9961033	0.9961033	0.991722	0.991722	1	1	0.9978581	0.9978581	0.99123	0.99123	0.9978581	0.9982868	0.9982868	0.9982868	0.9982868	0.998552	0.998552	0.9982868	0.9982868	0.9951054	0.9951054	0.9951054	0.9951054
0.9951054	0.9951054	0.9961033	0.9961033	0.99801	0.99801	0.9978581	0.9978581	0.9961033	0.9961033	0.991722	0.991722	1	1	0.9978581	0.9978581	0.99123	0.99123	0.9978581	0.9982868	0.9982868	0.9982868	0.9982868	0.998552	0.998552	0.9982868	0.9982868	0.9951054	0.9951054	0.9951054	0.9951054
0.9897433	0.9897433	0.9956553	0.9956553	0.9978581	0.9978581	0.99844	1	0.9956553	0.9956553	0.9960238	0.9960238	0.9978581	0.9978581	1	1	0.9980284	0.9980284	0.9772871	0.9954023	0.9954023	0.9954023	0.9954023	0.9932512	0.9932512	0.9954023	0.9954023	0.9897433	0.9897433	0.9897433	0.9897433
0.9897433	0.9897433	0.9956553	0.9956553	0.9978581	0.9978581	0.99844	1	0.9956553	0.9956553	0.9960238	0.9960238	0.9978581	0.9978581	1	1	0.9980284	0.9980284	0.9772871	0.9954023	0.9954023	0.9954023	0.9954023	0.9932512	0.9932512	0.9954023	0.9954023	0.9897433	0.9897433	0.9897433	0.9897433
0.9949707	0.9949707	0.9961683	0.9961683	0.995178	0.9999965	0.9980284	0.9980284	0.9961683	0.9961683	0.9919795	0.9919795	0.99123	0.99123	0.9980284	0.9980284	1	1	0.9980284	0.9982529	0.9982529	0.9982529	0.9982529	0.9984201	0.9984201	0.9982529	0.9982529	0.9949707	0.9949707	0.9949707	0.9949707
0.9949707	0.9949707	0.9961683	0.9961683	0.995178	0.9999965	0.9980284	0.9980284	0.9961683	0.9961683	0.9919795	0.9919795	0.99123	0.99123	0.9980284	0.9980284	1	1	0.9980284	0.9982529	0.9982529	0.9982529	0.9982529	0.9984201	0.9984201	0.9982529	0.9982529	0.9949707	0.9949707	0.9949707	0.9949707
0.9897433	0.9897433	0.9956553	0.9956553	0.9978581	0.9978581	0.998691	0.998691	0.9956553	0.9956553	0.9960238	0.9960238	0.9978581	0.9978581	0.9772871	0.9772871	0.9980284	0.9980284	1	0.9954023	0.9954023	0.9954023	0.9954023	0.9932512	0.9932512	0.9954023	0.9954023	0.9897433	0.9897433	0.9897433	0.9897433
0.998876	0.998876	0.9989432	0.9989432	0.9982868	0.9982868	0.9954023	0.9954023	0.9989432	0.9989432	0.9936476	0.9936476	0.9982868	0.9982868	0.9954023	0.9954023	0.9982529	0.9982529	0.9954023	1	1	1	1	0.9987474	0.9987474	1	1	0.998876	0.998876	0.998876	0.998876
0.998876	0.998876	0.9989432	0.9989432	0.9982868	0.9982868	0.9954023	0.9954023	0.9989432	0.9989432	0.9936476	0.9936476	0.9982868	0.9982868	0.9954023	0.9954023	0.9982529	0.9982529	0.9954023	1	1	1	1	0.9987474	0.9987474	1	1	0.998876	0.998876	0.998876	0.998876
0.998876	0.998876	0.9989432	0.9989432	0.9982868	0.9982868	0.9954023	0.9954023	0.9989432	0.9989432	0.9936476	0.9936476	0.9982868	0.9982868	0.9954023	0.9954023	0.9982529	0.9982529	0.9954023	1	1	1	1	0.9987474	0.9987474	1	1	0.998876	0.998876	0.998876	0.998876
0.998876	0.998876	0.9989432	0.9989432	0.9982868	0.9982868	0.9954023	0.9954023	0.9989432	0.9989432	0.9936476	0.9936476	0.9982868	0.9982868	0.9954023	0.9954023	0.9982529	0.9982529	0.9954023	1	1	1	1	0.9987474	0.9987474	1	1	0.998876	0.998876	0.998876	0.998876
0.9980723	0.9980723	0.9954065	0.9954065	0.998552	0.998552	0.9932512	0.9932512	0.9954065	0.9954065	0.9874894	0.9874894	0.998552	0.998552	0.9932512	0.9932512	0.9984201	0.9984201	0.9932512	0.9987474	0.9987474	0.9987474	0.9987474	1	1	0.9987474	0.9987474	0.9980723	0.9980723	0.9980723	0.9980723
0.9980723	0.9980723	0.9954065	0.9954065	0.998552	0.998552	0.9932512	0.9932512	0.9954065	0.9954065	0.9874894	0.9874894	0.998552	0.998552	0.9932512	0.9932512	0.9984201	0.9984201	0.9932512	0.9987474	0.9987474	0.9987474	0.9987474	1	1	0.9987474	0.9987474	0.9980723	0.9980723	0.9980723	0.9980723
0.998876	0.998876	0.9989432	0.9989432	0.9982868	0.9982868	0.9954023	0.9954023	0.9989432	0.9989432	0.9936476	0.9936476	0.9982868	0.9982868	0.9954023	0.9954023	0.9982529	0.9982529	0.9954023	1	1	1	1	0.9987474	0.9987474	1	1	0.998876	0.998876	0.998876	0.998876
0.998876	0.998876	0.9989432	0.9989432	0.9982868	0.9982868	0.9954023	0.9954023	0.9989432	0.9989432	0.9936476	0.9936476	0.9982868	0.9982868	0.9954023	0.9954023	0.9982529	0.9982529	0.9954023	1	1	1	1	0.9987474	0.9987474	1	1	0.998876	0.998876	0.998876	0.998876
0.991833	0.991833	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	1	1	1	1
0.991833	0.991833	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	1	1	1	1
0.991833	0.991833	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	1	1	1	1
0.991833	0.991833	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	1	1	1	1

Table 4: Degree of Similarity of Codons.

GCA	GCG	UAU	UAC	CAU	CAC	CAA	CAG	AAU	AAC	AAA	AAG	GAU	GAC	GAA	GAG	UGU	UGC	UGG	CGU	CGC	CGA	CGG	AGU	AGC	AGA	AGG	GGU	GGC	GGA	GGG
0.9971746	0.9971746	0.999321	0.999321	0.9961033	0.9961033	0.9956553	0.9956553	0.991321	0.991321	0.9973633	0.9973633	0.9961033	0.9961033	0.9956553	0.9956553	0.9961683	0.9961683	0.9956553	0.9989432	0.9989432	0.9989432	0.9989432	0.9954065	0.9954065	0.9989432	0.9989432	0.9971746	0.9971746	0.9971746	0.9971746
0.9971746	0.9971746	0.99851	0.99851	0.9961033	0.9961033	0.9956553	0.9956553	0.9971	0.9971	0.9973633	0.9973633	0.9961033	0.9961033	0.9956553	0.9956553	0.9961683	0.9961683	0.9956553	0.9989432	0.9989432	0.9989432	0.9989432	0.9954065	0.9954065	0.9989432	0.9989432	0.9971746	0.9971746	0.9971746	0.9971746
0.9970004	0.9970004	0.9995289	0.9995289	0.9983109	0.9983109	0.997565	0.997565	0.9995289	0.9995289	0.9966078	0.9966078	0.9983109	0.9983109	0.997565	0.997565	0.9983639	0.9983639	0.997565	0.99946	0.99946	0.99946	0.99946	0.9971125	0.9971125	0.99946	0.99946	0.9970004	0.9970004	0.9970004	0.9970004
0.9970004	0.9970004	0.9995289	0.9995289	0.9983109	0.9983109	0.997565	0.997565	0.9995289	0.9995289	0.9966078	0.9966078	0.9983109	0.9983109	0.997565	0.997565	0.9983639	0.9983639	0.997565	0.99946	0.99946	0.99946	0.99946	0.9971125	0.9971125	0.99946	0.99946	0.9970004	0.9970004	0.9970004	0.9970004
0.9970004	0.9970004	0.9995289	0.9995289	0.9983109	0.9983109	0.997565	0.997565	0.9995289	0.9995289	0.9966078	0.9966078	0.9983109	0.9983109	0.997565	0.997565	0.9983639	0.9983639	0.997565	0.99946	0.99946	0.99946	0.99946	0.9971125	0.9971125	0.99946	0.99946	0.9970004	0.9970004	0.9970004	0.9970004
0.9970004	0.9970004	0.9995289	0.9995289	0.9983109	0.9983109	0.997565	0.997565	0.9995289	0.9995289	0.9966078	0.9966078	0.9983109	0.9983109	0.997565	0.997565	0.9983639	0.9983639	0.997565	0.99946	0.99946	0.99946	0.99946	0.9971125	0.9971125	0.99946	0.99946	0.9970004	0.9970004	0.9970004	0.9970004
0.9970004	0.9970004	0.9995289	0.9995289	0.9983109	0.9983109	0.997565	0.997565	0.9995289	0.9995289	0.9966078	0.9966078	0.9983109	0.9983109	0.997565	0.997565	0.9983639	0.9983639	0.997565	0.99946	0.99946	0.99946	0.99946	0.9971125	0.9971125	0.99946	0.99946	0.9970004	0.9970004	0.9970004	0.9970004
0.9970004	0.9970004	0.9995289	0.9995289	0.9983109	0.9983109	0.997565	0.997565	0.9995289	0.9995289	0.9966078	0.9966078	0.9983109	0.9983109	0.997565	0.997565	0.9983639	0.9983639	0.997565	0.99946	0.99946	0.99946	0.99946	0.9971125	0.9971125	0.99946	0.99946	0.9970004	0.9970004	0.9970004	0.9970004
0.995958	0.995958	0.9998912	0.9998912	0.9956382	0.9956382	0.9961555	0.9961555	0.9998912	0.9998912	0.9983253	0.9983253	0.9956382	0.9956382	0.9961555	0.9961555	0.9957423	0.9957423	0.9961555	0.9982935	0.9982935	0.9982935	0.9982935	0.9942223	0.9942223	0.9982935	0.9982935	0.995958	0.995958	0.995958	0.995958
0.995958	0.995958	0.9998912	0.9998912	0.9956382	0.9956382	0.9961555	0.9961555	0.9998912	0.9998912	0.9983253	0.9983253	0.9956382	0.9956382	0.9961555	0.9961555	0.9957423	0.9957423	0.9961555	0.9982935	0.9982935	0.9982935	0.9982935	0.9942223	0.9942223	0.9982935	0.9982935	0.995958	0.995958	0.995958	0.995958
0.995958	0.995958	0.9998912	0.9998912	0.9956382	0.9956382	0.9961555	0.9961555	0.9998912	0.9998912	0.9983253	0.9983253	0.9956382	0.9956382	0.9961555	0.9961555	0.9957423	0.9957423	0.9961555	0.9982935	0.9982935	0.9982935	0.9982935	0.9942223	0.9942223	0.9982935	0.9982935	0.995958	0.995958	0.995958	0.995958
0.989094	0.989094	0.9973633	0.9973633	0.991722	0.991722	0.9960238	0.9960238	0.9973633	0.9973633	0.997322	0.997322	0.991722	0.991722	0.9960238	0.9960238	0.9919795	0.9919795	0.9960238	0.9936476	0.9936476	0.9936476	0.9936476	0.9874894	0.9874894	0.9936476	0.9936476	0.989094	0.989094	0.989094	0.989094
0.9989286	0.9989286	0.9954479	0.9954479	0.9974488	0.9974488	0.9914601	0.9914601	0.9954479	0.9954479	0.9867434	0.9867434	0.9974488	0.9974488	0.9914601	0.9914601	0.9972888	0.9972888	0.9914601	0.9987273	0.9987273	0.9987273	0.9987273	0.9998036	0.9998036	0.9987273	0.9987273	0.9989286	0.9989286	0.9989286	0.9989286
0.9989286	0.9989286	0.9954479	0.9954479	0.9974488	0.9974488	0.9914601	0.9914601	0.9954479	0.9954479	0.9867434	0.9867434	0.9974488	0.9974488	0.9914601	0.9914601	0.9972888	0.9972888	0.9914601	0.9987273	0.9987273	0.9987273	0.9987273	0.9998036	0.9998036	0.9987273	0.9987273	0.9989286	0.9989286	0.9989286	0.9989286
0.9989286	0.9989286	0.9954479	0.9954479	0.9974488	0.9974488	0.9914601	0.9914601	0.9954479	0.9954479	0.9867434	0.9867434	0.9974488	0.9974488	0.9914601	0.9914601	0.9972888	0.9972888	0.9914601	0.9987273	0.9987273	0.9987273	0.9987273	0.9998036	0.9998036	0.9987273	0.9987273	0.9989286	0.9989286	0.9989286	0.9989286
0.9989286	0.9989286	0.9954479	0.9954479	0.9974488	0.9974488	0.9914601	0.9914601	0.9954479	0.9954479	0.9867434	0.9867434	0.9974488	0.9974488	0.9914601	0.9914601	0.9972888	0.9972888	0.9914601	0.9987273	0.9987273	0.9987273	0.9987273	0.9998036	0.9998036	0.9987273	0.9987273	0.9989286	0.9989286	0.9989286	0.9989286
0.9980723	0.9980723	0.9954065	0.9954065	0.998552	0.998552	0.9932512	0.9932512	0.9954065	0.9954065	0.9874894	0.9874894	0.998552	0.998552	0.9932512	0.9932512	0.9984201	0.9984201	0.9932512	0.9987474	0.9987474	0.9987474	0.9987474	1	1	0.9987474	0.9987474	0.9980723	0.9980723	0.9980723	0.9980723
0.9980723	0.9980723	0.9954065	0.9954065	0.998552	0.998552	0.9932512	0.9932512	0.9954065	0.9954065	0.9874894	0.9874894	0.998552	0.998552	0.9932512	0.9932512	0.9984201	0.9984201	0.9932512	0.9987474	0.9987474	0.9987474	0.9987474	1	1	0.9987474	0.9987474	0.9980723	0.9980723	0.9980723	0.9980723
0.9980723	0.9980723	0.9954065	0.9954065	0.998552	0.998552	0.9932512	0.9932512	0.9954065	0.9954065	0.9874894	0.9874894	0.998552	0.998552	0.9932512	0.9932512	0.9984201	0.9984201	0.9932512	0.9987474	0.9987474	0.9987474	0.9987474	1	1	0.9987474	0.9987474	0.9980723	0.9980723	0.9980723	0.9980723
0.9980723	0.9980723	0.9954065	0.9954065	0.998552	0.998552	0.9932512	0.9932512	0.9954065	0.9954065	0.9874894	0.9874894	0.998552	0.998552	0.9932512	0.9932512	0.9984201	0.9984201	0.9932512	0.9987474	0.9987474	0.9987474	0.9987474	1	1	0.9987474	0.9987474	0.9980723	0.9980723	0.9980723	0.9980723
0.99871	0.99871	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	,98278	,98278	,98278	,98278
0.99871	0.99871	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	,98278	,98278	,98278	,98278
0.99871	0.99871	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	,98278	,98278	,98278	,98278
0.99871	0.99871	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	,98278	,98278	,98278	,98278
0.9988833	0.9988833	0.995389	0.995389	0.997475	0.997475	0.9914734	0.9914734	0.995389	0.995389	0.9866716	0.9866716	0.997475	0.997475	0.9914734	0.9914734	0.9973145	0.9973145	0.9914734	0.9987013	0.9987013	0.9987013	0.9987013	0.9998169	0.9998169	0.9987013	0.9987013	0.9988833	0.9988833	0.9988833	0.9988833
0.9988833	0.9988833	0.995389	0.995389	0.997475	0.997475	0.9914734	0.9914734	0.995389	0.995389	0.9866716	0.9866716	0.997475	0.997475	0.9914734	0.9914734	0.9973145	0.9973145	0.9914734	0.9987013	0.9987013	0.9987013	0.9987013	0.9998169	0.9998169	0.9987013	0.9987013	0.9988833	0.9988833	0.9988833	0.9988833
0.9988833	0.9988833	0.995389	0.995389	0.997475	0.997475	0.9914734	0.9914734	0.995389	0.995389	0.9866716	0.9866716	0.997475	0.997475	0.9914734	0.9914734	0.9973145	0.9973145	0.9914734	0.9987013	0.9987013	0.9987013	0.9987013	0.9998169	0.9998169	0.9987013	0.9987013	0.9988833	0.9988833	0.9988833	0.9988833
0.9988833	0.9988833	0.995389	0.995389	0.997475	0.997475	0.9914734	0.9914734	0.995389	0.995389	0.9866716	0.9866716	0.997475	0.997475	0.9914734	0.9914734	0.9973145	0.9973145	0.9914734	0.9987013	0.9987013	0.9987013	0.9987013	0.9998169	0.9998169	0.9987013	0.9987013	0.9988833	0.9988833	0.9988833	0.9988833
1	1	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	0.991833	0.991833	0.991833	0.991833

notice that all the elements of the block are same. This is also justified because of the fact that corresponding codons of these elements are synonymous codons. So we may claim that our similarity measures among the codons interpret the degeneracy of amino acids from a mathematical perspective.

To establish our findings and for easy understanding in the following we divide the whole 61 × 61 codon similarity table into five codon similarity tables viz., Codon Table for Degeneracy One, Two, Three, Four and Six respectively. Considering codon table for "*degeneracy two*" in the following we analyze the findings as other respective tables are also showing the same findings.

In the Table 6 we have noticed some 2 × 2 blocks where each of the elements of a block is same. Based on the elements of the block we can categorically split all the 2 × 2 blocks into two categories. In one category we notice all the elements of the blocks are 1. The degree of similarity 1 indicates that corresponding codons are belongs to same set of synonymous codons. The elements of the remaining category of the 2 × 2 blocks are different from one. This is also justified because in

Table 5: Degree of Similarity of Codons.

1	1	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	0.991833	0.991833	0.991833	0.991833
1	1	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	0.991833	0.991833	0.991833	0.991833
1	1	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	0.991833	0.991833	0.991833	0.991833
0.9971746	0.9971746	1	1	0.9961033	0.9961033	0.9956553	0.9956553	0.99781	0.99781	0.9973633	0.9973633	0.9961033	0.9961033	0.9956553	0.9956553	0.9961683	0.9961683	0.9956553	0.9989432	0.9989432	0.9989432	0.9989432	0.9954065	0.9954065	0.9989432	0.9989432	0.9971746	0.9971746	0.9971746	0.9971746
0.9971746	0.9971746	1	1	0.9961033	0.9961033	0.9956553	0.9956553	1	1	0.9973633	0.9973633	0.9961033	0.9961033	0.9956553	0.9956553	0.9961683	0.9961683	0.9956553	0.9989432	0.9989432	0.9989432	0.9989432	0.9954065	0.9954065	0.9989432	0.9989432	0.9971746	0.9971746	0.9971746	0.9971746
0.9951054	0.9951054	0.9961033	0.9961033	1	1	0.9978581	0.9978581	0.9961033	0.9961033	0.991722	0.991722	0.99801	0.99801	0.9978581	0.9978581	0.995178	0.995178	0.9978581	0.9982868	0.9982868	0.9982868	0.9982868	0.998552	0.998552	0.9982868	0.9982868	0.9951054	0.9951054	0.9951054	0.9951054
0.9951054	0.9951054	0.9961033	0.9961033	1	1	0.9978581	0.9978581	0.9961033	0.9961033	0.991722	0.991722	0.99801	0.99801	0.9978581	0.9978581	0.9999965	0.9999965	0.9978581	0.9982868	0.9982868	0.9982868	0.9982868	0.998552	0.998552	0.9982868	0.9982868	0.9951054	0.9951054	0.9951054	0.9951054
0.9897433	0.9897433	0.9956553	0.9956553	0.9978581	0.9978581	1	1	0.9956553	0.9956553	0.9960238	0.9960238	0.9978581	0.9978581	0.99844	0.99844	0.9980284	0.9980284	0.998691	0.9954023	0.9954023	0.9954023	0.9954023	0.9932512	0.9932512	0.9954023	0.9954023	0.9897433	0.9897433	0.9897433	0.9897433
0.9897433	0.9897433	0.9956553	0.9956553	0.9978581	0.9978581	1	1	0.9956553	0.9956553	0.9960238	0.9960238	0.9978581	0.9978581	0.99844	0.99844	0.9980284	0.9980284	0.998691	0.9954023	0.9954023	0.9954023	0.9954023	0.9932512	0.9932512	0.9954023	0.9954023	0.9897433	0.9897433	0.9897433	0.9897433
0.9971746	0.9971746	0.99781	0.99781	0.9961033	0.9961033	0.9956553	0.9956553	1	1	0.9973633	0.9973633	0.9961033	0.9961033	0.9956553	0.9956553	0.9961683	0.9961683	0.9956553	0.9989432	0.9989432	0.9989432	0.9989432	0.9954065	0.9954065	0.9989432	0.9989432	0.9971746	0.9971746	0.9971746	0.9971746
0.9971746	0.9971746	0.99781	0.99781	0.9961033	0.9961033	0.9956553	0.9956553	1	1	0.9973633	0.9973633	0.9961033	0.9961033	0.9956553	0.9956553	0.9961683	0.9961683	0.9956553	0.9989432	0.9989432	0.9989432	0.9989432	0.9954065	0.9954065	0.9989432	0.9989432	0.9971746	0.9971746	0.9971746	0.9971746
0.989094	0.989094	0.9973633	0.9973633	0.991722	0.991722	0.9960238	0.9960238	0.9973633	0.9973633	1	1	0.991722	0.991722	0.9960238	0.9960238	0.9919795	0.9919795	0.9960238	0.9936476	0.9936476	0.9936476	0.9936476	0.9874894	0.9874894	0.9936476	0.9936476	0.989094	0.989094	0.989094	0.989094
0.989094	0.989094	0.9973633	0.9973633	0.991722	0.991722	0.9960238	0.9960238	0.9973633	0.9973633	1	1	0.991722	0.991722	0.9960238	0.9960238	0.9919795	0.9919795	0.9960238	0.9936476	0.9936476	0.9936476	0.9936476	0.9874894	0.9874894	0.9936476	0.9936476	0.989094	0.989094	0.989094	0.989094
0.9951054	0.9951054	0.9961033	0.9961033	0.99801	0.99801	0.9978581	0.9978581	0.9961033	0.9961033	0.991722	0.991722	1	1	0.9978581	0.9978581	0.99123	0.99123	0.9978581	0.9982868	0.9982868	0.9982868	0.9982868	0.998552	0.998552	0.9982868	0.9982868	0.9951054	0.9951054	0.9951054	0.9951054
0.9951054	0.9951054	0.9961033	0.9961033	0.99801	0.99801	0.9978581	0.9978581	0.9961033	0.9961033	0.991722	0.991722	1	1	0.9978581	0.9978581	0.99123	0.99123	0.9978581	0.9982868	0.9982868	0.9982868	0.9982868	0.998552	0.998552	0.9982868	0.9982868	0.9951054	0.9951054	0.9951054	0.9951054
0.9897433	0.9897433	0.9956553	0.9956553	0.9978581	0.9978581	0.99844	1	0.9956553	0.9956553	0.9960238	0.9960238	0.9978581	0.9978581	1	1	0.9980284	0.9980284	0.9772871	0.9954023	0.9954023	0.9954023	0.9954023	0.9932512	0.9932512	0.9954023	0.9954023	0.9897433	0.9897433	0.9897433	0.9897433
0.9897433	0.9897433	0.9956553	0.9956553	0.9978581	0.9978581	0.99844	1	0.9956553	0.9956553	0.9960238	0.9960238	0.9978581	0.9978581	1	1	0.9980284	0.9980284	0.9772871	0.9954023	0.9954023	0.9954023	0.9954023	0.9932512	0.9932512	0.9954023	0.9954023	0.9897433	0.9897433	0.9897433	0.9897433
0.9949707	0.9949707	0.9961683	0.9961683	0.995178	0.9999965	0.9980284	0.9980284	0.9961683	0.9961683	0.9919795	0.9919795	0.99123	0.99123	0.9980284	0.9980284	1	1	0.9980284	0.9982529	0.9982529	0.9982529	0.9982529	0.9984201	0.9984201	0.9982529	0.9982529	0.9949707	0.9949707	0.9949707	0.9949707
0.9949707	0.9949707	0.9961683	0.9961683	0.995178	0.9999965	0.9980284	0.9980284	0.9961683	0.9961683	0.9919795	0.9919795	0.99123	0.99123	0.9980284	0.9980284	1	1	0.9980284	0.9982529	0.9982529	0.9982529	0.9982529	0.9984201	0.9984201	0.9982529	0.9982529	0.9949707	0.9949707	0.9949707	0.9949707
0.9897433	0.9897433	0.9956553	0.9956553	0.9978581	0.9978581	0.998691	0.998691	0.9956553	0.9956553	0.9960238	0.9960238	0.9978581	0.9978581	0.9772871	0.9772871	0.9980284	0.9980284	1	0.9954023	0.9954023	0.9954023	0.9954023	0.9932512	0.9932512	0.9954023	0.9954023	0.9897433	0.9897433	0.9897433	0.9897433
0.998876	0.998876	0.9989432	0.9989432	0.9982868	0.9982868	0.9954023	0.9954023	0.9989432	0.9989432	0.9936476	0.9936476	0.9982868	0.9982868	0.9954023	0.9954023	0.9982529	0.9982529	0.9954023	1	1	1	1	0.9987474	0.9987474	1	1	0.998876	0.998876	0.998876	0.998876
0.998876	0.998876	0.9989432	0.9989432	0.9982868	0.9982868	0.9954023	0.9954023	0.9989432	0.9989432	0.9936476	0.9936476	0.9982868	0.9982868	0.9954023	0.9954023	0.9982529	0.9982529	0.9954023	1	1	1	1	0.9987474	0.9987474	1	1	0.998876	0.998876	0.998876	0.998876
0.998876	0.998876	0.9989432	0.9989432	0.9982868	0.9982868	0.9954023	0.9954023	0.9989432	0.9989432	0.9936476	0.9936476	0.9982868	0.9982868	0.9954023	0.9954023	0.9982529	0.9982529	0.9954023	1	1	1	1	0.9987474	0.9987474	1	1	0.998876	0.998876	0.998876	0.998876
0.998876	0.998876	0.9989432	0.9989432	0.9982868	0.9982868	0.9954023	0.9954023	0.9989432	0.9989432	0.9936476	0.9936476	0.9982868	0.9982868	0.9954023	0.9954023	0.9982529	0.9982529	0.9954023	1	1	1	1	0.9987474	0.9987474	1	1	0.998876	0.998876	0.998876	0.998876
0.9980723	0.9980723	0.9954065	0.9954065	0.998552	0.998552	0.9932512	0.9932512	0.9954065	0.9954065	0.9874894	0.9874894	0.998552	0.998552	0.9932512	0.9932512	0.9984201	0.9984201	0.9932512	0.9987474	0.9987474	0.9987474	0.9987474	1	1	0.9987474	0.9987474	0.9980723	0.9980723	0.9980723	0.9980723
0.9980723	0.9980723	0.9954065	0.9954065	0.998552	0.998552	0.9932512	0.9932512	0.9954065	0.9954065	0.9874894	0.9874894	0.998552	0.998552	0.9932512	0.9932512	0.9984201	0.9984201	0.9932512	0.9987474	0.9987474	0.9987474	0.9987474	1	1	0.9987474	0.9987474	0.9980723	0.9980723	0.9980723	0.9980723
0.998876	0.998876	0.9989432	0.9989432	0.9982868	0.9982868	0.9954023	0.9954023	0.9989432	0.9989432	0.9936476	0.9936476	0.9982868	0.9982868	0.9954023	0.9954023	0.9982529	0.9982529	0.9954023	1	1	1	1	0.9987474	0.9987474	1	1	0.998876	0.998876	0.998876	0.998876
0.998876	0.998876	0.9989432	0.9989432	0.9982868	0.9982868	0.9954023	0.9954023	0.9989432	0.9989432	0.9936476	0.9936476	0.9982868	0.9982868	0.9954023	0.9954023	0.9982529	0.9982529	0.9954023	1	1	1	1	0.9987474	0.9987474	1	1	0.998876	0.998876	0.998876	0.998876
0.991833	0.991833	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	1	1	1	1
0.991833	0.991833	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	1	1	1	1
0.991833	0.991833	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	1	1	1	1
0.991833	0.991833	0.9971746	0.9971746	0.9951054	0.9951054	0.9897433	0.9897433	0.9971746	0.9971746	0.989094	0.989094	0.9951054	0.9951054	0.9897433	0.9897433	0.9949707	0.9949707	0.9897433	0.998876	0.998876	0.998876	0.998876	0.9980723	0.9980723	0.998876	0.998876	1	1	1	1

Table 6: Codon Table for Degeneracy Two.

	UUU	UUC	UAU	UAC	CAU	CAC	CAA	CAG	AAU	AAC	AAA	AAG	GAU	GAC	GAA	GAG	UGU	UGC
UUU	1	1	0.949	0.949	0.996	0.996	0.996	0.996	0.991	0.991	0.997	0.997	0.996	0.996	0.996	0.996	0.996	0.996
UUC	1	1	0.999	0.999	0.996	0.996	0.996	0.996	0.997	0.997	0.997	0.997	0.996	0.996	0.996	0.996	0.996	0.996
UAU	0.949	0.999	1	1	0.996	0.996	0.996	0.996	0.998	0.998	0.997	0.997	0.996	0.996	0.996	0.996	0.996	0.996
UAC	0.949	0.999	1	1	0.996	0.996	0.996	0.996	0.998	0.998	0.997	0.997	0.996	0.996	0.996	0.996	0.996	0.996
CAU	0.996	0.996	0.996	0.996	1	1	0.998	0.998	0.996	0.996	0.992	0.992	0.998	0.998	0.998	0.998	0.995	0.995
CAC	0.996	0.996	0.996	0.996	1	1	0.998	0.998	0.996	0.996	0.992	0.992	0.998	0.998	0.998	0.998	0.998	0.998
CAA	0.996	0.996	0.996	0.996	0.998	0.998	1	1	0.996	0.996	0.996	0.996	0.998	0.998	0.998	0.998	0.998	0.998
CAG	0.996	0.996	0.996	0.996	0.998	0.998	1	1	0.996	0.996	0.996	0.996	0.998	0.998	0.998	0.998	0.998	0.998
AAU	0.991	0.997	0.998	0.998	0.996	0.996	0.996	0.996	1	1	0.997	0.997	0.996	0.996	0.996	0.996	0.996	0.996
AAC	0.991	0.997	0.998	0.998	0.996	0.996	0.996	0.996	1	1	0.997	0.997	0.996	0.996	0.996	0.996	0.996	0.996
AAA	0.997	0.997	0.997	0.997	0.992	0.992	0.996	0.996	0.997	0.997	1	1	0.992	0.992	0.996	0.996	0.992	0.992
AAG	0.997	0.997	0.997	0.997	0.992	0.992	0.996	0.996	0.997	0.997	1	1	0.992	0.992	0.996	0.996	0.992	0.992
GAU	0.996	0.996	0.996	0.996	0.998	0.998	0.998	0.998	0.996	0.996	0.992	0.992	1	1	0.998	0.998	0.991	0.991
GAC	0.996	0.996	0.996	0.996	0.998	0.998	0.998	0.998	0.996	0.996	0.992	0.992	1	1	0.998	0.998	0.991	0.991
GAA	0.996	0.996	0.996	0.996	0.998	0.998	0.998	0.998	0.996	0.996	0.996	0.996	0.998	0.998	1	1	0.998	0.998
GAG	0.996	0.996	0.996	0.996	0.998	0.998	0.998	0.998	0.996	0.996	0.996	0.996	0.998	0.998	1	1	0.998	0.998
UGU	0.996	0.996	0.996	0.996	0.995	0.998	0.998	0.998	0.996	0.996	0.992	0.992	0.991	0.991	0.998	0.998	1	1
UGC	0.996	0.996	0.996	0.996	0.995	0.998	0.998	0.998	0.996	0.996	0.992	0.992	0.991	0.991	0.998	0.998	1	1

this case correspondences are in between two set of different synonymous codons.

Similarly, in the Table 7, Table 8, Table 9 and Table 10 we have some 4×4, 6×6, and 3×3 1×1 blocks respectively where features of the elements are same as Table 6.

In the literature of codon degeneracy different methods for comparing codons in terms of different aspects have been found. Based on different characteristics of codons other than our considered aspects we may have different cosine similarity among the codons. In

Table 7: Codon Table for Degeneracy Four.

	GUU	GUC	GUA	GUG	CCU	CCA	CCA	CCG	ACU	ACC	ACA	ACG	GCU	GCC	GCA	GCG	GGU	GGC	GGA	GGG
GUU	1	1	1	1	0.9989	0.9989	0.9989	0.9989	0.9998	0.9998	0.9998	0.9998	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989
GUC	1	1	1	1	0.9989	0.9989	0.9989	0.9989	0.9998	0.9998	0.9998	0.9998	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989
GUA	1	1	1	1	0.9989	0.9989	0.9989	0.9989	0.9998	0.9998	0.9998	0.9998	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989
GUG	1	1	1	1	0.9989	0.9989	0.9989	0.9989	0.9998	0.9998	0.9998	0.9998	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989
CCU	0.9989	0.9989	0.9989	0.9989	1	1	1	1	0.9989	0.9989	0.9989	0.9989	0.9987	0.9987	0.9987	0.9987	0.9989	0.9989	0.9989	0.9989
CCA	0.9989	0.9989	0.9989	0.9989	1	1	1	1	0.9989	0.9989	0.9989	0.9989	0.9987	0.9987	0.9987	0.9987	0.9989	0.9989	0.9989	0.9989
CCA	0.9989	0.9989	0.9989	0.9989	1	1	1	1	0.9989	0.9989	0.9989	0.9989	0.9987	0.9987	0.9987	0.9987	0.9989	0.9989	0.9989	0.9989
CCG	0.9989	0.9989	0.9989	0.9989	1	1	1	1	0.9989	0.9989	0.9989	0.9989	0.9987	0.9987	0.9987	0.9987	0.9989	0.9989	0.9989	0.9989
ACU	0.9998	0.9998	0.9998	0.9998	0.9989	0.9989	0.9989	0.9989	1	1	1	1	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989
ACC	0.9998	0.9998	0.9998	0.9998	0.9989	0.9989	0.9989	0.9989	1	1	1	1	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989
ACA	0.9998	0.9998	0.9998	0.9998	0.9989	0.9989	0.9989	0.9989	1	1	1	1	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989
ACG	0.9998	0.9998	0.9998	0.9998	0.9989	0.9989	0.9989	0.9989	1	1	1	1	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989
GCU	0.9989	0.9989	0.9989	0.9989	0.9987	0.9987	0.9987	0.9987	0.9989	0.9989	0.9989	0.9989	1	1	1	1	0.9918	0.9918	0.9918	0.9918
GCC	0.9989	0.9989	0.9989	0.9989	0.9987	0.9987	0.9987	0.9987	0.9989	0.9989	0.9989	0.9989	1	1	1	1	0.9918	0.9918	0.9918	0.9918
GCA	0.9989	0.9989	0.9989	0.9989	0.9987	0.9987	0.9987	0.9987	0.9989	0.9989	0.9989	0.9989	1	1	1	1	0.9918	0.9918	0.9918	0.9918
GCG	0.9989	0.9989	0.9989	0.9989	0.9987	0.9987	0.9987	0.9987	0.9989	0.9989	0.9989	0.9989	1	1	1	1	0.9918	0.9918	0.9918	0.9918
GGU	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9918	0.9918	0.9918	0.9918	1	1	1	1
GGC	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9918	0.9918	0.9918	0.9918	1	1	1	1
GGA	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9918	0.9918	0.9918	0.9918	1	1	1	1
GGG	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9918	0.9918	0.9918	0.9918	1	1	1	1

Table 8: Codon Table for Degeneracy Six.

	UUA	UUG	CUU	CUC	CUA	CUG	CGU	CGC	CGA	CGG	AGA	AGG	AGU	AGC	UCU	UCC	UCA	UCG
UUA	1	1	1	1	1	1	0.99946	0.99946	0.99946	0.99946	0.99946	0.99946	0.99711	0.99711	0.99711	0.99711	0.99711	0.99711
UUG	1	1	1	1	1	1	0.99946	0.99946	0.99946	0.99946	0.99946	0.99946	0.99711	0.99711	0.99711	0.99711	0.99711	0.99711
CUU	1	1	1	1	1	1	0.99946	0.99946	0.99946	0.99946	0.99946	0.99946	0.99711	0.99711	0.99711	0.99711	0.99711	0.99711
CUC	1	1	1	1	1	1	0.99946	0.99946	0.99946	0.99946	0.99946	0.99946	0.99711	0.99711	0.99711	0.99711	0.99711	0.99711
CUA	1	1	1	1	1	1	0.99946	0.99946	0.99946	0.99946	0.99946	0.99946	0.99711	0.99711	0.99711	0.99711	0.99711	0.99711
CUG	1	1	1	1	1	1	0.99946	0.99946	0.99946	0.99946	0.99946	0.99946	0.99711	0.99711	0.99711	0.99711	0.99711	0.99711
CGU	0.99946	0.99946	0.99946	0.99946	0.99946	0.99946	1	1	1	1	1	1	0.99875	0.99875	0.99875	0.99875	0.99875	0.99875
CGC	0.99946	0.99946	0.99946	0.99946	0.99946	0.99946	1	1	1	1	1	1	0.99875	0.99875	0.99875	0.99875	0.99875	0.99875
CGA	0.99946	0.99946	0.99946	0.99946	0.99946	0.99946	1	1	1	1	1	1	0.99875	0.99875	0.99875	0.99875	0.99875	0.99875
CGG	0.99946	0.99946	0.99946	0.99946	0.99946	0.99946	1	1	1	1	1	1	0.99875	0.99875	0.99875	0.99875	0.99875	0.99875
AGA	0.99946	0.99946	0.99946	0.99946	0.99946	0.99946	1	1	1	1	1	1	0.99875	0.99875	0.99875	0.99875	0.99875	0.99875
AGG	0.99946	0.99946	0.99946	0.99946	0.99946	0.99946	1	1	1	1	1	1	0.99875	0.99875	0.99875	0.99875	0.99875	0.99875
AGU	0.99711	0.99711	0.99711	0.99711	0.99711	0.99711	0.99875	0.99875	0.99875	0.99875	0.99875	0.99875	1	1	1	1	1	1
AGC	0.99711	0.99711	0.99711	0.99711	0.99711	0.99711	0.99875	0.99875	0.99875	0.99875	0.99875	0.99875	1	1	1	1	1	1
UCU	0.99711	0.99711	0.99711	0.99711	0.99711	0.99711	0.99875	0.99875	0.99875	0.99875	0.99875	0.99875	1	1	1	1	1	1
UCC	0.99711	0.99711	0.99711	0.99711	0.99711	0.99711	0.99875	0.99875	0.99875	0.99875	0.99875	0.99875	1	1	1	1	1	1
UCA	0.99711	0.99711	0.99711	0.99711	0.99711	0.99711	0.99875	0.99875	0.99875	0.99875	0.99875	0.99875	1	1	1	1	1	1
UCG	0.99711	0.99711	0.99711	0.99711	0.99711	0.99711	0.99875	0.99875	0.99875	0.99875	0.99875	0.99875	1	1	1	1	1	1

Table 9: Codon Table for Degeneracy Three.

	AUU	AUA	AUC
AUU	1	1	1
AUA	1	1	1
AUC	1	1	1

Table 10: Codon Table for Degeneracy One.

	UGG	AUG
UGG	1	.99875
AUG	.99875	1

our work, as we discussed above we have assigned some weights on the base position of the codons to find out a similarity measurement among the codons based on Lagerkvist's hypothesis i.e., based on positional impact, appearance of pyrimidine and purine in the second and third base position and Hydrogen bonding influence in nucleotides of a codon. Since the behavior of the nucleotides in all the codons shows similar in kind so we have found similar kinds of weights for each codons. Which pave the way of getting very close similarity in between the codons.

Comparative Study with Impression Classification Techniques

In this section our aim is to produce a systematic comparative study between the existing work proposed by Das *et al.*, 2016[12] and our proposed work. In order to compare these two methods, we identified some points that describe how to classify the amino acids based on degeneracy. While examining Table 11, we have noticed the following points

I. Das *et al.*, (2016)[12] have assigned some ternary number to each amino acid.
II. They have mapped these ternary numbers into 10 impression values (IP).
III. Finally, they have put these ten IP values into three groups and several subgroups whereas Total Impression IP value (TIP) same within a group.

As a consequence of these three facts different amino acids having different degeneracy clubbed into a same group. So in terms of degeneracy their method of grouping of amino acids is not significant. But, our defined similarity measure on codons put the all the amino acids having same degeneracy into one group. So our clustering method is more notable than to interpret the concept of degeneracy.

Network Representation of Codons

Every codon code a unique amino acid and the set of codons which are involved for coding a particular amino acid are called synonymous codons. From the literature study it has been observed that the general structure of different aspects of codons such as nucleotide substitutions, degeneracy etc can be described by the methodology taken from graph theory. Akhtar *et al.* (2015)[19] constructed three different types of undirected amino acids graph based on the point mutation in the first, second and third positions of a codon.

Figure 1 represents undirected unweighted codons graph $G(V, E)$ of 61 codons where represent set of vertices constitute all possible 61 codons and the set of edges connecting these vertices represented by E. Adjacency values between two codons of the matrix (Table 2, 3, 4 and Table 5) are greater than equal to 0.9967.

Table 11: Classification of Amino Acids based on Impression.

Groups	Amino acid With Ternary symbol	Impression value	TIP (I1 + I2 + I3)
First group	GAP – 000, Q – 111, X – 222	(0,0,0)	0
Second group	G – 001, D – 110 K – 112, O – 221	(0,1,1)	2
	L – 100, P – 011 fmet – 211, H – 122	(1,0,1)	
	S – 010, I – 101 M – 121, Y - 212	(1,1,0)	
Third group	A – 002, W- 220	(0, 2, 2)	4
	Hyl–200,Hyp– 022	(2, 0, 2)	
	T- 020, U- 202	(2, 2, 0)	
	E- 120, N- 102	(1, 2, 1)	
	V- 012, R – 210	(1, 1, 2)	
	F- 201, C- 021	(2, 1, 1)	

Mixing on Degree of Nodes

Definition 1

One of the important properties to study the nature of a network is mixing; it may be of assortative or disassortative in behavior. In a disassortative behavior network, higher degree has a tendency to connect with lower degree nodes. Disassortativity of a network can be measured by the Pearson correlation coefficient r of links nodes.

A positive correlation exhibits associations between the nodes of same degrees (assortativity), and the negative correlation exhibits connections between the nodes with dissimilar degrees (disassortativity).

Assessing and measuring the importance of a node in a network is of practical significance to improve the robustness, stability, and network synchronization, etc. Here, to calculate the correlation of mixing of amino acids network, equation (2) is used.

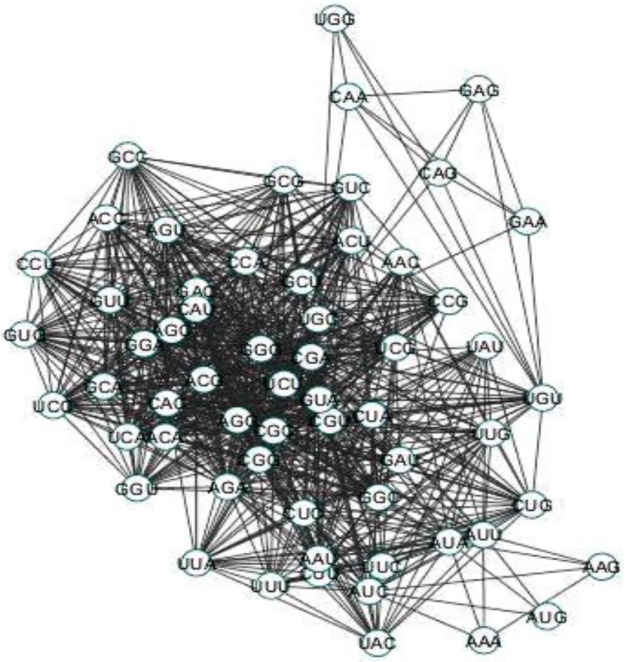

Figure 1: Codon Networks.

The coefficients of mixing of the network given by the Figure 1 is -0.0311 which revels the fact that the codon networks disassortative mixing in nature.

Weighted Directed Graph Representation of Ordered Codons Sequences

In this section, it has been tried to represent a directed weighted graph from any random ordered codons sequences. Let $G = (V, E)$ be a directed graph where vertices $V = \{v_1, v_2, v_3 \ldots\ldots v_n\}$ are the codons and edges $E = \{e_1, e_2, e_3 \ldots\ldots e_n\}$. Individual weight has been assigned between two codons as shown in Table 2, 3, 4 and 5. This assigned weight represents the degree of similarities between the codons. To illustrate our findings let us consider the followings codons sequence. In this section we try to describe synonymous codons and non-synonymous codon with the aid of graph structure.

…….UUC GCU GCU AAA UUU UUC ACC ACC AUG…….

Now, for the above random codons sequence the graph ordered from UUC can be drawn to the next GCU, then GCU to GCU (forming a self-loop) and so on. The weight of an edge e_i is denoted as we_i and is defined as the degree of similarity of the connecting vertices.

As shown in Figure 2, GCU is the next consecutive vertex of the starting vertex UUC. So, there is a direction from UUC to GCU with a weight of 0.9972, which signifies that these two are non-synonymous codon, i.e., low degree of similarity. A self-loop from GCU to GCU signifies that they are synonymous codons with a maximum degree of similarity 1.

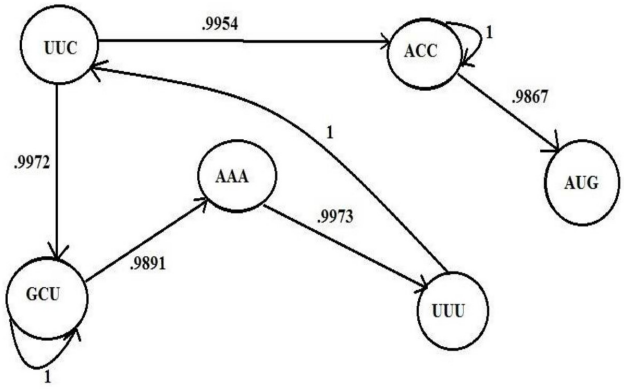

Figure 2: Weighted Directed Graph of Codons.

Similarly, to establish the other connections, it has been found that a weight 1, i.e., maximum degree of similarity between two distinct nodes UUU and UUC signifies that they are synonymous codons that represent the same amino acid.

CONCLUSION

In this paper we have interpreted the degeneracy property of genetic codons from a mathematical perspective. In our study, we demonstrated the degree of similarity among the codons using Cosine similarity. Furthermore, while analyzing the degree of similarities among 61 codons it has been noticed that some codons have degree of similarity 1, biologically which is substantiated because those codons are synonymous codons. Finally, we made a comparative study of our work with the work proposed by Das *et al.*, 2016.[16] In our future work we aim to analyze additional features of the genetic codon table from a mathematical perspective.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

ABBREVIATIONS

DNA: Deoxyribonucleic Acid; **RNA:** Ribonucleic acid; **mRna**: Messenger RNA.

SUMMARY

In this manuscript we formulate a new classifying technique with the help of cosine similarities to explain the degeneracy. Also study the assortative and disassortative nature of codons networks which may help us to understand the flow of genetic information in the evolution process of amino acids.

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