

PyFeat: A Python-based Effective Features Generation Tool from DNA, RNA, and Protein Sequences

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Supplementary Material

PyFeat Version 1.0

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1 Introduction

The PyFest is an extensive Python-based tool for generating various numerical feature presentation schemes from DNA, RNA and protein sequences. This tool is also able to select the best features among from previously generated vast amount of features. After that, it can train model, to evaluate model using various machine learning techniques.

2 Download Package

2.1 Direct Download:

PyFeat package can be [downloaded](#) by clicking the link. This package will be download in zip (.zip) format named PyFeat-master.zip.

2.2 Clone a GitHub Repository (Optional)

Cloning a repository syncs it to our local machine. After clone, we can add and edit files and then push and pull updates. We can follow any one procedure that given below with illustration (a) clone over HTTPS, (b) or clone over SSH.

2.2.1 Clone over HTTPS

`user@machine:~$ git clone https://github.com/mrzResearchArena/PyFeat.git`

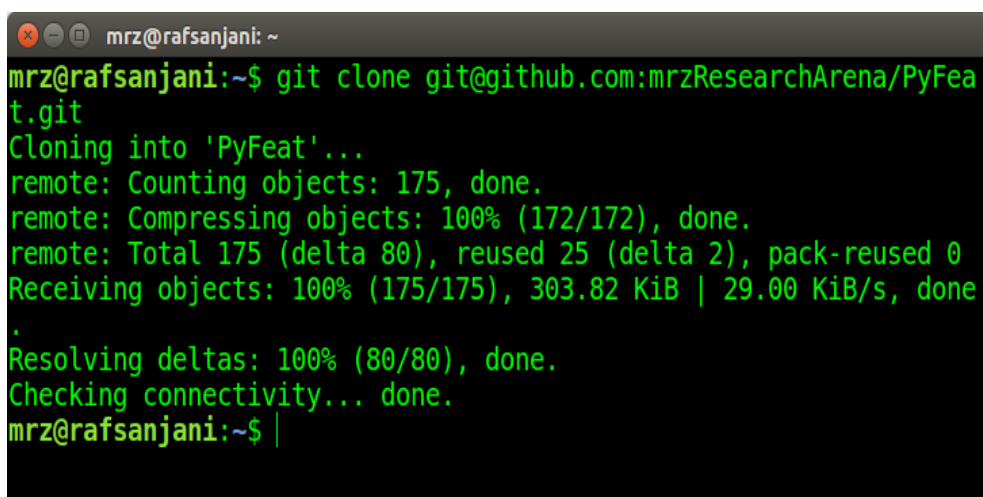
A terminal window titled 'mrz@rafsanjani: ~' showing the execution of the 'git clone' command. The output indicates that the repository 'PyFeat' was successfully cloned from 'https://github.com/mrzResearchArena/PyFeat.git'. The process includes counting 175 objects, compressing them, and receiving them at 77.00 KiB/s. The terminal text is as follows:

```
mrz@rafsanjani:~$ git clone https://github.com/mrzResearchArena/PyFeat.git
Cloning into 'PyFeat'...
remote: Counting objects: 175, done.
remote: Compressing objects: 100% (172/172), done.
remote: Total 175 (delta 80), reused 25 (delta 2), pack-reused 0
Receiving objects: 100% (175/175), 303.82 KiB | 77.00 KiB/s, done
.
Resolving deltas: 100% (80/80), done.
Checking connectivity... done.
mrz@rafsanjani:~$ |
```

Figure 1: Clone over HTTPS

2.2.2 Clone over SSH

`user@machine:~$ git clone git@github.com:mrzResearchArena/PyFeat.git`

A terminal window with a dark background and green text. The window title is 'mrz@rafsanjani: ~'. The command 'git clone git@github.com:mrzResearchArena/PyFeat.git' has been executed. The output shows the cloning process: 'Cloning into 'PyFeat'...', 'remote: Counting objects: 175, done.', 'remote: Compressing objects: 100% (172/172), done.', 'remote: Total 175 (delta 80), reused 25 (delta 2), pack-reused 0', 'Receiving objects: 100% (175/175), 303.82 KiB | 29.00 KiB/s, done.', 'Resolving deltas: 100% (80/80), done.', and 'Checking connectivity... done.'. The prompt 'mrz@rafsanjani:~\$' is visible at the bottom.

```
mrz@rafsanjani:~$ git clone git@github.com:mrzResearchArena/PyFeat.git
Cloning into 'PyFeat'...
remote: Counting objects: 175, done.
remote: Compressing objects: 100% (172/172), done.
remote: Total 175 (delta 80), reused 25 (delta 2), pack-reused 0
Receiving objects: 100% (175/175), 303.82 KiB | 29.00 KiB/s, done
.
Resolving deltas: 100% (80/80), done.
Checking connectivity... done.
mrz@rafsanjani:~$
```

Figure 2: Clone over SSH

Note: If the clone was successful, a new sub-directory appears on our local drive. This directory has the same name (PyFeat) as the [github](#) repository that we cloned. We can run any Linux-based command from any valid location or path, but by default, a command generally runs from `/home/user/` and user is the name of our computer but your computer name can be different (Example: `/home/bioinformatics/`).

3 Installation Process

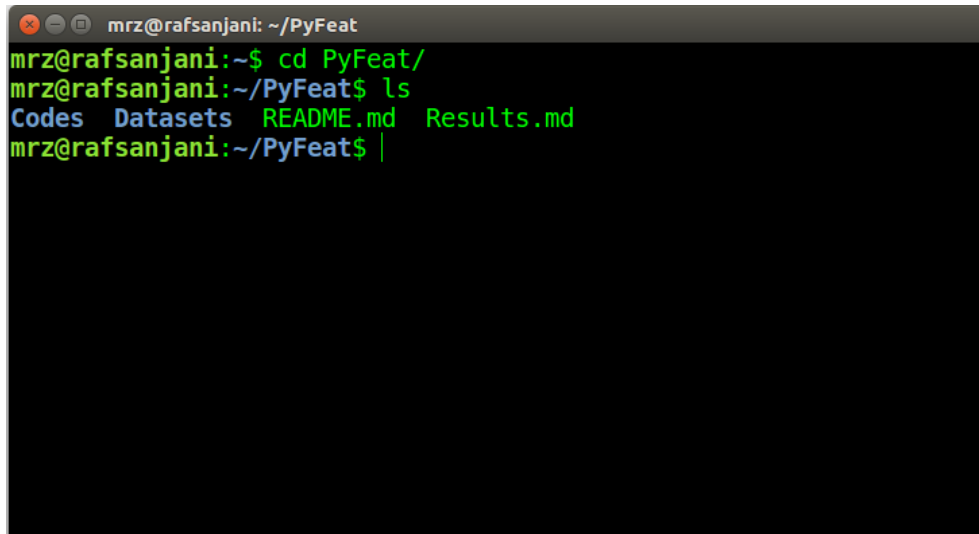
PyFest is an open-source Python-based tool, which operates depending on the Python environment (Python version 3.5 or above) and can be run on multi-OS systems (such as Linux-based OS, Mac OS, and Windows OS), but we will recommend you to use Linux-based OS. Before running PyFeat, a user should make sure all the following packages are installed in their Python environment:

1. Generate Features:
 - python (version ≥ 3.5), and
 - numpy (version $\geq 1.13.0$).
2. Performance Measures (Optional):
 - sklearn (version $\geq 0.19.0$),
 - pandas (version $\geq 0.21.0$), and
 - matplotlib (version $\geq 2.1.0$).

For convenience, we strongly recommended users to install the Anaconda (Python version ≥ 3.5) on your local computer. This software can be freely downloaded from <https://www.anaconda.com/download/>. We can also follow from <https://github.com/mrzResearchArena/PyFeat/blob/master/README.md> (Section 2.).

4 Package Description

PyFeat tool mainly contains two directory named ‘Codes’, and ‘Datasets’.

A terminal window with a dark background and light green text. The window title is 'mrz@rafsanjani: ~/PyFeat'. The command history shows: 'mrz@rafsanjani:~\$ cd PyFeat/', 'mrz@rafsanjani:~/PyFeat\$ ls', and the output 'Codes Datasets README.md Results.md'. The prompt 'mrz@rafsanjani:~/PyFeat\$' is followed by a cursor and a vertical bar.

```
mrz@rafsanjani: ~/PyFeat
mrz@rafsanjani:~$ cd PyFeat/
mrz@rafsanjani:~/PyFeat$ ls
Codes  Datasets  README.md  Results.md
mrz@rafsanjani:~/PyFeat$ |
```

Figure 3: Enter ‘PyFeat’ directory and seeing all the files

The ‘Codes’ directory/folder contains all the codes (*.py files). PyFeat includes four main programs: ‘main.py’, ‘runClassifiers.py’, ‘trainModel.py’, and ‘evaluateModel.py’.

- ‘main.py’ is the main programme, it will generate datasets.
- ‘runClassifiers.py’ programme, it will work for n-fold cross-validation with different machine learning classifiers and also provide the classifications results.
- ‘trainModel.py’ programme, it able to train an individual model.
- ‘evaluateModel.py’ programme, it able to evaluate the trained model.

```
mrz@rafsanjani: ~/PyFeat/Codes
mrz@rafsanjani:~/PyFeat$ cd Codes/
mrz@rafsanjani:~/PyFeat/Codes$ ls
ensure.py          runClassifiers.py
evaluateModel.py   save.py
generateFeatures.py selectedImportantFeatures.py
main.py            trainModel.py
read.py
mrz@rafsanjani:~/PyFeat/Codes$ |
```

Figure 4: Enter ‘Codes’ directory and seeing all the .py files

The ‘**Datasets**’ directory/folder contains another three directory/folder named ‘DNA’, ‘RNA’, and ‘Protein’ where we will find DNA, RNA, and protein sequences respectively.

```
mrz@rafsanjani: ~/PyFeat/Datasets
mrz@rafsanjani:~/PyFeat$ cd Datasets/
mrz@rafsanjani:~/PyFeat/Datasets$ ls
DNA Protein RNA
mrz@rafsanjani:~/PyFeat/Datasets$ |
```

Figure 5: Enter the ‘Datasets’ directory

5 Working Procedure

5.1 Generate Features

5.1.1 Training Purpose

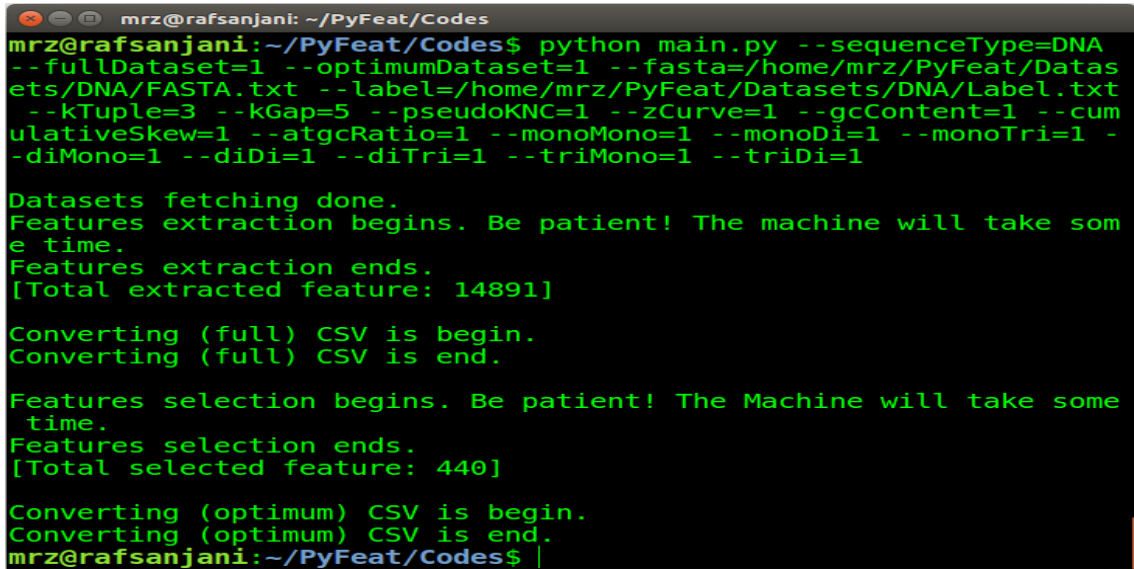
Generate datasets for training purpose. Unix command line given below.

We can use full argument:

```

user@machine:~/PyFeat/Codes$ python main.py --sequenceType=DNA
--fullDataset=1 --optimumDataset=1
--fasta=/home/user/PyFest/Datasets/DNA/FASTA.txt
--label=/home/user/PyFest/Datasets/DNA/Labels.txt
--kTuple=3 --kGap=5
--pseudoKNC=1 --zCurve=1 --gcContent=1 --cumulativeSkew=1 --atgcRatio=1 --monoMono=1
--monoDi=1 --monoTri=1 --diMono=1 --diDi=1 --diTri=1 --triMono=1 --triDi=1

```



```

mrz@rafsanjani: ~/PyFeat/Codes
mrz@rafsanjani:~/PyFeat/Codes$ python main.py --sequenceType=DNA
--fullDataset=1 --optimumDataset=1 --fasta=/home/mrz/PyFeat/Datas
ets/DNA/FASTA.txt --label=/home/mrz/PyFeat/Datasets/DNA/Label.txt
--kTuple=3 --kGap=5 --pseudoKNC=1 --zCurve=1 --gcContent=1 --cum
ulativeSkew=1 --atgcRatio=1 --monoMono=1 --monoDi=1 --monoTri=1 -
-diMono=1 --diDi=1 --diTri=1 --triMono=1 --triDi=1

Datasets fetching done.
Features extraction begins. Be patient! The machine will take som
e time.
Features extraction ends.
[Total extracted feature: 14891]

Converting (full) CSV is begin.
Converting (full) CSV is end.

Features selection begins. Be patient! The Machine will take some
time.
Features selection ends.
[Total selected feature: 440]

Converting (optimum) CSV is begin.
Converting (optimum) CSV is end.
mrz@rafsanjani:~/PyFeat/Codes$

```

Figure 6: Training with Arguments

or, we can also use corresponding optional argument:

```

user@machine:~/PyFeat/Codes$ python main.py -seq=DNA
-full=1 -optimum=1
-fa=/home/user/PyFeat/Datasets/DNA/FASTA.txt
-la=/home/user/PyFeat/Datasets/DNA/Label.txt
-ktuple=3 -kgap=5
-pseudo=1 -zcurve=1 -gc=1 -skew=1 -atgc=1 -f11=1 -f12=1 -f13=1 -f21=1 -f22=1 -f23=1
-f31=1 -f32=1

```

```
mrz@rafsanjani: ~/PyFeat/Codes$ python main.py -seq=DNA -full=1 -o
ptimum=1 -fa=/home/mrz/PyFeat/Datasets/DNA/FASTA.txt -la=/home/mr
z/PyFeat/Datasets/DNA/Label.txt -ktuple=3 -kgap=5 -pseudo=1 -zcur
ve=1 -gc=1 -skew=1 -atgc=1 -f11=1 -f12=1 -f13=1 -f21=1 -f22=1 -f2
3=1 -f31=1 -f32=1

Datasets fetching done.
Features extraction begins. Be patient! The machine will take som
e time.
Features extraction ends.
[Total extracted feature: 14891]

Converting (full) CSV is begin.
Converting (full) CSV is end.

Features selection begins. Be patient! The Machine will take some
time.
Features selection ends.
[Total selected feature: 441]

Converting (optimum) CSV is begin.
Converting (optimum) CSV is end.
mrz@rafsanjani:~/PyFeat/Codes$ |
```

Figure 7: Training with Corresponding Optional Arguments

It will generate a full dataset named **fullDataset.csv** (if `-full=1` or, `--fullDataset=1`), and it will also generate a selected features dataset named **optimumDataset.csv** (if `-optimum=1` or, `--optimumDataset=1`). On the contrary, if you don't want to generate full dataset simply set `-full=0` or, `--fullDataset=0`, and if you don't want to generate optimum dataset simply set `-optimum=0` or, `--optimumDataset=0`. The equal sign (=) is optional. To know more details about arguments: <https://github.com/mrzResearchArena/PyFeat/blob/master/README.md> (Table 1).

5.1.2 Evaluation Purpose

Generate datasets for evaluation purpose. Unix command line given below.

We can use full argument:

```
user@machine:~/PyFeat/Codes$ python main.py --sequenceType=Protein --testDataset=1
--fasta=/home/user/PyFeat/Datasets/Protein/independentFASTA.txt
--label=/home/user/PyFeat/Datasets/Protein/independentLabel.txt
--kTuple=3 --kGap=5
--pseudoKNC=1 --zCurve=1 --gcContent=1 --cumulativeSkew=1 --atgcRatio=1 --monoMono=1
--monoDi=1 --monoTri=1 --diMono=1 --diDi=1 --diTri=1 --triMono=1 --triDi=1
```

or, we can also use corresponding optional argument:

```
user@machine:~/PyFeat/Codes$ python main.py -seq=Protein -test=1
-fa=/home/user/PyFeat/Datasets/Protein/independentFASTA.txt
-la=/home/user/PyFeat/Datasets/Protein/independentLabel.txt
-ktuple=3 -kgap=5
-pseudo=1 -zcurve=1 -gc=1 -skew=1 -atgc=1 -f11=1 -f12=1 -f13=1 -f21=1 -f22=1 -f23=1
-f31=1 -f32=1
```

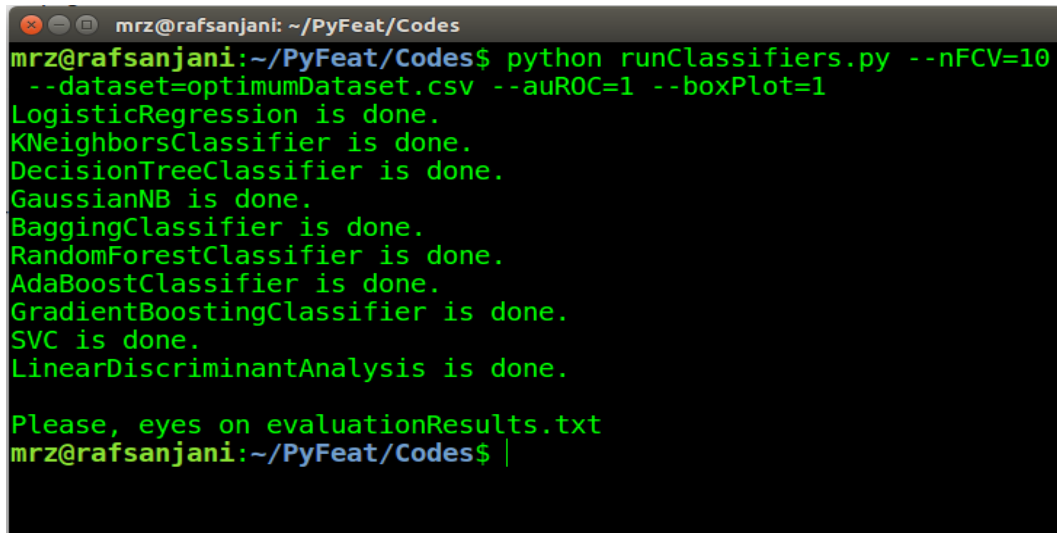

It will generate a full testing dataset named **testDataset.csv** (if `-test=1` or, `-testDataset==1`). To know more details about arguments: <https://github.com/mrzResearchArena/PyFeat/blob/master/README.md> (Table 1).

The process will run smoothly for **valid FASTA** sequences and row-wise binary class label $\{0, 1\}$, or $\{-1, +1\}$.

5.2 Run Machine Learning Classifiers

Running machine learning classifiers with n-fold cross-validation. Unix command line given below.

```
user@machine:~/PyFeat/Codes$ python runClassifiers.py --nFCV=10  
--dataset=optimumDataset.csv --auROC=1 --boxPlot=1
```



```
mrz@rafsanjani: ~/PyFeat/Codes  
mrz@rafsanjani:~/PyFeat/Codes$ python runClassifiers.py --nFCV=10  
--dataset=optimumDataset.csv --auROC=1 --boxPlot=1  
LogisticRegression is done.  
KNeighborsClassifier is done.  
DecisionTreeClassifier is done.  
GaussianNB is done.  
BaggingClassifier is done.  
RandomForestClassifier is done.  
AdaBoostClassifier is done.  
GradientBoostingClassifier is done.  
SVC is done.  
LinearDiscriminantAnalysis is done.  
  
Please, eyes on evaluationResults.txt  
mrz@rafsanjani:~/PyFeat/Codes$ |
```

Figure 8: Running different machine learning classifiers

It will provide classification results (**evaluationResults.txt**) from the user provides binary class dataset (.csv format), and it will also generate a ROC Curve (**auROC.png**), and an accuracy comparison via boxPlot (**AccuracyBoxPlot.png**). To know more details about arguments: <https://github.com/mrzResearchArena/PyFeat/blob/master/README.md> (Table 3).

5.3 Training Model

Training model with single classifier. Unix command line given below.

```
user@machine:~/PyFeat/Codes$ python trainModel.py --dataset=optimumDataset.csv  
--model=LR
```

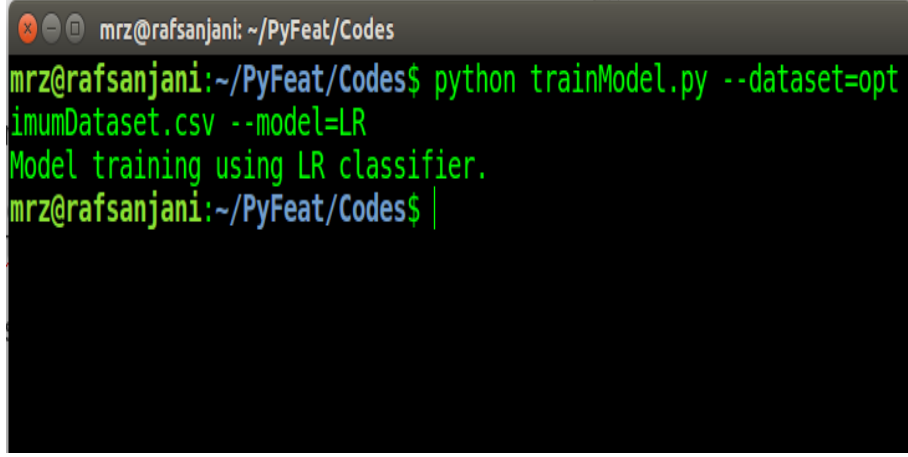
A terminal window with a dark background and light green text. The window title is 'mrz@rafsanjani: ~/PyFeat/Codes'. The command entered is 'python trainModel.py --dataset=optimumDataset.csv --model=LR'. The output shows 'Model training using LR classifier.' followed by a prompt 'mrz@rafsanjani:~/PyFeat/Codes\$ |'.

Figure 9: Training dataset with a single model

It will provide a **dumpModel.pkl** from the user provides binary class dataset (.csv format). To know more details about arguments: <https://github.com/mrzResearchArena/PyFeat/blob/master/README.md> (Table 4).

5.4 Evaluation Model

Evaluation model from the previously trained model. Unix command line given below.

```
user@machine:~/PyFeat/Codes$ python evaluateModel.py  
--optimumDatasetPath=optimumDataset.csv --testDatasetPath=testDataset.csv
```

Here, **optimumDataset.csv**, and **testDataset.csv** using as a training dataset and test dataset respectively. To know more details about arguments: <https://github.com/mrzResearchArena/PyFeat/blob/master/README.md> (Table 5).

6 Features Description

6.1 zCurve

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

$$\begin{cases} x \text{ axis} = (\sum A + \sum G) - (\sum C + \sum T) \\ y \text{ axis} = (\sum A + \sum C) - (\sum G + \sum T) \\ z \text{ axis} = (\sum A + \sum T) - (\sum G + \sum C) \end{cases} \quad (1)$$

Three features will generate using the Z-Curve method.

```

mrz@rafsanjani: ~/PyFeat/Codes
mrz@rafsanjani:~/PyFeat/Codes$ python main.py -fa=/home/mrz/PyFeat/Datasets/DNA/demoFASTAs.txt -la=/home/mrz/PyFeat/Datasets/DNA/demoLabels.txt -full=1 -optimum=1 -zcurve=1

Datasets fetching done.
Features extraction begins. Be patient! The machine will take some time.
Features extraction ends.
[Total extracted feature: 3]

Converting (full) CSV is begin.
Converting (full) CSV is end.

Features selection begins. Be patient! The Machine will take some time.
Features selection ends.
[Total selected feature: 2]

Converting (optimum) CSV is begin.
Converting (optimum) CSV is end.
mrz@rafsanjani:~/PyFeat/Codes$ |

```

Figure 10: zCurve features

6.2 gcContent

In general, GC-content is expressed as a percentage value (%).

$$GC\ Content = \frac{\sum G + \sum C}{\sum A + \sum C + \sum G + \sum T} \times 100\% \quad (2)$$

DNA with high GC-content is more stable than DNA with low GC-content. One feature will generate using the GC-content method.

```

mrz@rafsanjani: ~/PyFeat/Codes
mrz@rafsanjani:~/PyFeat/Codes$ python main.py -fa=/home/mrz/PyFeat/Datasets/DNA/demoFASTAs.txt -la=/home/mrz/PyFeat/Datasets/DNA/demoLabels.txt -full=1 -optimum=1 -gc=1

Datasets fetching done.
Features extraction begins. Be patient! The machine will take some time.
Features extraction ends.
[Total extracted feature: 1]

Converting (full) CSV is begin.
Converting (full) CSV is end.

Features selection begins. Be patient! The Machine will take some time.
Features selection ends.
[Total selected feature: 1]

Converting (optimum) CSV is begin.
Converting (optimum) CSV is end.
mrz@rafsanjani:~/PyFeat/Codes$ |

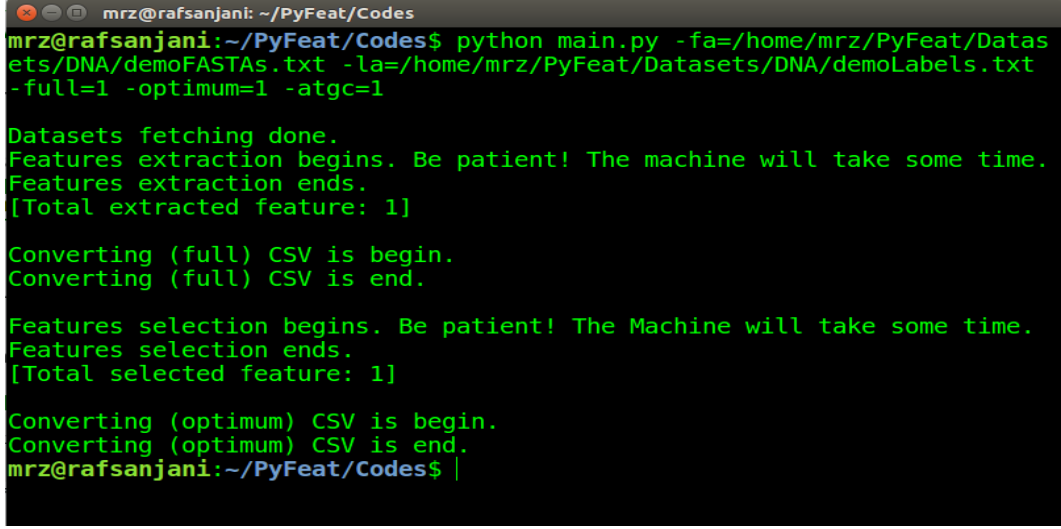
```

Figure 11: GC Content feature

6.3 atgcRatio

Single feature will generate using the AT/GT Ratio method. The equation is given below.

$$AT/GC Ratio = \frac{\sum A + \sum T}{\sum G + \sum C} \quad (3)$$



```
mrz@rafsanjani: ~/PyFeat/Codes
mrz@rafsanjani:~/PyFeat/Codes$ python main.py -fa=/home/mrz/PyFeat/Datasets/DNA/demoFASTAs.txt -la=/home/mrz/PyFeat/Datasets/DNA/demoLabels.txt -full=1 -optimum=1 -atgc=1

Datasets fetching done.
Features extraction begins. Be patient! The machine will take some time.
Features extraction ends.
[Total extracted feature: 1]

Converting (full) CSV is begin.
Converting (full) CSV is end.

Features selection begins. Be patient! The Machine will take some time.
Features selection ends.
[Total selected feature: 1]

Converting (optimum) CSV is begin.
Converting (optimum) CSV is end.
mrz@rafsanjani:~/PyFeat/Codes$ |
```

Figure 12: AT/GC ratio features

6.4 cumulativeSkew

Due to deamination process there is a difference of the count of G and T in forward and reverse strands. The forward strand often have more G and T. The cumulative skew is defined formally as:

$$GC \text{ skew} = \frac{\sum G - \sum C}{\sum G + \sum C}; \quad AT \text{ skew} = \frac{\sum A - \sum T}{\sum A + \sum T} \quad (4)$$

```

mrz@rafsanjani: ~/PyFeat/Codes$ python main.py -fa=/home/mrz/PyFeat/Datasets/DNA/demoFASTAs.txt -la=/home/mrz/PyFeat/Datasets/DNA/demoLabels.txt -full=1 -optimum=1 -skew=1

Datasets fetching done.
Features extraction begins. Be patient! The machine will take some time.
Features extraction ends.
[Total extracted feature: 2]

Converting (full) CSV is begin.
Converting (full) CSV is end.

Features selection begins. Be patient! The Machine will take some time.
Features selection ends.
[Total selected feature: 2]

Converting (optimum) CSV is begin.
Converting (optimum) CSV is end.
mrz@rafsanjani:~/PyFeat/Codes$ |

```

Figure 13: Cumulative skew features

Here as $\sum A$ represents the total number of A, $\sum C$ represents the total number of C from the sequence and so forth. Two features will generate using the cumulative skew method.

6.5 pseudoKNC

When $k=n$ then the $\sum_{i=1}^n 4^i$ features will exist for DNA and RNA, but $\sum_{i=1}^n 20^i$ features will exist for protein.

When $k=1$, feature structure will be **X**.

When $k=2$, feature structure will be **X**, and **XX**.

When $k=3$, feature structure will be **X**, **XX**, and **XXX**.

Described with appropriate examples:

When $k=1$ then only four (4) features will exist for DNA and RNA, but twenty (20) features will exist for protein. Features will be numbers of A, C, G and T/U of the whole sequence of DNA and RNA respectively.

When $k=2$ then only twenty (20) features will exist for DNA and RNA, but four hundred and twenty (420) features will exist for protein. Features will be numbers of A, C, G, T, AA, AC, AG, AT, CA, CC, CG, CT, GA, GC, GG, GT, TA, TC, TG, and TT of the whole sequence of DNA respectively.

When $k=3$ then only eighty four (84) features will exist for DNA and RNA, but eight thousand four hundred and twenty (8,420) features will exist for protein. Features will be numbers of A, C, G, T, AA, AC, AG, AT, CA, CC, CG, CT, GA, GC, GG, GT, TA, TC, TG, TT, AAA, AAC, AAG, AAT, ACA, ACC, ACG, ACT, AGA, AGC, AGG, AGT, ATA, ATC, ATG, ATT, CAA, CAC, CAG, CAT, CCA, CCC, CCG, CCT, CGA, CGC, CGG,

CGT, CTA, CTC, CTG, CTT, GAA, GAC, GAG, GAT, GCA, GCC, GCG, GCT, GGA, GGC, GGG, GGT, GTA, GTC, GTG, GTT, TAA, TAC, TAG, TAT, TCA, TCC, TCG, TCT, TGA, TGC, TGG, TGT, TTA, TTC, TTG, and TTT of the whole sequence of DNA respectively.

```

mrz@rafsanjani: ~/PyFeat/Codes
mrz@rafsanjani:~/PyFeat/Codes$ python main.py -fa=/home/mrz/PyFeat/Datasets/DNA/demoFASTAs.txt -la=/home/mrz/PyFeat/Datasets/DNA/demoLabels.txt -full=1 -optimum=1 -pseudo=1 -ktuple=3

Datasets fetching done.
Features extraction begins. Be patient! The machine will take some time.
Features extraction ends.
[Total extracted feature: 84]

Converting (full) CSV is begin.
Converting (full) CSV is end.

Features selection begins. Be patient! The Machine will take some time.
Features selection ends.
[Total selected feature: 11]

Converting (optimum) CSV is begin.
Converting (optimum) CSV is end.
mrz@rafsanjani:~/PyFeat/Codes$ |

```

Figure 14: PseudoKNC features with -ktuple=3

6.5.1 important definitions

$$\mathbf{X} = \begin{cases} \{A,C,T,G\}, & \text{if the problem involves DNA sequences} \\ \{A,C,T,U\}, & \text{if the problem involves RNA sequences} \\ \{A,C,D,E,F,G,H,I,K,L,M,N,P,Q,R,S,T,V,W,Y\}, & \text{if the problem involves protein sequences} \end{cases}$$

$x_i \in \mathbf{X}$ where i specifies the position of x in some subsequence. Counts of such subsequences of varying lengths is regarded as features in our method.

$j \in \{1, 2, 3...k\}$ where j specifies the number of gaps (don't care) in a subsequence.

6.6 monoMonoKGap

When -kgap=n then the $(4) \times (4) \times n$ features will exist for DNA and RNA but $(20) \times (20) \times n$ features will exist for protein.

When -kgap=1, feature structure will be $\mathbf{X_X}$.

When -kgap=2, feature structure will be $\mathbf{X_X_}$, and $\mathbf{X_X_}$.

When -kgap=3, feature structure will be $\mathbf{X_X_}$, $\mathbf{X_X_}$, and $\mathbf{X_X_}$.

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.

```

mrz@rafsanjani: ~/PyFeat/Codes
mrz@rafsanjani:~/PyFeat/Codes$ python main.py -fa=/home/mrz/PyFeat/Datasets/DNA/demoFASTAs.txt -la=/home/mrz/PyFeat/Datasets/DNA/demoLabels.txt -full=1 -optimum=1 -fll=1 -kgap=1

Datasets fetching done.
Features extraction begins. Be patient! The machine will take some time.
Features extraction ends.
[Total extracted feature: 16]

Converting (full) CSV is begin.
Converting (full) CSV is end.

Features selection begins. Be patient! The Machine will take some time.
Features selection ends.
[Total selected feature: 5]

Converting (optimum) CSV is begin.
Converting (optimum) CSV is end.
mrz@rafsanjani:~/PyFeat/Codes$ |

```

Figure 15: monoMonoKGap features when `-kgap=1`

6.7 monoDiKGap

When `-kgap=n` then the $(4) \times (4 \times 4) \times n$ features will exist for DNA and RNA, but $(20) \times (20 \times 20) \times n$ features will exist for protein.

When `-kgap=1`, feature structure will be **X_XX**.

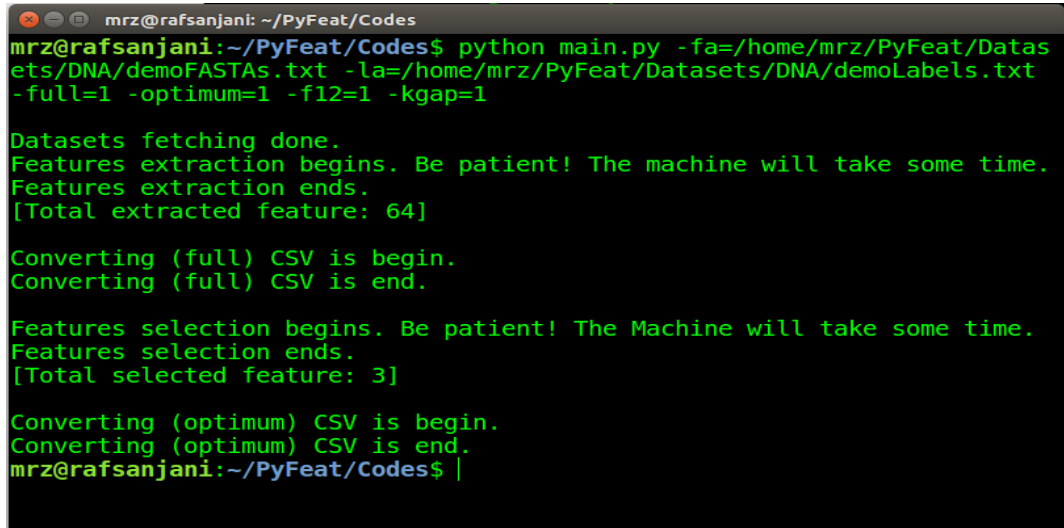
When `-kgap=2`, feature structure will be **X_XX**, and **X__XX**.

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.



```
mrz@rafsanjani: ~/PyFeat/Codes
mrz@rafsanjani:~/PyFeat/Codes$ python main.py -fa=/home/mrz/PyFeat/Datasets/DNA/demoFASTAs.txt -la=/home/mrz/PyFeat/Datasets/DNA/demoLabels.txt -full=1 -optimum=1 -f12=1 -kgap=1

Datasets fetching done.
Features extraction begins. Be patient! The machine will take some time.
Features extraction ends.
[Total extracted feature: 64]

Converting (full) CSV is begin.
Converting (full) CSV is end.

Features selection begins. Be patient! The Machine will take some time.
Features selection ends.
[Total selected feature: 3]

Converting (optimum) CSV is begin.
Converting (optimum) CSV is end.
mrz@rafsanjani:~/PyFeat/Codes$ |
```

Figure 16: monoDiKGap features when -kgap=1

6.8 monoTriKGap

When $-k\text{gap}=n$ then the $(4) \times (4 \times 4 \times 4) \times n$ features will exist for DNA and RNA, but $(20) \times (20 \times 20 \times 20) \times n$ features will exist for protein.

When $-k\text{gap}=1$, feature structure will be **X_XXX**.

When $-k\text{gap}=2$, feature structure will be **X_XXX**, and **X__XXX**.

When $-k\text{gap}=3$, feature structure will be **X_XXX**, **X__XXX**, and **X___XXX**.

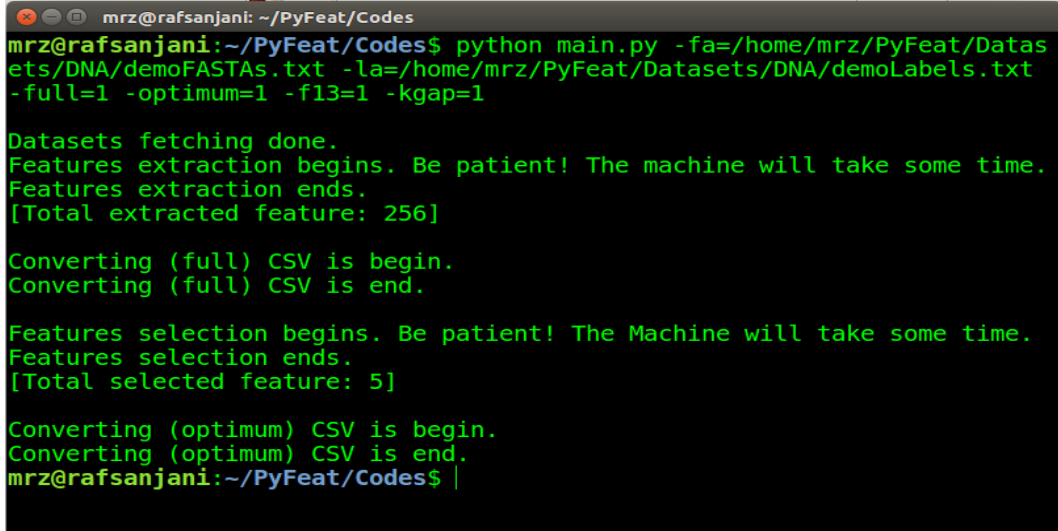
Described with appropriate examples:

When $-k\text{gap}=1$ then only two hundred and fifty six (256) features will exist for DNA and RNA, but hundred and sixty thousand (160,000) a huge amount of features will exist for protein. Features will be numbers of A_AAA, A_AAC, A_AAG, A_AAT, A_ACA, A_ACC, A_ACG, A_ACT, A_AGA, A_AGC, A_AGG, A_AGT, A_ATA, A_ATC, A_ATG, A_ATT, A_CAA, A_CAC, A_CAG, A_CAT, A_CCA, A_CCC, A_CCG, A_CCT, A_CGA, A_CGC, A_CGG, A_CGT, A_CTA, A_CTC, A_CTG, A_CTT, A_GAA, A_GAC, A_GAG, A_GAT, A_GCA, A_GCC, A_GCG, A_GCT, A_GGA, A_GGC, A_GGG, A_GGT, A_GTA, A_GTC, A_GTG, A_GTT, A_TAA, A_TAC, A_TAG, A_TAT, A_TCA, A_TCC, A_TCG, A_TCT, A_TGA, A_TGC, A_TGG, A_TGT, A_TTA, A_TTC, A_TTG, A_TTT, C_AAA, C_AAC, C_AAG, C_AAT, C_ACA, C_ACC, C_ACG, C_ACT, C_AGA, C_AGC, C_AGG, C_AGT, C_ATA, C_ATC, C_ATG, C_ATT, C_CAA, C_CAC, C_CAG, C_CAT, C_CCA, C_CCC, C_CCG, C_CCT, C_CGA, C_CGC, C_CGG, C_CGT, C_CTA, C_CTC, C_CTG, C_CTT, C_GAA, C_GAC, C_GAG, C_GAT, C_GCA, C_GCC, C_GCG, C_GCT, C_GGA, C_GGC, C_GGG, C_GGT, C_GTA, C_GTC, C_GTG, C_GTT, C_TAA, C_TAC, C_TAG, C_TAT, C_TCA, C_TCC, C_TCG, C_TCT, C_TGA, C_TGC, C_TGG, C_TGT, C_TTA, C_TTC, C_TTG, C_TTT, G_AAA, G_AAC, G_AAG, G_AAT, G_ACA, G_ACC, G_ACG, G_ACT, G_AGA, G_AGC, G_AGG, G_AGT, G_ATA, G_ATC, G_ATG, G_ATT, G_CAA, G_CAC, G_CAG, G_CAT, G_CCA, G_CCC, G_CCG, G_CCT, G_CGA, G_CGC, G_CGG, G_CGT, G_CTA, G_CTC, G_CTG, G_CTT, G_GAA, G_GAC, G_GAG, G_GAT, G_GCA, G_GCC, G_GCG, G_GCT, G_GGA, G_GGC, G_GGG, G_GGT, G_GTA, G_GTC, G_GTG, G_GTT, G_TAA, G_TAC, G_TAG, G_TAT, G_TCA, G_TCC, G_TCG, G_TCT, G_TGA, G_TGC, G_TGG, G_TGT, G_TTA, G_TTC, G_TTG, G_TTT, T_AAA, T_AAC, T_AAG, T_AAT, T_ACA, T_ACC, T_ACG, T_ACT, T_AGA, T_AGC, T_AGG, T_AGT, T_ATA, T_ATC, T_ATG, T_ATT, T_CAA, T_CAC, T_CAG, T_CAT, T_CCA, T_CCC, T_CCG, T_CCT, T_CGA, T_CGC, T_CGG, T_CGT, T_CTA, T_CTC, T_CTG, T_CTT, T_GAA, T_GAC, T_GAG, T_GAT, T_GCA, T_GCC, T_GCG, T_GCT, T_GGA, T_GGC, T_GGG, T_GGT, T_GTA, T_GTC, T_GTG, T_GTT, T_TAA, T_TAC, T_TAG, T_TAT, T_TCA, T_TCC, T_TCG, T_TCT, T_TGA, T_TGC, T_TGG, T_TGT, T_TTA, T_TTC, T_TTG, and T_TTT of the whole sequence of DNA respectively.

When $-k\text{gap}=2$ then only hundred and twenty eight (512) features will exist for DNA and RNA, but sixteen thousand (320,000) a huge amount of features will exist for protein. Features will be numbers of A_AAA, A_AAC, A_AAG, A_AAT, A_ACA, A_ACC, A_ACG, A_ACT, A_AGA, A_AGC, A_AGG, A_AGT, A_ATA, A_ATC, A_ATG, A_ATT, A_CAA, A_CAC, A_CAG, A_CAT, A_CCA, A_CCC, A_CCG, A_CCT, A_CGA, A_CGC, A_CGG, A_CGT, A_CTA, A_CTC, A_CTG, A_CTT, A_GAA, A_GAC, A_GAG, A_GAT, A_GCA,

A_GCC, A_GCG, A_GCT, A_GGA, A_GGC, A_GGG, A_GGT, A_GTA, A_GTC, A_GTG,
A_GTT, A_TAA, A_TAC, A_TAG, A_TAT, A_TCA, A_TCC, A_TCG, A_TCT, A_TGA,
A_TGC, A_TGG, A_TGT, A_TTA, A_TTC, A_TTG, A_TTT, C_AAA, C_AAC, C_AAG,
C_AAT, C_ACA, C_ACC, C_ACG, C_ACT, C_AGA, C_AGC, C_AGG, C_AGT, C_ATA,
C_ATC, C_ATG, C_ATT, C_CAA, C_CAC, C_CAG, C_CAT, C_CCA, C_CCC, C_CCG,
C_CCT, C_CGA, C_CGC, C_CGG, C_CGT, C_CTA, C_CTC, C_CTG, C_CTT, C_GAA,
C_GAC, C_GAG, C_GAT, C_GCA, C_GCC, C_GCG, C_GCT, C_GGA, C_GGC, C_GGG,
C_GGT, C_GTA, C_GTC, C_GTG, C_GTT, C_TAA, C_TAC, C_TAG, C_TAT, C_TCA,
C_TCC, C_TCG, C_TCT, C_TGA, C_TGC, C_TGG, C_TGT, C_TTA, C_TTC, C_TTG,
C_TTT, G_AAA, G_AAC, G_AAG, G_AAT, G_ACA, G_ACC, G_ACG, G_ACT, G_AGA,
G_AGC, G_AGG, G_AGT, G_ATA, G_ATC, G_ATG, G_ATT, G_CAA, G_CAC, G_CAG,
G_CAT, G_CCA, G_CCC, G_CCG, G_CCT, G_CGA, G_CGC, G_CGG, G_CGT, G_CTA,
G_CTC, G_CTG, G_CTT, G_GAA, G_GAC, G_GAG, G_GAT, G_GCA, G_GCC, G_GCG,
G_GCT, G_GGA, G_GGC, G_GGG, G_GGT, G_GTA, G_GTC, G_GTG, G_GTT, G_TAA,
G_TAC, G_TAG, G_TAT, G_TCA, G_TCC, G_TCG, G_TCT, G_TGA, G_TGC, G_TGG,
G_TGT, G_TTA, G_TTC, G_TTG, G_TTT, T_AAA, T_AAC, T_AAG, T_AAT, T_ACA,
T_ACC, T_ACG, T_ACT, T_AGA, T_AGC, T_AGG, T_AGT, T_ATA, T_ATC, T_ATG,
T_ATT, T_CAA, T_CAC, T_CAG, T_CAT, T_CCA, T_CCC, T_CCG, T_CCT, T_CGA,
T_CGC, T_CGG, T_CGT, T_CTA, T_CTC, T_CTG, T_CTT, T_GAA, T_GAC, T_GAG,
T_GAT, T_GCA, T_GCC, T_GCG, T_GCT, T_GGA, T_GGC, T_GGG, T_GGT, T_GTA,
T_GTC, T_GTG, T_GTT, T_TAA, T_TAC, T_TAG, T_TAT, T_TCA, T_TCC, T_TCG,
T_TCT, T_TGA, T_TGC, T_TGG, T_TGT, T_TTA, T_TTC, T_TTG, T_TTT, A__AAA,
A__AAC, A__AAG, A__AAT, A__ACA, A__ACC, A__ACG, A__ACT, A__AGA, A__AGC, A__AGG,
A__AGT, A__ATA, A__ATC, A__ATG, A__ATT, A__CAA, A__CAC, A__CAG, A__CAT, A__CCA,
A__CCC, A__CCG, A__CCT, A__CGA, A__CGC, A__CGG, A__CGT, A__CTA, A__CTC, A__CTG,
A__CTT, A__GAA, A__GAC, A__GAG, A__GAT, A__GCA, A__GCC, A__GCG, A__GCT,
A__GGA, A__GGC, A__GGG, A__GGT, A__GTA, A__GTC, A__GTG, A__GTT, A__TAA,
A__TAC, A__TAG, A__TAT, A__TCA, A__TCC, A__TCG, A__TCT, A__TGA, A__TGC, A__TGG,
A__TGT, A__TTA, A__TTC, A__TTG, A__TTT, C__AAA, C__AAC, C__AAG, C__AAT, C__ACA,
C__ACC, C__ACG, C__ACT, C__AGA, C__AGC, C__AGG, C__AGT, C__ATA, C__ATC, C__ATG,
C__ATT, C__CAA, C__CAC, C__CAG, C__CAT, C__CCA, C__CCC, C__CCG, C__CCT, C__CGA,
C__CGC, C__CGG, C__CGT, C__CTA, C__CTC, C__CTG, C__CTT, C__GAA, C__GAC, C__GAG,
C__GAT, C__GCA, C__GCC, C__GCG, C__GCT, C__GGA, C__GGC, C__GGG, C__GGT,
C__GTA, C__GTC, C__GTG, C__GTT, C__TAA, C__TAC, C__TAG, C__TAT, C__TCA, C__TCC,
C__TCG, C__TCT, C__TGA, C__TGC, C__TGG, C__TGT, C__TTA, C__TTC, C__TTG, C__TTT,
G__AAA, G__AAC, G__AAG, G__AAT, G__ACA, G__ACC, G__ACG, G__ACT, G__AGA,
G__AGC, G__AGG, G__AGT, G__ATA, G__ATC, G__ATG, G__ATT, G__CAA, G__CAC, G__CAG,
G__CAT, G__CCA, G__CCC, G__CCG, G__CCT, G__CGA, G__CGC, G__CGG, G__CGT,
G__CTA, G__CTC, G__CTG, G__CTT, G__GAA, G__GAC, G__GAG, G__GAT, G__GCA,
G__GCC, G__GCG, G__GCT, G__GGA, G__GGC, G__GGG, G__GGT, G__GTA, G__GTC,
G__GTG, G__GTT, G__TAA, G__TAC, G__TAG, G__TAT, G__TCA, G__TCC, G__TCG, G__TCT,
G__TGA, G__TGC, G__TGG, G__TGT, G__TTA, G__TTC, G__TTG, G__TTT, T__AAA,
T__AAC, T__AAG, T__AAT, T__ACA, T__ACC, T__ACG, T__ACT, T__AGA, T__AGC, T__AGG,
T__AGT, T__ATA, T__ATC, T__ATG, T__ATT, T__CAA, T__CAC, T__CAG, T__CAT, T__CCA,
T__CCC, T__CCG, T__CCT, T__CGA, T__CGC, T__CGG, T__CGT, T__CTA, T__CTC, T__CTG,

T_CTT, T_GAA, T_GAC, T_GAG, T_GAT, T_GCA, T_GCC, T_GCG, T_GCT, T_GGA, T_GGC, T_GGG, T_GGT, T_GTA, T_GTC, T_GTG, T_GTT, T_TAA, T_TAC, T_TAG, T_TAT, T_TCA, T_TCC, T_TCG, T_TCT, T_TGA, T_TGC, T_TGG, T_TGT, T_TTA, T_TTC, T_TTG, and T_TTT of the whole sequence of DNA respectively.



```

mrz@rafsanjani: ~/PyFeat/Codes
mrz@rafsanjani:~/PyFeat/Codes$ python main.py -fa=/home/mrz/PyFeat/Datasets/DNA/demoFASTAs.txt -la=/home/mrz/PyFeat/Datasets/DNA/demoLabels.txt -full=1 -optimum=1 -f13=1 -kgap=1

Datasets fetching done.
Features extraction begins. Be patient! The machine will take some time.
Features extraction ends.
[Total extracted feature: 256]

Converting (full) CSV is begin.
Converting (full) CSV is end.

Features selection begins. Be patient! The Machine will take some time.
Features selection ends.
[Total selected feature: 5]

Converting (optimum) CSV is begin.
Converting (optimum) CSV is end.
mrz@rafsanjani:~/PyFeat/Codes$ |

```

Figure 17: monoTriKGap features when -kgap=1

6.9 diMonoKGap

When -kgap= n then the $(4 \times 4) \times (4) \times n$ features will exist for DNA and RNA but $(20 \times 20) \times (20) \times n$ features will exist for protein.

When -kgap=1, feature structure will be **XX_X**.

When -kgap=2, feature structure will be **XX_X**, and **XX__X**.

When -kgap=3, feature structure will be **XX_X**, **XX__X**, and **XX___X**.

```
mrz@rafsanjani: ~/PyFeat/Codes
mrz@rafsanjani:~/PyFeat/Codes$ python main.py -fa=/home/mrz/PyFeat/Datasets/DNA/demoFASTAs.txt -la=/home/mrz/PyFeat/Datasets/DNA/demoLabels.txt -full=1 -optimum=1 -f21=1 -kgap=1

Datasets fetching done.
Features extraction begins. Be patient! The machine will take some time.
Features extraction ends.
[Total extracted feature: 64]

Converting (full) CSV is begin.
Converting (full) CSV is end.

Features selection begins. Be patient! The Machine will take some time.
Features selection ends.
[Total selected feature: 39]

Converting (optimum) CSV is begin.
Converting (optimum) CSV is end.
mrz@rafsanjani:~/PyFeat/Codes$ |
```

Figure 18: diMonoKGap features when -kgap=1

6.10 diDiKGap

When -kgap= n then the $(4 \times 4) \times (4 \times 4) \times n$ features will exist for DNA and RNA but $(20 \times 20) \times (20 \times 20) \times n$ features will exist for protein.

When -kgap=1, feature structure will be **XX_XX**.

When -kgap=2, feature structure will be **XX_XX**, and **XX__XX**.

When -kgap=3, feature structure will be **XX_XX**, **XX__XX**, and, **XX___XX**.

```
mrz@rafsanjani: ~/PyFeat/Codes
mrz@rafsanjani:~/PyFeat/Codes$ python main.py -fa=/home/mrz/PyFeat/Datasets/DNA/demoFASTAs.txt -la=/home/mrz/PyFeat/Datasets/DNA/demoLabels.txt -full=1 -optimum=1 -f22=1 -kgap=1

Datasets fetching done.
Features extraction begins. Be patient! The machine will take some time.
Features extraction ends.
[Total extracted feature: 256]

Converting (full) CSV is begin.
Converting (full) CSV is end.

Features selection begins. Be patient! The Machine will take some time.
Features selection ends.
[Total selected feature: 27]

Converting (optimum) CSV is begin.
Converting (optimum) CSV is end.
mrz@rafsanjani:~/PyFeat/Codes$ |
```

Figure 19: diDiKGap features with -kgap=1

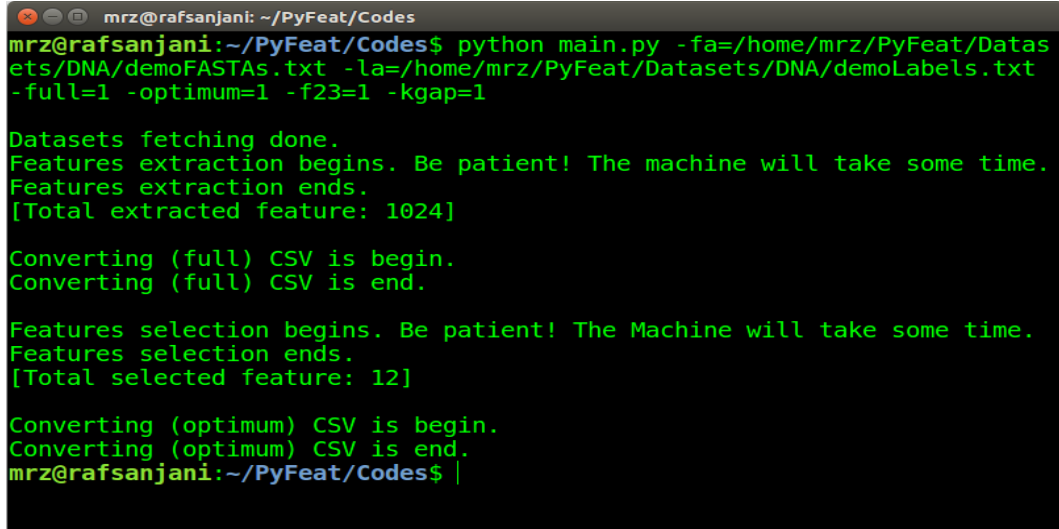
6.11 diTriKGap

When $-kgap=n$ then the $(4 \times 4) \times (4 \times 4 \times 4) \times n$ features will exist for DNA and RNA but $(20 \times 20) \times (20 \times 20 \times 20) \times n$ features will exist for protein.

When $-kgap=1$, feature structure will be **XX_XXX**.

When $-kgap=2$, feature structure will be **XX_XXX**, and **XX__XXX**.

When $-kgap=3$, feature structure will be **XX_XXX**, **XX__XXX**, and **XX___XXX**.



```
mrz@rafsanjani: ~/PyFeat/Codes
mrz@rafsanjani:~/PyFeat/Codes$ python main.py -fa=/home/mrz/PyFeat/Datasets/DNA/demoFASTAs.txt -la=/home/mrz/PyFeat/Datasets/DNA/demoLabels.txt -full=1 -optimum=1 -f23=1 -kgap=1

Datasets fetching done.
Features extraction begins. Be patient! The machine will take some time.
Features extraction ends.
[Total extracted feature: 1024]

Converting (full) CSV is begin.
Converting (full) CSV is end.

Features selection begins. Be patient! The Machine will take some time.
Features selection ends.
[Total selected feature: 12]

Converting (optimum) CSV is begin.
Converting (optimum) CSV is end.
mrz@rafsanjani:~/PyFeat/Codes$ |
```

Figure 20: diTriKGap features with $-kgap=1$

6.12 triMonoKGap

When $-kgap=n$ then the $(4 \times 4 \times 4) \times 4 \times n$ features will exist for DNA and RNA but $(20 \times 20 \times 20) \times 20 \times n$ features will exist for protein.

When $-kgap=1$, feature structure will be **XXX_X**.

When $-kgap=2$, feature structure will be **XXX_X**, and **XXX__X**.

When $-kgap=3$, feature structure will be **XXX_X**, **XXX__X**, and **XXX___X**.

```
mrz@rafsanjani: ~/PyFeat/Codes$ python main.py -fa=/home/mrz/PyFeat/Datasets/DNA/demoFASTAs.txt -la=/home/mrz/PyFeat/Datasets/DNA/demoLabels.txt -full=1 -optimum=1 -f31=1 -kgap=1

Datasets fetching done.
Features extraction begins. Be patient! The machine will take some time.
Features extraction ends.
[Total extracted feature: 256]

Converting (full) CSV is begin.
Converting (full) CSV is end.

Features selection begins. Be patient! The Machine will take some time.
Features selection ends.
[Total selected feature: 2]

Converting (optimum) CSV is begin.
Converting (optimum) CSV is end.
mrz@rafsanjani:~/PyFeat/Codes$ |
```

Figure 21: triMonoKGap features with -kgap=1

6.13 triDiKGap

When -kgap= n then the $(4 \times 4 \times 4) \times (4 \times 4) \times n$ features will exist for DNA and RNA but $(20 \times 20 \times 20) \times (20 \times 20) \times n$ features will exist for protein.

When -kgap=1, feature structure will be **XXX_XX**.

When -kgap=2, feature structure will be **XXX_XX**, and **XXX__XX**.

When -kgap=3, feature structure will be **XXX_XX**, **XXX__XX**, and **XXX___XX**.

```
mrz@rafsanjani: ~/PyFeat/Codes$ python main.py -fa=/home/mrz/PyFeat/Datasets/DNA/demoFASTAs.txt -la=/home/mrz/PyFeat/Datasets/DNA/demoLabels.txt -full=1 -optimum=1 -f32=1 -kgap=1

Datasets fetching done.
Features extraction begins. Be patient! The machine will take some time.
Features extraction ends.
[Total extracted feature: 1024]

Converting (full) CSV is begin.
Converting (full) CSV is end.

Features selection begins. Be patient! The Machine will take some time.
Features selection ends.
[Total selected feature: 16]

Converting (optimum) CSV is begin.
Converting (optimum) CSV is end.
mrz@rafsanjani:~/PyFeat/Codes$ |
```

Figure 22: triDiKGap features with -kgap=1

7 Feature Calculation

The number of features generated by each of our feature extraction models are shown in Table 1. Here we have employed kGaps of varying degrees. We use values ranging from 1 to 5 in case of DNA and RNA sequences and 1 to 10 in case of protein sequences. By applying Adaboost to our extracted features we select 950 features having maximum importance score for DNA and RNA and 1625 features for protein sequences.

Table 1: Feature calculation for DNA, RNA, and protein sequences

Feature Name	Feature extraction for DNA/RNA	Feature extraction for protein
zCurve	3
gcContent	1
atgcRatio	1
cumulativeSkew	2
pseudoKNC	84	8,420
monoMonoKGap	160	4,000
monoDiKGap	640	80,000
monoTriKGap	2,560
diMonoKGap	640	80,000
diDiKGap	2,560
diTriKGap	10,240
triMonoKGap	2,560
triDiKGap	10,240
Total	29,691	172,420

Table 1 shows, the feature extracted from DNA, RNA, and protein. Total 29,691 feature extracted from both DNA and RNA; and 172,420 feature extracted from protein.

8 AdaBoost

For feature selection and to reduce the impact of the curse of dimensionality and at the same time maintain informative features [1] we have employed AdaBoost classification model to calculate the average impurity-curtailement achieved by splitting upon each of the features in all of the trees trained on different weight distributions of the instances. Here we use Adaboost classifier implemented in scikit-learn package [2] in python with its default learning rate of 1 and C4.5 as its base learner. C4.5 has been widely used as the base learner for this classifier which also demonstrated good performance in our study. We have tried different number of base learners which among them, using 500 obtained the best results.

Note that the RNA and Protein datasets that we used as case studies include train and independent test set which enable us to assess the generality of our model and avoid any possible overfitting. We then select n features with the maximum score for model training. It is to be noted that this selection mechanism is much more cost-effective compared to the wrapper-based methods since only one run of the AdaBoost model is sufficient for the

selection process. Moreover, it is more effective compared to the other methods as different trees incorporate different instance weight distributions into the impurity measure which in turn adds diversity to the way features are selected for node splitting in different trees, thus making the selection process less likely to be adversely affected by the presence correlated features having equally high pre-dictive capability. It makes the choice of features diverse and robust in the presence of high feature multi-collinearity [3].

References

- [1] Eamonn Keogh and Abdullah Mueen. Curse of dimensionality. In *Encyclopedia of Machine Learning and Data Mining*, pages 314–315. Springer, 2017.
- [2] Fabian Pedregosa, Gaël Varoquaux, Alexandre Gramfort, Vincent Michel, Bertrand Thirion, Olivier Grisel, Mathieu Blondel, Peter Prettenhofer, Ron Weiss, Vincent Dubourg, et al. Scikit-learn: Machine learning in python. *Journal of machine learning research*, 12(Oct):2825–2830, 2011.
- [3] Ruihu Wang. Adaboost for feature selection, classification and its relation with svm, a review. *Physics Procedia*, 25:800–807, 2012.
- [4] Bin Liu, Fule Liu, Longyun Fang, Xiaolong Wang, and Kuo-Chen Chou. repdna: a python package to generate various modes of feature vectors for dna sequences by incorporating user-defined physicochemical properties and sequence-order effects. *Bioinformatics*, 31(8):1307–1309, 2014.
- [5] Dong-Sheng Cao, Qing-Song Xu, and Yi-Zeng Liang. propy: a tool to generate various modes of chous pseAAC. *Bioinformatics*, 29(7):960–962, 2013.
- [6] Zhen Chen, Pei Zhao, Fuyi Li, André Leier, Tatiana T Marquez-Lago, Yanan Wang, Geoffrey I Webb, A Ian Smith, Roger J Daly, Kuo-Chen Chou, et al. ifeature: a python package and web server for features extraction and selection from protein and peptide sequences. *Bioinformatics*, 1:4, 2018.
- [7] Md Rafsan Jani, Md Toha Khan Mozlish, Sajid Ahmed, Dewan Md Farid, and Swakkhar Shatabda. irecspot-ef: Effective sequence based features for recombination hotspot prediction. *Computers in biology and medicine*, 2018.
- [8] Bin Liu. Bioseq-analysis: a platform for dna, rna and protein sequence analysis based on machine learning approaches. *Briefings in bioinformatics*, 2017.
- [9] Bin Liu, Hao Wu, Deyuan Zhang, Xiaolong Wang, and Kuo-Chen Chou. Pse-analysis: a python package for dna/rna and protein/peptide sequence analysis based on pseudo components and kernel methods. *Oncotarget*, 8(8):13338, 2017.
- [10] Bin Liu, Fule Liu, Xiaolong Wang, Junjie Chen, Longyun Fang, and Kuo-Chen Chou. Pse-in-one: a web server for generating various modes of pseudo components of dna, rna, and protein sequences. *Nucleic acids research*, 43(W1):W65–W71, 2015.

- [11] Bin Liu, Fule Liu, Longyun Fang, Xiaolong Wang, and Kuo-Chen Chou. reprna: a web server for generating various feature vectors of rna sequences. *Molecular Genetics and Genomics*, 291(1):473–481, 2016.
- [12] Nan Xiao, Dong-Sheng Cao, Min-Feng Zhu, and Qing-Song Xu. protr/protrweb: R package and web server for generating various numerical representation schemes of protein sequences. *Bioinformatics*, 31(11):1857–1859, 2015.