**SeqFea-Learn: A Python pipeline tool for feature extraction, feature selection, machine learning and deep learning based on DNA, RNA and protein sequence data**

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**Methods Description**

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# Introduction

**SeqFea-Learn** is a Python pipeline tool for analyzing DNA, RNA, and protein sequencing data that integrated 19 feature extraction methods for DNA, 15 feature extraction methods for RNA, 32 feature extraction methods for Protein sequencing data, 21 feature selection methods, 15 dimensionality reduction methods, 7 clustering methods, 5 sampling methods, 10 classification methods, and 3 deep learning methods. This document will provide user detailed descriptions for each method.

# DNA feature extraction method

**SeqFea-Learn** contains 19 DNA feature extraction methods.

|  |  |
| --- | --- |
| Feature Extraction Method | Method Number |
| Kmer | 1 |
| Reverse compliment kmer (RCKmer) | 2 |
| Nucleic acid composition (NAC) | 3 |
| Di-nucleotide composition (DNC) | 4 |
| Tri-Nucleotide Composition (TNC) | 5 |
| Binary encoding (BE) | 6 |
| zCurve Mathematical Formula (zCurve) | 7 |
| Dinucleotide based auto covariance (DAC) | 8 |
| Dinucleotide based cross covariance (DCC) | 9 |
| Di-nucleotide based auto-cross covariance (DACC) | 10 |
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1. Kmer

For Kmer descriptor, the DNA sequences are represented as the occurrence frequencies of  neighboring nucleic acids. The Kmer (k=3) descriptor can be calculated as:



where  is the number of kmer type , while  is the length of a nucleotide sequence.

1. Reverse compliment kmer (RCKmer)

The reverse compliment kmer is a variant of kmer descriptor, in which the kmers are not expected to be strand specific. For instance, for a DNA sequence, there are 16 types of 2-mers (i.e. 'AA', 'AC', 'AG', 'AT', 'CA', 'CC', 'CG', 'CT', 'GA', 'GC', 'GG', 'GT', 'TA', 'TC', 'TG', 'TT'), ‘TT’ is reverse compliment with ‘AA’. After removing the reverse compliment kmers, there are only 10 distinct kmers in the reverse compliment kmer approach ('AA', 'AC', 'AG', 'AT', 'CA', 'CC', 'CG', 'GA', 'GC', 'TA').

1. Pseudo dinucleotide composition (PseDNC)

PseDNC is an approach incorporating the contiguous local sequence-order information and the global sequence-order information into the feature vector of the DNA sequence. Given a DNA sequence D, the PseDNC feature vector of D is defined:





where  is the normalized occurrence frequency of dinucleotides in the RNA sequence, the parameter  is an integer, representing the highest counted rank (or tier) of the correlation along a RNA sequence, w is the weight factor ranged from 0 to 1,  is called the correlation factor that reflects the sequence-order correlation between all the most contiguous dinucleotides along a RNA sequence, which is defined:



where the correlation function is given by



where  is the number of physicochemical indices, in this approach, 6 indices reflecting the local RNA structural properties are employed to generate the PseDNC feature vector,  represents the numerical value of the  physicochemical index of the dinucleotide .

1. Pseudo k-tuple nucleotide composition (PseKNC)

PseKNC extends the PseDNC approach by incorporating *k*-tuple nucleotide composition. Given a DNA sequence D, the feature vector of D is defined:





where  is the number of the total counted ranks (or tiers) of the correlations along a DNA sequence;  is the frequency of oligonucleotide that is normalized to ; is a weight factor; is given by



which represents the  structural correlation factor between all the  most contiguous dinucleotides. The correlation function  is defined by



where  is the number of physicochemical indices, in this study, 6 indices reflecting the local DNA structural properties are employed to generate the PseKNC feature vector;  represents the numerical value of the  physicochemical index for the dinucleotide .

1. Dinucleotide-based auto covariance (DAC)

The DAC measures the correlation of the same physicochemical index between two dinucleotides separated by a distance of lag along the sequence, which can be calculated as:



where  is a physicochemical index,  is the length of the RNA sequence  means the numerical value of the physicochemical index  for the dinucleotide  at position ,  is the average value for physicochemical index  along the whole sequence:

In such a way, the length of DAC feature vector is , where  is the number of physicochemical indices, and  is the maximum of sequence.

1. Dinucleotide-based cross covariance (DCC)

Given a DNA sequence, the DCC approach measures the correlation of two different physicochemical indices between two dinucleotides separated by lag nucleic acids along the sequence, which can be calculated by:



where  are two different physicochemical indices,  is the length of the DNA sequence,  is the numerical value of the physicochemical index  for the dinucleotide .  is the average value for physicochemical index value  along the whole sequence:



In such a way, the length of the DCC feature vector is ,  is the maximum of sequence; N is the number of physicochemical indices.

1. Dinucleotide-based auto-cross covariance (DACC)

DACC is a combination of DAC and DCC. Therefore, the length of the DACC feature vector is , where N is the number of physicochemical indices and  is the maximum of sequence.

1. Trinucleotide-based auto covariance (TAC)

The Trinucleotide-based auto covariance (TAC) encoding measures the correlation of the same physicochemical index between trinucleotides separated by lag nucleic acids along the sequence, and can be calculated as:



where  is a physicochemical index,  is the length of the DNA sequence  means the numerical value of the physicochemical index  for the dinucleotide  at position , is the average value for physicochemical index  along the whole sequence. The dimension of TAC feature vector is , where  is the number of physicochemical indices, and  is the maximum of sequence.

1. Trinucleotide-based cross covariance (TCC)

The trinucleotide-based cross covariance (TCC) encoding measures the correlation of two different physicochemical indices between two trinucleotides separated by nucleic acids along the sequence. The TCC encoding can be calculated as:



where  are two different physicochemical indices,  is the length of the DNA sequence,  is the numerical value of the physicochemical index  for the dinucleotide .  is the average value for physicochemical index value  along the whole sequence:



In such a way, the length of the TCC feature vector is ,  is the maximum of sequence; N is the number of physicochemical indices.

1. Trinucleotide-based auto-cross covariance (TACC)

The trinucleotide-based auto-cross covariance (TACC) encoding is a combination of TAC and TACC encoding. Thus, the dimension of the TACC encoding is , where N is the number of physicochemical indices and  is the maximum of DNA sequence.

1. Nucleic acid composition (NAC)

The nucleic acid composition (NAC) encoding calculates the frequency of each nucleic acid type in a nucleotide sequence. The frequencies of all 4 natural nucleic acids (i.e. “ACGT or U”) can be calculated as:



where *N*(*t*) is the number of nucleic acid type *t*, while *N* is the length of a nucleotide sequence.

1. Di-nucleotide composition (DNC)

The Di-Nucleotide Composition gives 16 descriptors. It is defined as:



where is the number of di-nucleotide represented by nucleic acid types *r* and *s*.

1. Tri-nucleotide composition (TNC)

The Tri-Nucleotide Composition gives 64 descriptors. It is defined as:



where is the number of tri-nucleotide represented by nucleic acid types *r, s* and *t*.

1. zCurve mathematical formula (zCurve)

Z-curve theory is often used in genomic sequence analysis. It has got three components in three axis. They are defined as following.



Three features will generate using the zCurve method.

1. Monokgap theoretical description (MonoKGap)

When -kgap=n then the  features will exist for DNA and RNA but  features will exist for protein. When -kgap=1, feature structure will be X\_X.

When -kgap=2, feature structure will be X\_X, and X\_\_X. When -kgap=3, feature structure will be X\_X. X\_\_X, and X\_\_\_X. Described with appropriate examples: When -kgap=1 then only sixteen features will exist for DNA and RNA but four hundred (400) features will exist for protein. Features will be numbers of A\_A, A\_C, A\_G, A\_T, C\_A, C\_C, C\_G, C\_T, G\_A, G\_C, G\_G, G\_T, T\_A, T\_C, T\_G, and T\_T of the whole sequence of DNA respectively. When -kgap=2 then only thirty-two features will exist for DNA and RNA but eight hundred (800) features will exist for protein. Features will be numbers of A\_A, A\_C, A\_G, A\_T, C\_A,C\_C, C\_G, C\_T, G\_A, G\_C, G\_G, G\_T, T\_A, T\_C, T\_G,T\_T, A\_\_A, A\_\_C, A\_\_G, A\_\_T, C\_\_A, C\_\_C, C\_\_G, C\_\_T, G\_\_A, G\_\_C, G\_\_G, G\_\_T, T\_\_A, T\_\_C, T\_\_G, and T\_\_T of the whole sequence of DNA respectively.

When -kgap=3 then only forty-eight features will exist for DNA and RNA, but one thousand and two hundred (1,200) features will exist for protein. Features will be numbers of A\_A, A\_C, A\_G, A\_T, C\_A,C\_C, C\_G, C\_T, G\_A, G\_C, G\_G, G\_T, T\_A, T\_C, T\_G,T\_T, A\_\_A, A\_\_C, A\_\_G,A\_\_T, C\_\_A, C\_\_C, C\_\_G, C\_\_T, G\_\_A, G\_\_C, G\_\_G, G\_\_T, T\_\_A, T\_\_C, T\_\_G, T\_\_T, A\_\_\_A, A\_\_\_C, A\_\_\_G, A\_\_\_T, C\_\_\_A, C\_\_\_C, C\_\_\_G, C\_\_\_T, G\_\_\_A, G\_\_\_C, G\_\_\_G,G\_\_\_T, T\_\_\_A, T\_\_\_C, T\_\_\_G, and T\_\_\_T of the whole sequence of DNA respectively.

1. MonoDiKGap Theoretical Description (MonoDiKGap)

When kgap=n then the  features will exist for DNA and RNA, but features will exist for protein.

When -kgap=1, feature structure will be X\_XX.

When -kgap=2, feature structure will be X\_XX, and X\_\_XX.

When -kgap=3, feature structure will be X\_XX, X\_\_XX, and X\_\_\_XX. Described with appropriate examples:

When -kgap=1 then only sixty-four (64) features will exist for DNA and RNA, but eight thousand (8,000) features will exist for protein. Features will be numbers of A\_AA, A\_AC,A\_AG, A\_AT, A\_CA, A\_CC, A\_CG, A\_CT, A\_GA, A\_GC, A\_GG, A\_GT, A\_TA, A\_TC, A\_TG,A\_TT, C\_AA, C\_AC, C\_AG, C\_AT, C\_CA, C\_CC, C\_CG, C\_CT, C\_GA, C\_GC, C\_GG, C\_GT,C\_TA, C\_TC, C\_TG, C\_TT, G\_AA, G\_AC, G\_AG, G\_AT, G\_CA, G\_CC, G\_CG, G\_CT, G\_GA,G\_GC, G\_GG, G\_GT, G\_TA, G\_TC, G\_TG, G\_TT, T\_AA, T\_AC, T\_AG, T\_AT, T\_CA, T\_CC,T\_CG, T\_CT, T\_GA, T\_GC, T\_GG, T\_GT, T\_TA, T\_TC, T\_TG, and T\_TT of the whole sequence of DNA respectively.

When -kgap=2 then only hundred and twenty-eight (128) features will exist for DNA and RNA, but sixteen thousand (16,000) features will exist for protein. Features will be numbers of A\_AA, A\_AC,A\_AG, A\_AT, A\_CA, A\_CC, A\_CG, A\_CT, A\_GA, A\_GC, A\_GG, A\_GT, A\_TA, A\_TC, A\_TG,A\_TT, C\_AA, C\_AC, C\_AG, C\_AT, C\_CA, C\_CC, C\_CG, C\_CT, C\_GA, C\_GC, C\_GG, C\_GT,C\_TA, C\_TC, C\_TG, C\_TT, G\_AA, G\_AC, G\_AG, G\_AT, G\_CA, G\_CC, G\_CG, G\_CT, G\_GA,G\_GC, G\_GG, G\_GT, G\_TA, G\_TC, G\_TG, G\_TT, T\_AA, T\_AC, T\_AG, T\_AT, T\_CA, T\_CC,T\_CG, T\_CT, T\_GA, T\_GC, T\_GG, T\_GT, T\_TA, T\_TC, T\_TG,T\_TT, A\_\_AA, A\_\_AC, A\_\_AG, A\_\_AT, A\_\_CA, A\_\_CC, A\_\_CG, A\_\_CT, A\_\_GA, A\_\_GC,A\_\_GG, A\_\_GT, A\_\_TA, A\_\_TC, A\_\_TG, A\_\_TT, C\_\_AA, C\_\_AC, C\_\_AG, C\_\_AT, C\_\_CA,C\_\_CC, C\_\_CG, C\_\_CT, C\_\_GA, C\_\_GC, C\_\_GG, C\_\_GT, C\_\_TA, C\_\_TC, C\_\_TG, C\_\_TT,G\_\_AA, G\_\_AC, G\_\_AG, G\_\_AT, G\_\_CA, G\_\_CC, G\_\_CG, G\_\_CT, G\_\_GA, G\_\_GC, G\_\_GG,G\_\_GT, G\_\_TA, G\_\_TC, G\_\_TG, G\_\_TT, T\_\_AA, T\_\_AC, T\_\_AG, T\_\_AT, T\_\_CA, T\_\_CC,T\_\_CG, T\_\_CT, T\_\_GA, T\_\_GC, T\_\_GG, T\_\_GT, T\_\_TA, T\_\_TC, T\_\_TG, and T\_\_TT of the whole sequence of DNA respectively.

# RNA feature extraction method

**SeqFea-Learn** contains 15 RNA feature extraction methods.

|  |  |
| --- | --- |
| Feature Extraction Method | Method Number |
| Kmer | 1 |
| Reverse compliment Kmer (RCKmer) | 2 |
| Nucleic acid composition (NAC) | 3 |
| Di-nucleotide composition (DNC) | 4 |
| Tri-Nucleotide Composition (TNC) | 5 |
| Binary encoding (BE) | 6 |
| zCurve Mathematical Formula (zCurve) | 7 |
| Dinucleotide based auto covariance (DAC) | 8 |
| Dinucleotide based cross covariance (DCC) | 9 |
| Di-nucleotide based auto-cross covariance (DACC) | 10 |
| Position-specific dinucleotide propensity (PSDNP) | 11 |
| Position-specific trinucleotide propensity (PSTNP) | 12 |
| MonoKGap theoretical description (MonoKGap) | 13 |
| MonoDiKGap theoretical description (MonodiKGap) | 14 |
| Pseudo di-nucleotide composition (PseDNC) | 15 |

1. Kmer

For kmer descriptor [1, 2], the RNA sequences are represented as the occurrence frequencies of  neighboring nucleic acids. The Kmer (k=3) descriptor can be calculated as:



where  is the number of kmer type , while  is the length of a nucleotide sequence.

1. Reverse compliment kmer (RCKmer)

The reverse compliment kmer [1, 3] is a variant of kmer descriptor, in which the kmers are not

expected to be strand-specific. For instance, for a DNA sequence, there are 16 types of 2-mers (i.e. 'AA', 'AC', 'AG', 'AT', 'CA', 'CC', 'CG', 'CT', 'GA', 'GC', 'GG', 'GT', 'TA', 'TC', 'TG', 'TT'), ‘TT’ is reverse compliment with ‘AA’. After removing the reverse compliment kmers, there are only 10 distinct kmers in the reverse compliment kmer approach ('AA', 'AC', 'AG', 'AT', 'CA', 'CC', 'CG', 'GA', 'GC', 'TA').

1. Pseudo dinucleotide composition (PseDNC)

PseDNC [4] is an approach incorporating the contiguous local sequence-order information and the global sequence-order information into the feature vector of the RNA sequence. Given a RNA sequence D, the PseDNC feature vector of D is defined:





where  is the normalized occurrence frequency of dinucleotides in the RNA sequence, the parameter  is an integer, representing the highest counted rank (or tier) of the correlation along a RNA sequence, w is the weight factor ranged from 0 to 1,  is called the correlation factor that reflects the sequence-order correlation between all the most contiguous dinucleotides along a RNA sequence, which is defined:



where the correlation function is given by



where  is the number of physicochemical indices, in this approach, 6 indices reflecting the local RNA structural properties are employed to generate the PseDNC feature vector,  represents the numerical value of the  physicochemical index of the dinucleotide .

1. Dinucleotide-based auto covariance (DAC)

The DAC [5, 6] measures the correlation of the same physicochemical index between two dinucleotides separated by a distance of lag along the sequence, which can be calculated as:



where  is a physicochemical index,  is the length of the RNA sequence  means the numerical value of the physicochemical index  for the dinucleotide  at position ,  is the average value for physicochemical index  along the whole sequence:

In such a way, the length of DAC feature vector is , where  is the number of physicochemical indices, and  is the maximum of sequence.

1. Dinucleotide-based cross covariance (DCC)

Given a RNA sequence, the DCC approach [5, 6] measures the correlation of two different physicochemical indices between two dinucleotides separated by lag nucleic acids along the sequence, which can be calculated by:



Where  are two different physicochemical indices,  is the length of the RNA sequence,  is the numerical value of the physicochemical index  for the dinucleotide .  is the average value for physicochemical index value  along the whole sequence:



In such a way, the length of the DCC feature vector is ,  is the maximum of sequence; N is the number of physicochemical indices.

1. Dinucleotide-based auto-cross covariance (DACC)

DACC is a combination of DAC and DCC [5, 6]. Therefore, the length of the DACC feature vector is , where N is the number of physicochemical indices and  is the maximum of sequence.

1. Nucleic acid composition (NAC)

The Nucleic acid composition (NAC) [7] encoding calculates the frequency of each nucleic acid type in a nucleotide sequence. The frequencies of all 4 natural nucleic acids (i.e. “ACGT or U”) can be calculated as:



where *N*(*t*) is the number of nucleic acid type *t*, while *N* is the length of a nucleotide sequence.

1. Di-nucleotide composition (DNC)

The Di-Nucleotide Composition [7] gives 16 descriptors. It is defined as:



where is the number of di-nucleotide represented by nucleic acid types *r* and *s*.

1. Tri-nucleotide composition (TNC)

The Tri-Nucleotide Composition [7] gives 64 descriptors. It is defined as:



where is the number of tri-nucleotide represented by nucleic acid types *r, s* and *t*.

1. zCurve mathematical formula (zCurve)

Z-curve theory [8] is often used in genomic sequence analysis. It has got three components in three axis. They are de\_ned as following.



Three features will generate using the zCurve method.

1. MonoKGap Theoretical Description (MonoKGap)

When kgap=n then the  features will exist for RNA [8].

When -kgap=1, feature structure will be X\_X.

When -kgap=2, feature structure will be X\_X, and X\_\_X.

When -kgap=3, feature structure will be X\_X. X\_\_X, and X\_\_\_X.

Described with appropriate examples:

When -kgap=1 then only sixteen (16) features will exist for DNA and RNA but four hundred (400) features will exist for protein. Features will be numbers of A\_A, A\_C, A\_G, A\_T, C\_A,C\_C, C\_G, C\_T, G\_A, G\_C, G\_G, G\_T, T\_A, T\_C, T\_G, and T\_T of the whole sequence of DNA respectively.

When -kgap=2 then only thirty two (32) features will exist for DNA and RNA but eight

hundred (800) features will exist for protein. Features will be numbers of A\_A, A\_C, A\_G, A\_T, C\_A,C\_C, C\_G, C\_T, G\_A, G\_C, G\_G, G\_T, T\_A, T\_C, T\_G,T\_T, A\_\_A, A\_\_C, A\_\_G,A\_\_T, C\_\_A, C\_\_C, C\_\_G, C\_\_T, G\_\_A, G\_\_C, G\_\_G, G\_\_T, T\_\_A, T\_\_C, T\_\_G, and T\_\_T of the whole sequence of DNA respectively.

When -kgap=3 then only forty eight (48) features will exist for DNA and RNA, but one

thousand and two hundred (1,200) features will exist for protein. Features will be numbers

of A\_A, A\_C, A\_G, A\_T, C\_A,C\_C, C\_G, C\_T, G\_A, G\_C, G\_G, G\_T, T\_A, T\_C, T\_G,T\_T, A\_\_A, A\_\_C, A\_\_G,A\_\_T, C\_\_A, C\_\_C, C\_\_G, C\_\_T, G\_\_A, G\_\_C, G\_\_G, G\_\_T, T\_\_A, T\_\_C, T\_\_G, T\_\_T, A\_\_\_A, A\_\_\_C, A\_\_\_G, A\_\_\_T, C\_\_\_A, C\_\_\_C, C\_\_\_G, C\_\_\_T, G\_\_\_A, G\_\_\_C, G\_\_\_G,G\_\_\_T, T\_\_\_A, T\_\_\_C, T\_\_\_G, and T\_\_\_T of the whole sequence of DNA respectively.

1. MonoDiKGap Theoretical Description (MonoDiKGap)

When -kgap=n then the  features will exist for RNA [8].

When -kgap=1, feature structure will be X\_XX.

When -kgap=2, feature structure will be X\_XX, and X\_\_XX.

When -kgap=3, feature structure will be X\_XX, X\_\_XX, and X\_\_\_XX.

Described with appropriate examples:

When -kgap=1 then only sixty four (64) features will exist for DNA and RNA, but eight thousand (8,000) features will exist for protein. Features will be numbers of A\_AA, A\_AC,A\_AG, A\_AT, A\_CA, A\_CC, A\_CG, A\_CT, A\_GA, A\_GC, A\_GG, A\_GT, A\_TA, A\_TC, A\_TG,A\_TT, C\_AA, C\_AC, C\_AG, C\_AT, C\_CA, C\_CC, C\_CG, C\_CT, C\_GA, C\_GC, C\_GG, C\_GT,C\_TA, C\_TC, C\_TG, C\_TT, G\_AA, G\_AC, G\_AG, G\_AT, G\_CA, G\_CC, G\_CG, G\_CT, G\_GA,G\_GC, G\_GG, G\_GT, G\_TA, G\_TC, G\_TG, G\_TT, T\_AA, T\_AC, T\_AG, T\_AT, T\_CA, T\_CC,T\_CG, T\_CT, T\_GA, T\_GC, T\_GG, T\_GT, T\_TA, T\_TC, T\_TG, and T\_TT of the whole sequence of DNA respectively.

When -kgap=2 then only hundred and twenty eight (128) features will exist for DNA and RNA, but sixteen thousand (16,000) features will exist for protein. Features will be numbers of A\_AA, A\_AC,A\_AG, A\_AT, A\_CA, A\_CC, A\_CG, A\_CT, A\_GA, A\_GC, A\_GG, A\_GT, A\_TA, A\_TC, A\_TG,A\_TT, C\_AA, C\_AC, C\_AG, C\_AT, C\_CA, C\_CC, C\_CG, C\_CT, C\_GA, C\_GC, C\_GG, C\_GT,C\_TA, C\_TC, C\_TG, C\_TT, G\_AA, G\_AC, G\_AG, G\_AT, G\_CA, G\_CC, G\_CG, G\_CT, G\_GA,G\_GC, G\_GG, G\_GT, G\_TA, G\_TC, G\_TG, G\_TT, T\_AA, T\_AC, T\_AG, T\_AT, T\_CA, T\_CC,T\_CG, T\_CT, T\_GA, T\_GC, T\_GG, T\_GT, T\_TA, T\_TC, T\_TG,T\_TT, A\_\_AA, A\_\_AC, A\_\_AG, A\_\_AT, A\_\_CA, A\_\_CC, A\_\_CG, A\_\_CT, A\_\_GA, A\_\_GC,A\_\_GG, A\_\_GT, A\_\_TA, A\_\_TC, A\_\_TG, A\_\_TT, C\_\_AA, C\_\_AC, C\_\_AG, C\_\_AT, C\_\_CA,C\_\_CC, C\_\_CG, C\_\_CT, C\_\_GA, C\_\_GC, C\_\_GG, C\_\_GT, C\_\_TA, C\_\_TC, C\_\_TG, C\_\_TT,G\_\_AA, G\_\_AC, G\_\_AG, G\_\_AT, G\_\_CA, G\_\_CC, G\_\_CG, G\_\_CT, G\_\_GA, G\_\_GC, G\_\_GG,G\_\_GT, G\_\_TA, G\_\_TC, G\_\_TG, G\_\_TT, T\_\_AA, T\_\_AC, T\_\_AG, T\_\_AT, T\_\_CA, T\_\_CC,T\_\_CG, T\_\_CT, T\_\_GA, T\_\_GC, T\_\_GG, T\_\_GT, T\_\_TA, T\_\_TC, T\_\_TG, and T\_\_TT of the whole sequence of DNA respectively.

# Protein feature extraction method

**SeqFea-Learn** contains 31 Protein feature extraction methods.

|  |  |
| --- | --- |
| Protein feature extraction methods | Method Number |
| Amino acid composition (AAC) | 1 |
| Dipeptide composition (DC) | 2 |
| Composition of k-spaced amino acid pairs (CKSAAP) | 3 |
| Grouped dipeptide composition (GDC) | 4 |
| Grouped tripeptide composition (GTC) | 5 |
| Conjoint triad (CT) | 6 |
| K-spaced conjoint triad (KSCTriad) | 7 |
| Composition (C) | 8 |
| Transition (T) | 9 |
| Distribution (D) | 10 |
| Encoding based on grouped weight (EBGW) | 11 |
| Auto covariance (AC) | 12 |
| Moreau-Broto autocorrelation (Morean-Broto) | 13 |
| Moran autocorrelation (Moran) | 14 |
| Geary autocorrelation (Geary) | 15 |
| Quasi-sequence-order (QSO) | 16 |
| Pseudo-amino acid composition (PseAAC) | 17 |
| Amphiphilic pseudo-amino acid composition (APAAC) | 18 |
| Amino acid composition PSSM (AAC-PSSM) | 19 |
| Dipeptide composition PSSM (DPC-PSSM) | 20 |
| Bi-gram PSSM (Bi-PSSM) | 21 |
| Auto covariance PSSM (AC-PSSM) | 22 |
| Pseudo PSSM (PsePSSM) | 23 |
| AB-PSSM | 24 |
| Secondary structure composition (SSC) | 25 |
| Accessible surface area composition (ASA) | 26 |
| Torsional angles composition (TAC) | 27 |
| Torsional angles bigram (TA-bigram) | 28 |
| Structural probabilities bigram (SP-bigram) | 29 |
| Torsional angles auto-covariance (TAAC) | 30 |
| Structural probabilities auto-covariance (SPAC) | 31 |

Type 1: Amino acid composition information-based methods

1. Amino acid composition (AAC)

The amino acid composition is the fraction of each amino acid type within a protein. The amino acid composition gives 20 features and the fractions of all 20 natural amino acids are calculated as



where  is the number of the amino acid type  and  is the length of the sequence.

1. Dipeptide composition (DC)

The dipeptide composition is used to transform the variable length of proteins to fixed length feature vectors.A dipeptide composition has been used earlier by Grassmann et al. and Reczko and Bohr for the development of fold recognition methods.We adopt the same dipeptide composition-based approach in developing a deep neural networks-based method for predicting protein-protein inter-action.The dipeptide composition gives a fixed pattern length of 400.Dipeptide composition encapsulates information about the fraction of amino acids as well as their local order.The dipeptide composition is defined as



wherethe number of dipeptide represented by amino acid typeand.

1. -gap dipeptide composition introduces (g-GapDC)

The -gap dipeptide composition introduces (-Gap DC) extracts important intrinsic correlation information of protein sequences in multidimensional space. For a protein ,  of the sequence length C, the calculation process of the -Gap DC can be expressed as





where  represents the number of residues in the primary structure of the two amino acids, represents the number of occurrences of the -th feature in the -gap dipeptide, and  represents the frequency at which the -th feature in the -gap dipeptide appears in the sequences. When , there is no gap between two adjacent amino acid residues, and when , it means that one amino acid residue is between two adjacent amino acid residues. From equation (9), a protein sequence can be represented as a 400-dimensional feature vector.

1. Grouped di-peptide composition (GDC)

The Grouped di-peptide composition encoding is another variation of the DPC descriptor. It is composed of a total of 25 descriptors that are defined as:



where  is the number of the di-peptide type , and  is the length of the sequence.

1. Grouped tri-peptide composition (GTC)

The Grouped tri-peptide composition encoding is also a variation of TPC descriptor, which generates 125 descriptors, defined as:



where  is the number of the tri-peptide type , and  is the length of the sequence.

1. Conjoint triad (CT)

First, 20 amino acids are clustered into seven classes based on dipoles and volumes of side chains. Considering the interaction between the amino acid and its vicinal amino acids, the three continuous amino acids are regarded as a unit, so that we can obtain  triad types. We calculate the frequency of occurrence of each triad called . Then the 343-dimensional feature vector is obtained according to equation (6).



1. *k*-Spaced Conjoint Triad (KSCTriad)

The *k*-spaced conjoint triad descriptor is based on the conjoint ctriad descriptor,

which not only calculates the numbers of three continuous amino acid units, but also considers the continuous amino acid units that are separated by any *k* residues (The default maximum value of *k* is set to 5). For example, AxRxT is a 1-spaced triad. Thus, the dimensionality of the KSCTriad encoded feature vector is 343 (*k*+1).

1. Composition, transition and distribution (CTD)

8.1 Composition

For CTD, taking hydrophobicity as an example, all amino acids are classified into three categories: polar, neutral, and hydrophobic. The replacement sequence consists of three types, and the composition descriptors of the polar, neutral, and hydrophobic residues of the protein can be calculated as follows:



where  is the number of amino acid type  in the coding sequence and  is sequence length.

8.2 Transition

The transition descriptor first converts the original sequence into a replacement sequence, and T includes three characteristics, the dipeptide composition frequency from the polar group to the neutral group and the composition frequency from the neutral group to the polar group. Transitions between the neutral group and the hydrophobicity and these between hydrophobic group and the polar group are defined in the same way. The T descriptor is defined as follows:



Where  and  are the  and  dipeptide frequency, respectively.  is the sequence length.

8.3 Distribution

For each group (polar, neutral and hydrophobic), the D descriptor can generate five values. We obtain the position of the first, 25%, 50%, 75% and 100% of the specific encoded group sequence and then divided the position by the whole sequence. Given sequence MTTTVPKVFAFHEF. It can be represented as '32223213323213' according to Hydrophobicity\_PRAM900101. '1' represents polar, '2' represents neutral, '3' represents hydrophobicity. Take '3' for example, there are 6 residues encoded '3'. The first '3' is 1. The second '3' is . The third '3' is . The fourth '3' is . The fifth '3 is . The position in the first, the second, the third, the fourth, the fifth '3' of whole sequence are 1, 1, 8, 9, 14, respectively. So the distribution descriptor for '3' are ,,,,.

The C descriptor generates a 39-dimensional feature vector, the T descriptor generates a 39-dimensional feature vector, and the D descriptor generates a 195-dimensional feature vector. For each protein sequence, the CTD generates a 273-dimensional feature vector.

1. Encoding based on grouped weight coding (EBGW)

Studies have shown that different amino acids have different physical and chemical properties. The EBGW can capture the sequence and physicochemical information based on grouped situation. These amino acids are classified into four categories:

neutral and hydrophobic amino acids 

neutral and polarity amino acids 

acidic amino acids 

basic amino acids .

Thus, we can get three combinations, each of which can partition the 20 amino acid residues into two disjoint group:  vs , or vs, and  vs . Let be a protein sequence, we can transform it into three binary sequences by three homomorphic mapswhich are defined as follows:







where , and we call as characteristic sequence of the protein sequence.

Then , , are three binary sequences of length *L*. These sequences are divided into a number of sub-sequences of increasing length successively. A fixed parameter *N* is set and the sub-sequence can be expressed as, where represents the integer operator. Calculate the frequency of 1 in each sub-sequence, each  can be converted into an *N*-dimensional feature vector. To sum up, for a protein sequence *P* with length *L*, a 3*N*-dimension vector can be obtained.

Type 2: Physicochemical information-based methods

1. Auto covariance (AC)

Suppose a protein sequence P with *L* amino acid residues; i.e.



where  represents the amino acid residue at the sequence position 1,  the amino acid residue at position 2 and so forth.

The AC approach measures the correlation of the same property between two residues separated by a distance of along the sequence, which can be calculated as:



where is a physicochemical index, is the length of the protein sequence, means the numerical value of the physicochemical index for the amino acid  at position ,  is the average value for physicochemical index along the whole sequence. In such a way, the length of AC feature vector is , where *N* is the number of physicochemical indices extracted from AAindex; ** is the maximum of sequence.

1. Moreau-Broto autocorrelation (Morean-Broto)

Moreau-Broto autocorrelation descriptor is defined as:



where , and  indicate the  and the  amino acids of the protein sequence, respectively.  and indicate the normalized physicochemical values of  and . The  is the parameter that needs to be adjusted.

1. Moran autocorrelation (Moran)

Moran autocorrelation descriptor is defined as:



where  represents the mean value of whole protein sequence for specific physicochemical property.

1. Geary autocorrelation (Geary)

Geary autocorrelation descriptor is defined as:



1. Quasi-sequence-order descriptors (QSO)

The sequence order features can also be used for representing amino acid distribution patterns of a specific physicochemical property along protein or peptide sequence. These descriptors are derived from both the Schneider-Wrede physicochemical distance matrix and the Grantham chemical distance matrix between each pair of the 20 amino acids. Theth rank sequence-order-coupling number is defined as



whereis the distance between the two amino acids at positionand. Maxlag is the maximum lag and the length of the protein must be not less than maxlag. The maxlag is equal to 30 in the experiment. For each amino acid type, the type-1 quasi-sequence-order descriptor can be defined as



where is the normalized occurrence of amino acid type-1 and is a weighting factor. The type-2 quasi-sequence-order is defined as



In addition to the Schneider-Wrede physicochemical distance matrix used by Chou et al., another chemical distance matrix by Grantham is also used here. The sequence-order features produce a total ofdescriptors.

1. Pseudo-amino acid composition (PseAAC)

Pseudo-amino acid composition are utilized to extract the physicochemical information. Pseudo-amino acid composition (PseAAC) represents the composition information of the protein and sequence order information. The feature vector of PseAAC can be represented:



where the first 20-dimentional feature vector represents the amino acid composition information, and the latter  dimensional vector represents the order information of protein sequence.  is the length of amino acid sequence.



where  is the normalized frequency of 20 amino acids in protein.  is the layer sequence correlation factor calculated according to the equation (2). Sequence correlation factor can be obtained from the hydrophobicity, hydrophilicity, and side-chain mass of the amino acid.

1. Amphiphilic pseudo amino acid composition (APAAC)

APAAC (http://www. csbio. sjtu. edu. cn/bioinf/PseAAC/type2. htm) are also called type-2 pseudoamino acid composition. The definitions of these qualities are similar to PAAC descriptors. First, two variables are derived from the original hydrophobicity valuesand hydrophilicity valueof 20 amino acids





whereand,the hydrophobicity and hydrophilicity correlation functions, are defined respectively as



where sequence order factors can be defined as







Then a set of descriptors called "Amphiphilic Pseudo Amino Acid Composition” are defined as





whereis the weight factor and is taken as, andis equal to 30 in the experiment. So, we produce a total ofdescriptors.

Type 3: Evolutionary information-based method

In order to obtain the evolutionary information of the amino acid sequence, all the protein sequences in the dataset are compared with the non-redundant database SwissProt using the PSI-BLAST program. The program can search sequences based on the iterative BLAST search method. Evolutionary information in the position specific scoring matrix (PSSM) plays an important role in biological system analysis.

During the running process, the parameter E-value threshold of PSI-BLAST is set to 0.001, the maximum number of iterations is set to 3, and the remaining parameters are set by default. Then PSSM of each protein sequence is obtained. For a protein sequence whose length is , PSSM is shown in equation (49).



where each row of the PSSM represents a log likelihood score for amino acid substitutions occurring at corresponding positions in the query sequence. Where  represents the  position of query sequence being mutated to type  during evolution process. The scores are positive integers or negative integers. A positive integer indicates that more mutations have occurred in the alignment and a negative integer indicates that fewer substitutions have occurred in the alignment.

1. Amino acid composition PSSM (AAC-PSSM)

In this calculating process of amino acid composition PSSM (AAC-PSSM), the PSSM is standardized by the logic function. PSSM elements are map to the interval [0,1].



PSSM are converted to feature vector by AAC-PSSM via equation (51)



where ,  represents the composition information of the  amino acid residue, which is the average score of  amino acid in PSSM.

1. Dipeptide composition PSSM (DPC-PSSM)

The PSSM contains evolutionary information. ACC-PSSM only represents the composition information from PSSM, and loses the order information, which is insufficient to fully represent the evolutionary information. Dipeptide composition PSSM (DPC-PSSM) can reflect the sequence-order information in the PSSM, which converts the character signal into the numerical signal, and the extracted feature vector can be expressed as



where , the dimension of DPC-PSSM is 400.

1. Bi-gram PSSM (Bi-PSSM)

For Bi-gram PSSM, the frequency of the transition from the  amino acids to the  amino acids is calculated:



Therefore, there are 400 possible cases for , then the Bi-gram PSSM eigenvector for each protein sequence is:



1. Auto covariance PSSM (AC-PSSM)

AC-PSSM can transform the PSSMs of different lengths into fixed-length vector. The AC variable measures the correlation of the same property between two residues separated by a distance of lag along the sequence, which can be calculated as:



whereis one of the residues,is the length of the protein sequence,is the PSSM score of amino acidat position,is the average score for amino acid  along the whole sequence:



In such a way, the number of AC variables can be calculated as, where  is the maximum of sequence.

1. Cross covariance PSSM (CC-PSSM)

CC-PSSM can transform the PSSMs of different lengths into fixed-length vectors. The CC variable measures the correlation of two different properties between two residues separated by lag along the sequence, which can be calculated by:



whereare two different amino acids andis the average score for amino acidalong the sequence. Since the CC variables are not symmetric, the total number of CC variables is.

1. Auto-cross covariance PSSM (ACC-PSSM)

ACC-PSSM as one of the multivariate modeling tools, can transform the PSSMs of different lengths into fixed-length vectors by measuring the correlation between any two properties. ACC results in two kinds of variables: AC between the same property, and cross-covariance (CC) between two different properties. Each protein sequence is represented as a vector of either AC variable or ACC variable that is a combination of AC and CC.

1. Pseudo PSSM (PsePSSM)

According to the pseudo amino acid composition, we obtain the PsePSSM feature vector:



where, each protein sequence can generate the dimensional feature vector. The first 20-dimensional vector represents the composition information of the PSSM matrix, and the remaining  dimensional feature vector represents the order evolutionary information. PsePSSM can transform an inconsistent protein sequence into a consistent numerical vector by feature extraction.

1. AB-PSSM

AB-PSSM is based on the averaged PSSM profiles over blocks, each with 5 percent of a sequence. Thus, a protein sequence, regardless of its length, is divided into 20 blocks and each block consists of 20 features (derived from the 20 columns in PSSMs). Mathematically, for the  block, the feature  is a  dimensional feature vector, which is generated by using the following equation:



where  is the size of the  block, which is 5 percent of the length of a sequence and Pej i is a  vector extracted from the PSSM profile at the  position in the  block. For each sequence, there are a total of 20 blocks; therefore, the final feature is a 400-dimensional vector.

Type 4: Structural information-based methods

1. Secondary structure composition (SSC)

This feature is the normalized count or frequency of the structural motifs present at the amino-acid residue positions. There are three types of motifs: *α*-helix (H), *β*-sheet (E) and random coil (C). SPIDER2 returns a vector *SS* of dimension *L* × 1 containing this information. Thus, we can define this feature as following:



where, *L* is the length of the protein and



where, *SSj* is the structural motif at position *j* of the protein sequence and *fi* is one of the 3 different motif symbols.

1. Accessible surface area composition (ASA)

The accessible surface area composition is the normalized sum of accessible surface area defined by:



where ASA is the vector of accessible surface area of dimension *L* × 1 containing the values of accessible surface area for all the amino acid residues.

1. Torsional angles composition (TAC)

Four different types of torsional angles: *ϕ*, *ψ*, *τ* and *θ* are returned by SPIDER2 for each residue. First, we convert each of them into radians from degree angles and then take sign and cosine of the angles at each residue position. Thus, we get a matrix of dimension. We denotethis matrix by *T*. Torsional angles composition is defined as



1. Torsional angles bigram (TA-bigram)

The Bigram for the torsional angles is similar to that of the PSSM matrix and is defined as:



1. Structural probabilities bigram (SP-bigram)

Structural probabilities for each position of the amino-acid residue are given in the SPD2 file as a matrix of dimension *L* × 3, which we denote by *P*. The Bigram of the structural probabilities is similar to that of PSSM matrix and is defined as:



1. Torsional angles auto-covariance (TAAC)

This feature is also derived from the torsional angles and is defined as:



1. Structural probabilities auto-covariance (SPAC)

This feature is also derived from the structural probabilities and is defined as:



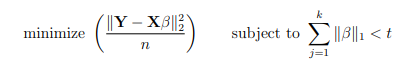
# Feature selection method

**SeqFea-Learn** contains 21 feature selection methods.

|  |  |
| --- | --- |
| Feature selection methods | Method Number |
| LASSO | 1 |
| Elastic net (EN) | 2 |
| L1-SVM | 3 |
| L1-Logistic Regression | 4 |
| Extra-Trees-RFE | 5 |
| XGBosst-RFE | 6 |
| SVM-RFE | 7 |
| Logistic Regression-RFE | 8 |
| Mutual information (MI) | 9 |
| Minimum redundancy maximum relevance (MRMR) | 10 |
| Joint mutual information (JMI) | 11 |
| Maximum relevance maximum distance (MRMD) | 12 |
| Information gain (IG) | 13 |
| Chi-square test (CHI2) | 14 |
| Pearson correlation (Pearson) | 15 |
| ReliefF | 16 |
| Trace Ratio | 17 |
| Gini Index | 18 |
| Spectral Feature Selection (SPEC) | 19 |
| Fisher Score | 20 |
| T-Score | 21 |

1. LASSO

LASSO is a regularization and variable selection method for statistical models. The LASSO minimizes the sum of squared errors, with a upper bound on the sum of the absolute values of the model parameters. The lasso estimate is defined by the solution to the optimization problem:



where is the upper bound for the sum of the coefficients. This optimization problem is equivalent to the parameter estimation that follows



where and λ ≥ 0 is the parameter that controls the strength of the penalty, the larger the value of λ, the greater the amount of shrinkage.

1. Elastic net

Given a dataset , consider the linear regression model with squared error as the loss function, and the optimization goal is:



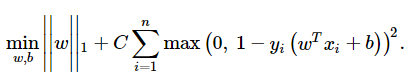
The shortcoming of above loss function is that when there are many features, it is easy to tend to be overfitting, so the equation can be seen as a convex linear combination of  norm and  norm.



where  is the number of samples.  is the weight coefficient.  aer the penalty parameters. Equation is called elastic net (EN). EN has good performance when dealing with the correlation between feature factors.

1. L1-SVM

Support vector machine (SVM) has been an effective and popular method in machine learning, including the application of this method to biomedical problems. Instead of using general L 2-norm for SVM, applying L 1-norm which tends to produce sparse solutions, makes it possible to considerably reduce the number of features of a large feature set. The maximum number of features selected by L 1-norm SVM is bounded by the number of samples. Unlike L 2-norm SVM, the number of features to be reduced is automatically selected by the regularization parameter. The optimization problem of L 1-norm SVM could be described as follows:



Here, parameter C reflects a regularization parameter that solves the trade-off problem between the training error and the complexity of the model and ||w||1 denotes the L 1-norm of the weight vector w.

1. L1-LR

The L1-regularized logistic regression (L1-RLR) is an embedded feature selection that combines feature selection with the learner training process. It selects the optimal feature subset during the training process of the learning system. The L1 norm can be solved sparsely, which reduces the computational complexity and the risk of overfitting.

Given the sample data set ,  represent the sample feature vector,  represent the sample class label. Thus, the L1 logistic regression can be transformed into an unconstrained optimization problem.

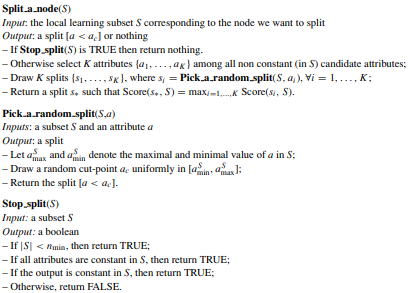


where  represents L1 norm.  represents the weight coefficient.  represents the penalty term which determines the number of selected features. The larger penalty term is, the more features are selected.

**The Recursive Feature Elimination (RFE) method is a feature selection approach. It works by recursively removing attributes and building a model on those attributes that remain. It uses the model accuracy to identify which attributes (and combination of attributes) contribute the most to predicting the target attribute.**

1. Extra-Trees-RFE

The Extra-Trees algorithm builds an ensemble of unpruned decision or regression trees according to the classical top-down procedure. Its two main differences with other treebased ensemble methods are that it splits nodes by choosing cut-points fully at random and that it uses the whole learning sample (rather than a bootstrap replica) to grow the trees.



The Extra-Trees splitting procedure for numerical attributes is given in Table above.

1. XGBoost-RFE

XGBoost is an efficient and fast gradient boosting decision tree algorithm, which uses weighted quantile sketch, regularized learning, and cache-aware block structure tree learning for ensemble learning. For the given dataset , the numbers of samples and features are  and . The objective function can be described as:



where  is loss function,  is the  tree,  represents regularized term. The second-order Taylor term is employed to represent the loss function for  iteration, and the approximation can be used to optimize the loss function, as the equation (13) show:



where  represents the first order gradient,  is the second order gradient. We can see the loss function only depends on the first and second gradient. In the training process of XGBoost, we use gain to determine the optimal split node.



where  and  represent the number of samples of the left and right nodes after the split node, respectively. .  are the penalty parameters. Gain represents the gain score for each split of a tree, and the final feature importance score is calculated by the average gain. The average gain is the total gain of all trees divided by the total number of splits for each feature. The higher the feature importance score of XGBoost is, the more important the corresponding feature is.

1. SVM-RFE

Support vector machine is a machine learning method based on statistical learning theory. It has better generalization ability and higher classification in solving nonlinear and high dimensional data problems. Its basic principle is to map the input sample set to the high-dimensional space, construct the optimal hyperplane, and automatically find out the support vectors that have better classification ability for the classification through the learning algorithm.

For a given sample dataset 



Then we can find the optimal classification plane. For the classification problem of high-dimensional space, the SVM model should be able to correctly classify the two types of samples while ensuring the maximum classification interval. Then using  kernel function to obtain the optimal classification plane:



The kernel functions in SVM include linear kernel functions, polynomial kernel functions, radial basis kernel functions, and sigmoid kernel functions.

1. Logistic Regression-RFE

Logistic regression models the probabilities for classification problems with two possible outcomes. It’s an extension of the linear regression model for classification problems.  Instead of fitting a straight line or hyperplane, the logistic regression model uses the logistic function to squeeze the output of a linear equation between 0 and 1. The logistic function is defined as:



The step from linear regression to logistic regression is kind of straightforward. In the linear regression model, we have modelled the relationship between outcome and features with a linear equation:



For classification, we prefer probabilities between 0 and 1, so we wrap the right side of the equation into the logistic function. This forces the output to assume only values between 0 and 1.



1. Mutual Information

Mutual Information Feature Selection (MIFS) considers both the feature relevance and feature redundancy in the feature selection phase, the feature score for a new unselected feature  can be formulated as follows:



In MIFS, the feature relevance is evaluated by , while the second term penalizes features that have a high mutual information with the currently selected features such that feature redundancy is minimized.

1. Minimum Redundancy Maximum Relevance

Minimum redundancy maximum relevance (MRMR) criterion is set to the value of  to be the reverse of the number of selected features:



Hence, with more selected features, the effect of feature redundancy is gradually reduced.The intuition is that with more non-redundant features selected, it becomes more difficult for new features to be redundant to the features that have already been in . In [Brown et al. 2012], it gives another interpretation that the pairwise independence between features becomes stronger as more features are added to , possibly because of noise information in the data. MRMR is also strongly linked to the Conditional likelihoodmaximization framework if we iteratively revise the value of  to be  , and set the other parameter  to be zero.

1. Joint Mutual Information

MIFS and MRMR reduce feature redundancy in the feature selection process. An alternative criterion, Joint Mutual Information[Yang and Moody 1999; Meyer et al. 2008] is proposed to increase the complementary information that is shared between unselected features and selected features given the class labels. The feature selection criterion is listed as follows:



The basic idea of JMI is that we should include new features that are complementary

to the existing features given the class labels.JMI cannot be directly reduced to the condition likelihood maximization framework.In [Brown et al. 2012], the authors demonstrate that with simple manipulations, the JMI criterion can be re-written as:



Therefore, it is also a special case of the linear combination of Shannon information

terms by iteratively setting  and  to be .

1. Maximum Relevance Maximum Distance (MRMD)

Feature selection method has two main part of the decision: 1) Pearson’s correlation coefficient (PCC) is utilized to measure the relevance between features in a subset; 2) Euclidean distance (ED), Cosine distance (CD) and Tanimoto (TO) is utilized to calculate the redundancy among features in a subset.

The Pearson correlation coefficient shows the closely relationship between features and labels. Distance between features is used to measure the redundancy. Finally, MRMD selects features which has strong correlation with labeled and lowest redundancy features subset.

1. Information gain

Information Gain (IG) measures the importance of a feature by its correlation with class labels. It assumes that when a feature has a strong correlation with the class label, it can help achieve good classification performance.

The Mutual information score for feature  is:



It can be observed that in MIM, the scores of features are assessed individually. Therefore, only the feature correlation is considered while the feature redundancy is completely ignored. After it obtains the MIM feature scores for all features, we choose the features with the highest feature scores and add them to the selected feature set. The process repeats until the desired number of selected features is obtained.It can also be observed that MIM is a special case of linear combination of Shannon information terms in Eq. (13) where both  and  are equal to zero.

1. CHI2 Test

Chi-squared test ( test) is one of statistical method for feature selection. The chi-squared test is applied to determine whether there is significant difference between two events. is a measure of how much expected counts E and observed counts N deviate from each other (Chen, et al., 2009). A high value of indicates that the hypothesis of independence, which implies that expected and observed counts are similar, is incorrect. This score can be sued to select the n features with the highest values for test chi-square statistic from x, which must contain only non-negative features such as Booleans or frequencies, relative to the classes.

where is the observed value and is the expected value.

1. Pearson Correlation

The Pearson correlation is also known as the “product moment correlation coefficient”. Pearson Correlation is one of the simplest methods to explore features’ relation to the response variable. It is a measure of the linear correlation between two variables X and Y. The resulting value lies in [-1:1], with -1 meaning perfect negative correlation that means one variable increase whereas the other decrease, with +1 meaning perfect positive correlation and 0 meaning no linear correlation between two variables.

The Pearson’s correlation is commonly represented by

where n is sample size, are the individual sample points indexed with , (the sample mean), and analogously for .

1. Relief Algorithm

Relief algorithm is currently the most efficient filter feature evaluation algorithm. It fully considers the correlation between categories and features and solves the problem of multi-class feature dimension reduction. Its main idea is to calculate the correlation between features and categories, and then update the feature weights according to the degree of correlation, and quickly process high-dimensional data to remove unnecessary features effectively. Among them, the higher the weight value, the stronger the classification ability of the feature.

When dealing with multi-class  feature selection, the ReliefF algorithm first selects  samples with the nearest distance  from each category, then the  samples of the same kind as  are combined into a set . According to the class to which the classification belongs, the samples of different classes of  respectively constitute the set,; finally the weight  of each feature is updated. The update weight formula is:



where  denotes a certain feature,  denotes the number of samples,  denotes the distance between sample  and sample  with respect to a certain feature ,  denotes the proportion of  class samples to the total number of samples, and  denotes the category to which  belongs.

1. Trace Ratio

A feature subset is selected based on the corresponding score (subset-level score), which is calculated in a trace ratio form. Since the number of all possible feature subsets is very huge, it is often prohibitively expensive in computational cost to search in a brute force manner for the feature subset with the maximum subset-level score. Instead of calculating the scores of all the feature subsets, traditional methods calculate the score for each feature, and then select the leading features based on the rank of these feature-level scores. However, selecting the feature subset based on the feature-level score cannot guarantee the optimum of the subset-level score. In this paper, we directly optimize the subset-level score, and propose a novel algorithm to efficiently find the global optimal feature subset such that the subset-level score is maximized.

1. Gini Index

Gini Index transforms the samples space into a feature specific normalized samples space without compromising the intra-class feature distribution. In the second stage of the framework, it identifies the features that discriminates the classes most by applying gini coefficient of inequality.

Gini coefficient of inequality, a popular mechanism to estimate the distribution of income over a population, to analyze distribution of a feature across the classes. If gini = 0, every person in the population receives equal percentage of income and if gini = 1, single person receives 100% of the income. A commonly used approach to represent the inequality and estimate the area under the curve is Lorenz Curve. In Lorenz curve, individuals are sorted by size in increasing order and the cumulative proportion of individuals (x-axis) is plotted against the corresponding cumulative proportion of their total size on y-axis. It has been shown that sample Gini coefficient calculated by Equation below is biased and is to be multiplied by n/(n − 1) to become unbiased.



where µ is sample mean. It has been shown that sample Gini coefficient calculated by Equation (3) is biased and is to be multiplied by n/(n − 1) to become unbiased.

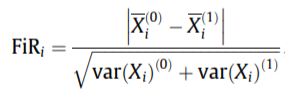
1. Spectral Feature Selection

Spectral feature selection studies how to select features according to the structures of the graph induced from . It employs the spectrum of the graph to measure feature relevance and elaborate how to realize spectral feature selection. The target concept is represented by the graph structures (clusters indicated by the ellipses). Different shapes denote different values assigned by a feature. According to spectral clustering theory, the leading k eigenvectors of L form the optimal soft cluster indicators that separate G into k parts. Therefore, if k is known, we can also use the following function for ranking:



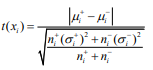
1. Fisher Score

Fisher score typically used in binary classification problems, the Fisher ration (FiR) is defined as the distance between the sample means for each class per feature divided by their variances:



1. T-Score

T-score is one of the commonly used feature selection methods. This method calculates a relation score by using the sample size, mean and standard deviation values of the features for each class. Features with less score is eliminated from the data set. The formula of t-score is shown in



The feature selection process of t-score method is executed in the form of features that are ranked by descending order according to the computed scores, then desired number of features are selected starting from the top.

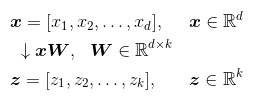
# Dimensionality reduction method

**SeqFea-Learn** contains 15 dimensionality reduction methods.

|  |  |
| --- | --- |
| Dimensionality Reduction Methods | Method Number |
| Principal component analysis (PCA) | 1 |
| Kernel PCA (KPCA) | 2 |
| Locally linear embedding (LLE) | 3 |
| Multi-dimensional scaling (MDS) | 4 |
| t-distributed stochastic neighbor embedding (T-SNE) | 5 |
| Truncated singular value decomposition (SVD) | 6 |
| Non-negative matrix factorization (NMF) | 7 |
| Gaussian random projection (GRP) | 8 |
| Sparse random projection (SRP) | 9 |
| Independent component analysis (ICA) | 10 |
| Factor analysis (FA) | 11 |
| Agglomerate feature (AF) | 12 |
| Autoencoder | 13 |
| Gaussian noise autoencoder | 14 |
| Variational autoencoder | 15 |

1. Principal component analysis (PCA)

PCA is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. PCA aims to find the directions of maximum variance in high-dimensional data and projects it onto a new subspace with equal or fewer dimensions than the original one. If we use PCA for dimensionality reduction, we construct a dimensional transformation matrix that allows us to map a sample vector onto a new dimensional feature subspace that has fewer dimensions than the original -dimensional feature space:



1. Kernel PCA (KPCA)

PCA is a linear method. That is it can only be applied to datasets which are linearly separable. But, if we use it to non-linear datasets, we might get a result which may not be the optimal dimensionality reduction. Kernel PCA uses a kernel function to project dataset into a higher dimensional feature space, where it is linearly separable. It is similar to the idea of Support Vector Machines.

1. Locally Liner Embedding (LLE)

The LLE algorithm, is based on simple geometric intuitions. Suppose the data consist of real-valued vectors, each of dimensionality, sampled from some smooth underlying manifold. We can characterize the local geometry of these patches by linear coefficients that reconstruct each data point from its neighbors. In the simplest formulation of LLE, one identifies nearest neighbors per data point, as measured by Euclidean distance. Reconstruction errors are then measured by the cost function:

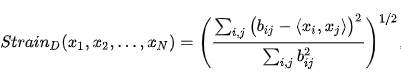


which adds up the squared distances between all the data points and their reconstructions.

1. Multi-dimensional Scaling (MDS)

Multidimensional scaling is a means of visualizing the level of similarity of individual cases of a dataset. MDS is used to translate “information about the pairwise distance among a set of n objects or individuals” into a configuration of n points mapped into an abstract Cartesian space.

It takes an input matrix dissimilarities between pairs of items and outputs a coordinate matrix whose configuration minimizes a loss function called strain. General forms of loss functions called stress in distance MDS and Strain in classical MDS. The strain is given by:



where are terms of the matrix defined on step 2 of the following algorithm.

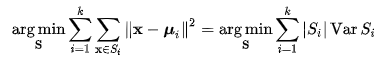
# Clustering method

**SeqFea-Learn** contains 7 clustering methods.

|  |  |
| --- | --- |
| Clustering methods | Method Number |
| K-means | 1 |
| Spectral Clustering | 2 |
| Gaussian Mixture Clustering | 3 |
| Affinity Propagation Clustering | 4 |
| Mean Shift | 5 |
| DBSCAN | 6 |
| OPTICS | 7 |

1. K-means clustering

K-means clustering is a method of vector quantization, originally from signal processing. K-means clustering aims to partition observations into clusters in which each observation belongs to the cluster with the nearest mean, serving as a porotype of the cluster. Given a set of observations (,,…), where each observation is a -dimensional real vector, -means is to minimize the within-cluster sum of squares (WCSS):



where is the mean of points in . This is equivalent to minimizing the pairwise squared deviations of points in the same cluster.

1. Spectral Clustering

Spectral clustering techniques make use of the spectrum of the similarity matrix of the data to perform dimensionality reduction before clustering in fewer dimensions. The similarity matrix is provided as an input and consists of a quantitative assessment of the relative similarity of each pair of points in the dataset.

# Sampling method

**SeqFea-Learn** contains 5 sampling methods.

|  |  |
| --- | --- |
| Sampleing methods | Method Number |
| Random over sampling  (ROS) | 1 |
| Synthetic minority oversampling technique (SMOTE) | 2 |
| Adaptive synthetic (ADASYN) | 3 |
| Random under sampling (RUS) | 4 |
| Neighbourhood cleaning rule (NCR) | 5 |

# Classification method

**SeqFea-Learn** integrated 13 classification methods to make predictions.

|  |  |
| --- | --- |
| Classifier | Method Number |
| Support vector machine (SVM) | 1 |
| K-nearest neighbor (KNN) | 2 |
| Random forest (RF) | 3 |
| Extremely randomized trees (Extra-Trees) | 4 |
| Gradient boosting decision tree (GBDT) | 5 |
| XGBoost | 6 |
| LightGBM | 7 |
| Bagging classifier (Bagging) | 8 |
| AdaBoost | 9 |
| Gaussian Naïve Bayes (GNB) | 10 |
| Deep neural network (DNN) | 11 |
| Convolutional neural network (CNN) | 12 |
| Recurrent neural network (RNN) | 13 |

1. **Support vector machine (SVM)**

Support vector machine is a machine learning method based on statistical learning theory. It has better generalization ability and higher classification in solving nonlinear and high dimensional data problems. Its basic principle is to map the input sample set to the high-dimensional space, construct the optimal hyperplane, and automatically find out the support vectors that have better classification ability for the classification through the learning algorithm.

For a given sample dataset 



Then we can find the optimal classification plane. For the classification problem of high-dimensional space, the SVM model should be able to correctly classify the two types of samples while ensuring the maximum classification interval. Then using  kernel function to obtain the optimal classification plane:



The kernel functions in SVM include linear kernel functions, polynomial kernel functions, radial basis kernel functions, and sigmoid kernel functions.

1. **K-nearest neighbor (KNN)**

The idea of the KNN algorithm is to calculate the similarity of each sample between the test set and the training set. Then count the most similar samples to classify the prediction via the majority voting method. The specific steps of the KNN algorithm can be describe as:

Step 1: Input the sample dataset and calculate neighbor samples according to the feature information.

Step 2: calculate the sample weight in order, using the equation:



where,  is the variable of the new sample,  is the similarity score and  is the category attribute function.

Step 3 Compare the weights of the two categories and classify the samples the category with the largest weight.

1. **Random forest (RF)**

RF is a classifier based on decision tree and Bagging algorithm. First, the training sets are generated using the bootstrap method. Secondly, for each training set, the decision tree model is constructed. At each step of split selection, RF determines the optimal split node from a subset of features according to Gini coefficient. Then the ensemble learning method can be built up based on the majority voting principle



where,  represents single decision tree, and  is the output label.

1. **Extremely randomized trees (ET)**

ET is similar to RF, but RF applies the Bagging algorithm, and ET uses all training samples to construct each decision tree. Random forest obtains the optimal split attribute from a random subset, and the ET is completely random to obtain the split node.

1. **XGBoost**

XGBoost is an ensemble learning algorithm based on gradient boosting, which is an optimization model that combines a linear model with a boosting tree model. It uses not only the first derivative but also the second derivative of the loss function for second-order derivation.

For a given  sample and  feature datasets , the XGBoost algorithm objective function is defined as



where  is the loss function, the smaller  is, the better the performance of the algorithm.  is the -th tree,  is the regular term, used to control the complexity of the model, ,  is the vector of the score in the leaf,  is the regularization parameter,  is the minimum loss required to further segment the leaf nodes. Then, according to Taylor expansion optimization of the objective function, the second-order Taylor of the loss function after the  iteration is obtained.



where  represents the first derivative of each sample and  represents the second derivative of each sample, and the loss function depends only on the first and second derivatives of each data point.

1. **LightGBM**

LightGBM is a variant of gradient tree boosting. As we can know, when the number of samples is large or the feature dimension is high, the efficiency and accuracy of GTB still cannot obtain satisfactory results. Ke et al proposed a highly efficient gradient boosting decision tree using gradient-based one-side sampling (GOSS) and exclusive feature bundling (EFB) called LightGBM. This algorithm uses GOSS to determine the split point via calculating variance gain. First, sorting the absolute values of the gradients of the training examples in descending order and the top  data samples of gradient values are selected called . Then the subset  whose size is  is randomly selected from the retained samples . Finally, the instances are split through the estimated variance  on .



where , , ,****,  represents the negative gradient of the loss function,  is employed to normalize the sum of gradients.