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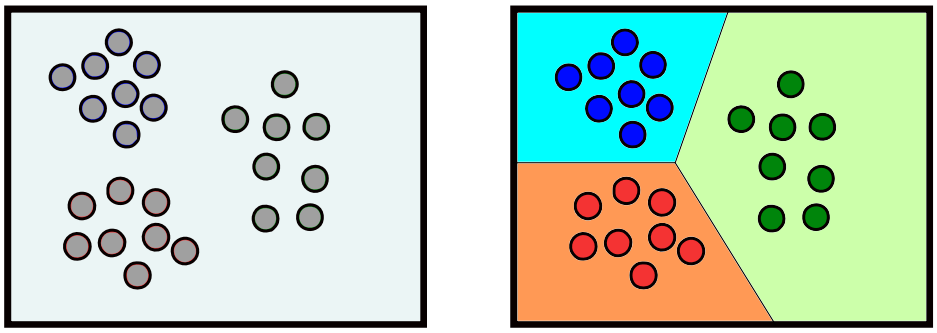
第 1 章 序論

第 1節　背景

近年，情報通信社会の発展に伴いデータ量が増大し，日々多様なデータがコンピュータに蓄積されている．検索エンジンなどのインターネット上のサービスでは，蓄積されたビッグデータの解析や分類を行うことで，利用者に適切な情報を素早く送ることを可能にしている．ビッグデータを人の手によって分類することには困難が伴うため，計算機を用いて自動的にデータの分類を行うための技術であるクラスタリングが必要となる．クラスタリングとは，与えられたデータの個体間に存在する類似性に基づいて，個体をいくつかのクラスタと呼ばれるグループに分割を行う教師なし機械学習の手法である．図 1.1 に示すように，ある一定のルールに従って存在するデータがあったときに，クラスタリングを行うことでそれぞれのデータがどのクラスタに属するかということを示すことができる．

データをクラスタに分類した際に，それぞれのデータが各クラスタに属す度合いを表した値を帰属度と呼ぶ．帰属度が 0 と 1 のみで表され，それぞれのデータが各クラスタに明確に分類されるクラスタリングをハードクラスタリングと呼び，一方で帰属度が 0 と 1 の間の値で表され，データが属するクラスタを柔軟に表すことができるクラスタリングをファジィクラスタリングと呼ぶ．現実に存在しているデータには，明確に分類できるものだけでなく本質的に分類できない複雑なものも存在し，そういったデータの分類にはファジィクラスタリングが有効である．



(a) クラスタリング前　　(b) クラスタリング後

図 1.1: クラスタリングについて

第 2節　目的

既存の手法における課題として，各クラスタのサイズに差がある場合，クラスタリングから有意な結果が得られないというものがある．ここで，クラスタのサイズとは，クラスタに属するデータの数と，そのクラスタに属するデータ間の類似度に基づくものであり，データの数が多い，または類似度が小さいクラスタをサイズが大きいクラスタとし，データの数が少ない，または類似度が大きいクラスタをサイズが大きいクラスタとする．現在，各クラスタのサイズを考慮してクラスタリングを行う手法が複数提案されており，本研究はその中でも，Standard Fuzzy c-Means with vAriable controlling cluster size (sFCMA) [1], Entropy-regularized Fuzzy c-Means vAriable controlling clusters size (eFCMA) [2], q-divergence based Fuzzy c-Means with vAriable controlling cluster size (qFCMA) [3] の 3 手法について，各手法の特性を把握するとともに，最も有効な手法を発見することを目的とする．

第 3節　構成

本文書の構成を次に示す．第 2 章では，提案手法について説明する．第 3 章では，人工データ実験による各手法の特性比較を行う．第 4 章では，実データ実験による各手法の精度比較を行う．最後に第 5 章では，本文書の結論を述べる．また，付録では，プログラムソースを掲載している．

第 2 章
提案手法

第 1節　はじめに

本章では，本研究で提案するファジィクラスタリング手法について説明する．まず第 2 節で定義を示し，次に第 4 節から第 5 節で各手法の最適化問題と，各変数の更新式について述べる．

第 2節　定義

次節で述べるファジィクラスリングの最適化問題における各変数の定義について，表 2.1 に示す．

表 2.1: ファジイクラスタリングの最適化問題における定義

N	データ数	x_k	データ
C	クラスタ数	v_i	クラスタ中心
λ, m	ファジィ化パラメータ	$u_{i,k}$	帰属度
α_i	クラスタサイズ調整変数		

第 3節　sFCMA

Standard Fuzzy c-Means with vAriable controlling cluster size (sFCMA) [1] の最適化問題を以下に示す.

$$\underset{u,v,\alpha}{\text{minimize}} \sum_{i=1}^{C}\sum_{k=1}^{N}(\alpha_i)^{1-m}(u_{i,k})^m||x_k - v_i||_2^2 \tag{2.1}$$

$$\text{subject to } \sum_{i=1}^{C} u_{i,k} = 1,\ \sum_{i=1}^{C}\alpha_i = 1 \text{ and } m > 1,\ \alpha_i > 0 \tag{2.2}$$

次に，クラスタ中心 v_i の更新式を以下に示す.

$$v_i = \frac{\sum_{k=1}^{N}(u_{i,k})^m x_k}{\sum_{k=1}^{N}(u_{i,k})^m} \tag{2.3}$$

次に，帰属度 $u_{i,k}$ の更新式を以下に示す.

$$u_{i,k} = \frac{1}{\sum_{j=1}^{c}\frac{\alpha_j}{\alpha_i}\left(\frac{d_{j,k}}{d_{i,k}}\right)^{\frac{1}{1-m}}} \tag{2.4}$$

次に，クラスタサイズ調整変数 α_i の更新式を以下に示す.

$$\alpha_i = \frac{1}{\sum_{j=1}^{C}\left(\sum_{k=1}^{N}\frac{(u_{j,k})^m d_{j,k}}{(u_{i,k})^m d_{i,k}}\right)^{\frac{1}{m}}} \tag{2.5}$$

第 4節　eFCMA

Entropy-regularized Fuzzy c-Means vAriable controlling clusters size (eFCMA) [2] の最適化問題を以下に示す.

$$\underset{u,v,\alpha}{\text{minimize}} \sum_{i=1}^{C}\sum_{k=1}^{N}u_{i,k}||x_k - v_i||_2^2 + \lambda^{-1}\sum_{i=1}^{C}\sum_{k=1}^{N}u_{i,k}\log\left(\frac{u_{i,k}}{\alpha_i}\right) \tag{2.6}$$

$$\text{subject to } \sum_{i=1}^{C} u_{i,k} = 1,\ \sum_{i=1}^{C}\alpha_i = 1 \text{ and } \lambda > 0, \quad \alpha_i > 0 \tag{2.7}$$

次に，クラスタ中心 v_i の更新式を以下に示す.

$$v_i = \frac{\sum_{k=1}^{N}u_{i,k}x_k}{\sum_{k=1}^{N}u_{i,k}} \tag{2.8}$$

次に，帰属度 $u_{i,k}$ の更新式を以下に示す．

$$u_{i,k} = \frac{\pi_i \exp(-\lambda||x_k - v_i||_2^2)}{\sum_{j=1}^{C} \alpha_j \exp(-\lambda||x_k - v_j||_2^2)} \tag{2.9}$$

次に，クラスタサイズ調整変数 α_i の更新式を以下に示す．

$$\alpha_i = \frac{\sum_{k=1}^{N} u_{i,k}}{N} \tag{2.10}$$

第 5節　qFCMA

q-divergence based Fuzzy c-Means with vAriable controlling cluster size (qFCMA) [3] の最適化問題を以下に示す．

$$\underset{u,v,\alpha}{\text{minimize}} \sum_{i=1}^{C}\sum_{k=1}^{N} (\alpha_i)^{1-m}(u_{i,k})^m ||x_k - v_i||_2^2 + \frac{\lambda^{-1}}{m-1} \sum_{i=1}^{C}\sum_{k=1}^{N} (\alpha_i)^{1-m}(u_{i,k})^m \tag{2.11}$$

$$\text{subject to } \sum_{i=1}^{C} u_{i,k} = 1,\ \sum_{i=1}^{C} \alpha_i = 1 \text{ and } \lambda > 0,\ m > 1,\ \alpha_i > 0 \tag{2.12}$$

次に，クラスタ中心 v_i の更新式を以下に示す．

$$v_i = \frac{\sum_{k=1}^{N} (u_{i,k})^m x_k}{\sum_{k=1}^{N} (u_{i,k})^m} \tag{2.13}$$

次に，帰属度 $u_{i,k}$ の更新式を以下に示す．

$$u_{i,k} = \frac{\alpha_i (1 + \lambda(1-m)||x_i - v_k||_2^2)^{\frac{1}{1-m}}}{\sum_{j=1}^{C} \alpha_j (1 + \lambda(1-m)||x_j - v_k||_2^2)^{\frac{1}{1-m}}} \tag{2.14}$$

次に，クラスタサイズ調整変数 α_i の更新式を以下に示す．

$$\alpha_i = \frac{1}{\sum_{j=1}^{C} \left(\sum_{k=1}^{N} \frac{(u_{j,k})^m (1-\lambda(1-m)d_{j,k})}{(u_{i,k})^m (1-\lambda(1-m)d_{i,k})} \right)^{\frac{1}{m}}} \tag{2.15}$$

第 6節　おわりに

本章では，本研究で提案するファジィクラスタリング手法について説明した．まず第 2 節で定義を示し，次に第 4 節から 5 節で各手法の最適化問題と，各変数の更新式について述べた．

第 3 章
人工データによる実験

第 1節　はじめに

本章では，人工データを用いた実験について述べる．まず第 2 節で本実験で用いる人工データについて説明する．次に第 3 節でアルゴリズムについて述べる．最後に第 4 節で実験により得られた分類関数を用いて各手法の特性比較を行う．

第 2節　人工データについて

人工データとして，クラス数 2，各クラスのデータ数 50，合計データ数 100 のデータを平均値 $(-1, -1)$，標準偏差 (0.5, 0.5) 及び平均値 (1, 1)，標準偏差 (0.5, 0.5) のガウスサンプリングで生成したデータを用いた (図 3.1)．

第 3節　アルゴリズム

1. クラスタ中心 v をランダムに与え，クラスタサイズ調整変数 α をクラスタ数の逆数で初期化する．
2. クラスタ中心 v を用いて帰属度 u を更新する．
3. 帰属度 u を用いてクラスタ中心 v 及びクラスタサイズ調整変数 α を更新する．
4. u, v, α の変化の合計が 10^{-10} 未満に収束すれば終了し，そうでない場合は 2 に戻る．

第 4節　分類関数による特性比較

分類関数は，各クラスタに対する帰属度を座標空間上に可視化したもので，分類関数を見ることにより，データがどのクラスタに属するかということが調べることができるとともに，各手法がファジィであるかクリスプであるかを判別することができる．

sFCMA の実験結果を図 3.2a, 3.2b に示す．パラメータ m を 2.00 から 1.01 に変化させた

ところ，分類関数は m の値が大きいほどファジィになり，小さいほどクリスプになることが分かった．

次に，eFCMA の実験結果を図 3.3a, 3.3b に示す．垂直軸は分類関数値を，底面はデータ空間を表す．網掛けで示されるのが分類関数であり，各点がデータを表している．パラメータ λ を 1 から 10 に変化させたところ，分類関数は λ の値が小さいほどファジィになり，大きいほどクリスプになることが分かった．

qFCMA の実験結果を図 3.4a, 3.4b, 3.4c に示す．こちらは，パラメータ (m, λ) の組み合わせとして，$(2.00, 1)$, $(1.01, 1)$, $(1.01, 10)$ の 3 通りでクラスタリングを行った．図 3.4a 及び図 3.4b の分類関数より，m の値が大きいほどファジィになり，小さいほどクリスプになることが分かった．また，図 3.4b 及び図 3.4c の分類関数より，λ の値が小さいほどファジィになり，大きいほどクリスプになることが分かった．そして，図 3.2 及び図 3.4a, 3.4b の分類関数より qFCMA において $m - 1 \to +0$ とすると sFCMA と同じ特性が得られ，図 3.3 及び図 3.4b, 3.4c より，$\lambda \to \infty$ とすると eFCMA と同様の特性を示すことがわかった．これらの実験結果より qFCMA は sFCMA と eFCMA の特性を併せ持つと言える．

第 5節　おわりに

本章では，人工データを用いた実験について述べた．まず第 2 節で本実験で用いる人工データについて説明した．次に第 3 節でアルゴリズムについて述べた．最後に第 4 節で実験により得られた分類関数を用いて各手法の特性比較を行った．

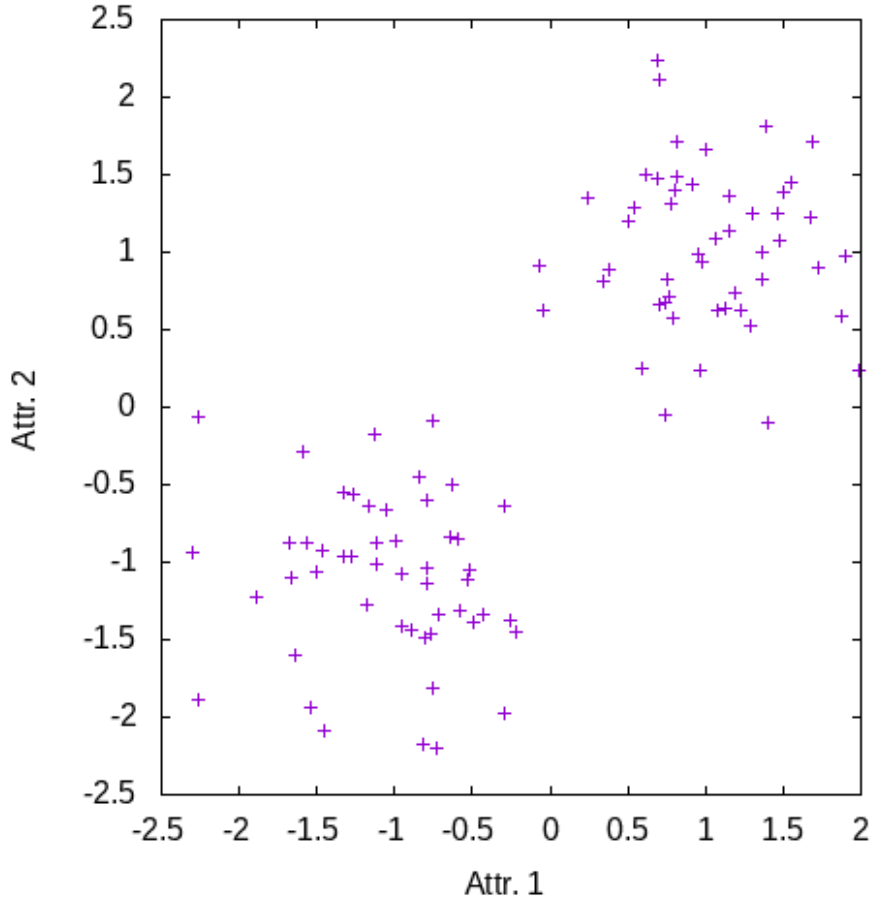
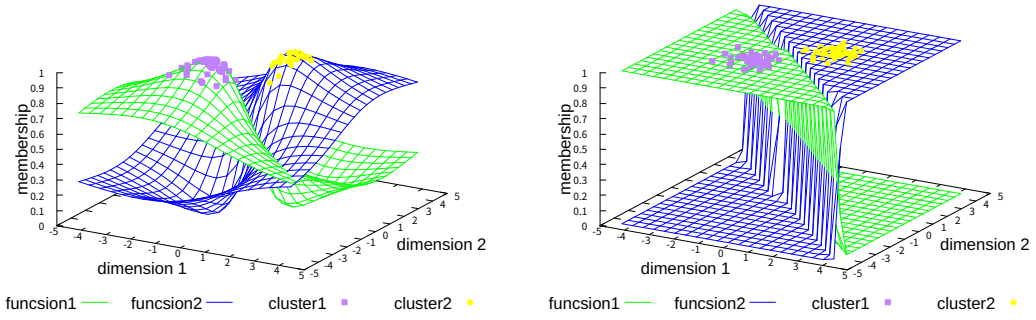
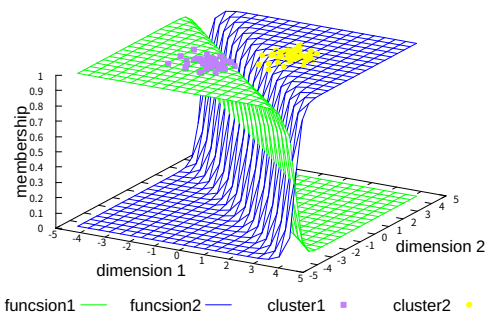


図 3.1: 人工データ

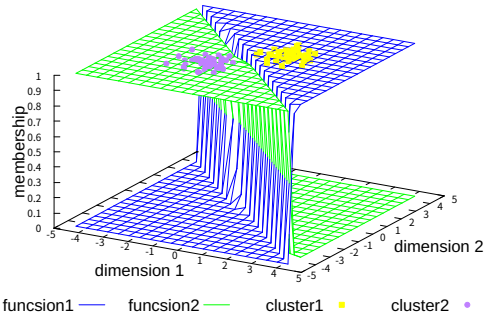


(a) m=2.00　　(b) m=1.01

図 3.2: sFCMA の人工データの実験結果

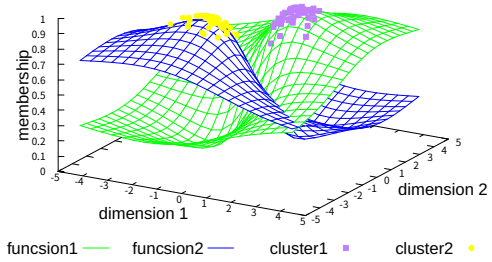


(a) λ=1

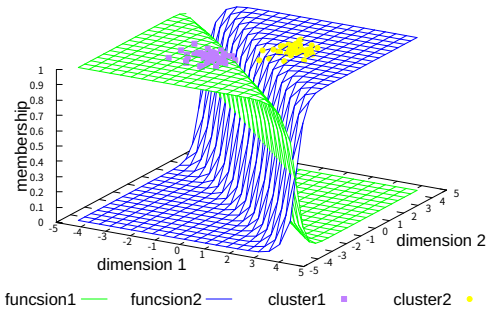


(b) λ=10

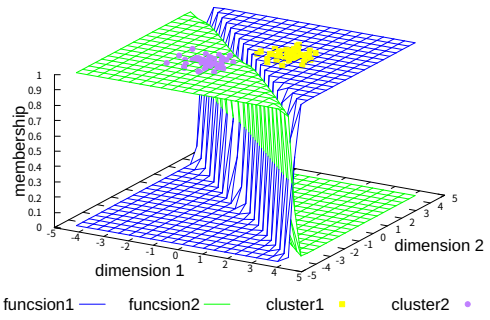
図 3.3: eFCMA の人工データの実験結果



(a) $m = 2.00,\ \lambda = 1$



(b) $m = 1.01,\ \lambda = 1$



(c) $m = 1.01,\ \lambda = 10$

図 3.4: qFCMA の人工データの実験結果

第 4 章
実データによる実験

第 1節　はじめに

本章では，実データを用いた実験について述べる．まず第 2 節で本実験で用いる実データについて説明する．次に第 3 節でアルゴリズムについて述べる．最後に第 4 節で実験により得られた評価指標を用いて各手法の精度比較を行う．

第 2節　実データについて

実データとしては，個体数 403，クラス数 4 の，被験者の勉強時間や試験結果などの 5 属性を収録した “User Knowledge Modeling Dasta Set” を用いた．

第 3節　アルゴリズム

1. 帰属度 u を正解帰属度で初期化し，クラスタサイズ調整変数 α をクラスタ数の逆数で初期化する．
2. 帰属度 u を用いてクラスタ中心 v 及びクラスタサイズ調整変数 α を更新する．
3. u, v, α の変化の合計が 10^{-10} 未満に収束すれば終了し，そうでない場合は 2 に戻る．

第 4節　ARI による精度比較

sFCMA, eFCMA, qFCMA の実データ実験の結果について，それぞれ図 4.1, 4.2, 4.3 に示す．sFCMA では m の値を 1.1 から 3.0 まで 0.1 刻み，eFCMA では λ の値を 1 から 100 まで 1 刻み，qFCMA では m の値を 1.1 から 3.0 まで 0.1 刻み，λ の値を 1 から 100 まで 1 刻みで変化させた．

それぞれの手法の最高 ARI を表 4.1 に示す．最も高い ARI を示した手法は sFCMA であり，他の 2 手法と比較して ARI に 0.4 以上の差が見られた．

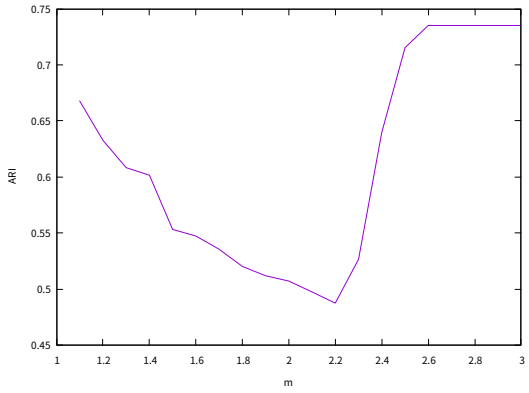


図 4.1: sFCMA の実データの実験結果

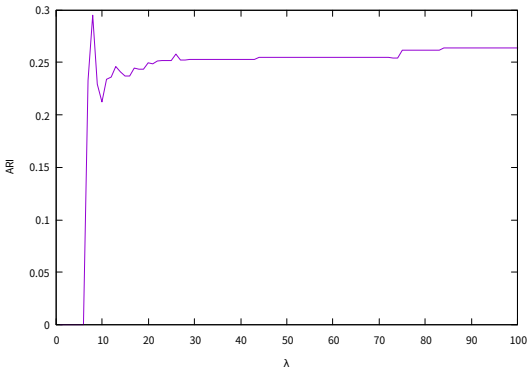


図 4.2: eFCMA の実データの実験結果

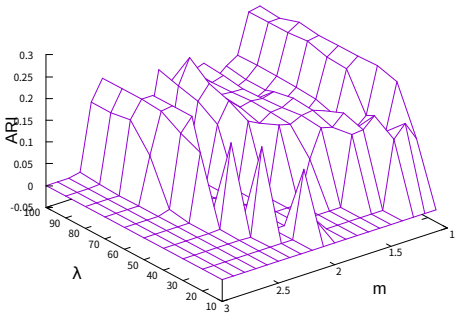


図 4.3: qFCMA の実データの実験結果

表 4.1: 各手法の ARI の最高値とパラメータ

手法名	ARI の最高値	パラメータ値
sFCMA	0.73515	$m = 3$
eFCMA	0.29500	$\lambda = 8$
qFCMA	0.26286	$\lambda = 80$, $m = 1.1$

第 5節　おわりに

本章では，実データを用いた実験について述べた．まず第 2 節で本実験で用いる人工データについて説明した．次に第 3 節でアルゴリズムについて述べた．最後に第 4 節で実験により得られた評価指標を用いて各手法の精度比較を行った．

第 5 章 結論

本文書では，第 2 章では，提案手法について説明した．第 3 章では，人工データ実験により各手法の特性比較を行った．第 4 章では，実データ実験により各手法の精度比較を行った．最後に第 5 章では，本文書の結論を述べた．また，付録では，プログラムソースを掲載した．

本研究では，既に提案されていた 3 種のクラスタリング手法の特性と精度について現在に至るまで明らかになっていなかったため，人工データを用いた特性比較及び実データを用いた精度比較を行った．その結果として，sFCMA は m が大きくなるとファジィになり，eFCMA は λ が大きくなるほどクリスプになることが分かった．また，qFCMA は sFCMA と eFCMA の両方の特性を併せ持つということが分かった．精度は sFCMA が最も高評価となった．要因として，この手法の最適化問題にエントロピー項が含まれないということが考えられる．sFCMA の精度には，エントロピー項が含まれる eFCMA, qFCMA の 2 手法と比較して大きな差が見られた．今後の課題は，今回用いなかった他の実データで 3 手法の比較を行い，精度についての裏付けを行うことである．

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付録 A プログラムソース

vector.h

```
1  #include<iostream>
2  #include<cstring>
3
4  #ifndef __VECTOR__
5  #define __VECTOR__
6
7  class Matrix;
8
9
10 class Vector{
11  private:
12   int Size;
13   double *Element;
14  public:
15   Vector(int size=0);
16   ~Vector(void);
17   explicit Vector(int dim, double arg, const char *s);
18   Vector(const Vector &arg);
19   Vector &operator=(const Vector &arg);
20   Vector(Vector &&arg);
21   Vector &operator=(Vector &&arg);
22   int size(void) const;
23   double operator[](int index) const;
24   double &operator[](int index);
25   Vector operator+(void) const;
26   Vector operator-(void) const;
27   Vector &operator+=(const Vector &rhs);
28   Vector &operator-=(const Vector &rhs);
29   Vector &operator*=(double rhs);
30   Vector &operator/=(double rhs);
31   Vector operator+(const Vector &rhs) const;
32   Vector operator-(const Vector &rhs) const;
```

```
33    double operator*(const Vector &rhs) const;
34    bool operator==(const Vector &rhs) const;
35    bool operator!=(const Vector &rhs) const;
36    Vector sub(int begin, int end) const;
37    void set_sub(int begin, int end, const Vector &arg);
38  };
39
40  Vector operator*(double lhs, const Vector &rhs);
41  Vector operator/(const Vector &lhs, double rhs);
42  std::ostream &operator<<(std::ostream &os, const Vector &rhs);
43  double max_norm(const Vector &arg);
44  double squared_norm(const Vector &arg);
45  double norm_square(const Vector &arg);
46  double L1norm_square(const Vector &arg);
47  Vector fraction(const Vector &arg);
48
49  #endif
```

vector.cxx

```
1   #include<iostream>
2   #include<cstdlib>
3   #include<cmath>
4   #include"vector.h"
5
6
7   Vector::Vector(int size) try :
8     Size(size), Element(new double[Size]){
9   }
10  catch(std::bad_alloc){
11    std::cerr << "Vector::Vector(int size): Out of Memory!" << std::endl;
12    throw;
13   }
14
15  Vector::~Vector(void){
16    delete []Element;
17  }
18
19  Vector::Vector(const Vector &arg) try :
20    Size(arg.Size), Element(new double[Size]){
21    for(int i=0;i<Size;i++){
22      Element[i]=arg.Element[i];
23    }
24  }
25  catch(std::bad_alloc){
26    std::cerr << "Vector::Vector(int size): Out of Memory!" << std::endl;
27    throw;
28   }
```

```
29
30  Vector::Vector(Vector &&arg)
31    : Size(arg.Size), Element(arg.Element){
32    arg.Size=0;
33    arg.Element=nullptr;
34  }
35
36  Vector::Vector(int dim, double arg, const char *s) try :
37    Size(dim), Element(new double[Size]){
38    if(strcmp(s, "all")!=0){
39      std::cerr << "Invalid string parameter" << std::endl;
40      exit(1);
41    }
42    for(int i=0;i<Size;i++){
43      Element[i]=arg;
44    }
45  }
46  catch(std::bad_alloc){
47    std::cerr << "Vector::Vector(int size): Out of Memory!" << std::endl;
48    throw;
49   }
50
51  Vector &Vector::operator=(const Vector &arg){
52    if(this==&arg)        return *this;
53    if(this->Size != arg.Size){
54      Size=arg.Size;
55      delete []Element;
56      try{
57        Element=new double[Size];
58      }
59      catch(std::bad_alloc){
60        std::cerr << "Out of Memory" << std::endl;
61        throw;
62      }
63    }
64    for(int i=0;i<Size;i++){
65      Element[i]=arg.Element[i];
66    }
67    return *this;
68  }
69
70  Vector &Vector::operator=(Vector &&arg){
71    if(this!=&arg){
72      Size=arg.Size;
73      Element=arg.Element;
74      arg.Size=0;
75      arg.Element=nullptr;
76    }
77    return *this;
78  }
```

```
79
80  int Vector::size(void) const{
81    return Size;
82  }
83
84  double Vector::operator[](int index) const{
85    return Element[index];
86  }
87
88  double &Vector::operator[](int index){
89    return Element[index];
90  }
91
92  Vector Vector::operator+(void) const{
93    return *this;
94  }
95
96  Vector Vector::operator-(void) const{
97    Vector result=*this;
98    for(int i=0;i<result.Size;i++){
99      result[i]*=-1.0;
100   }
101   return result;
102 }
103
104 Vector &Vector::operator+=(const Vector &rhs){
105   if(rhs.Size==0){
106     std::cout << "Vector::operator+=:Size 0" << std::endl;
107     exit(1);
108   }
109   else if(Size!=rhs.Size){
110     std::cout << "Vector::operator+=:Size Unmatched" << std::endl;
111     exit(1);
112   }
113   else{
114     for(int i=0;i<Size;i++){
115       Element[i]+=rhs[i];
116     }
117   }
118   return *this;
119 }
120
121 Vector &Vector::operator*=(double rhs){
122   for(int i=0;i<Size;i++){
123     Element[i]*=rhs;
124   }
125   return *this;
126 }
127
128 Vector &Vector::operator/=(double rhs){
```

```
129     for(int i=0;i<Size;i++){
130       Element[i]/=rhs;
131     }
132     return *this;
133   }
134
135
136   Vector &Vector::operator-=(const Vector &rhs){
137     if(rhs.Size==0){
138       std::cout << "Vector::operator-=:Size 0" << std::endl;
139       exit(1);
140     }
141     else if(Size!=rhs.Size){
142       std::cout << "Vector::operator-=:Size Unmatched" << std::endl;
143       exit(1);
144     }
145     else{
146       for(int i=0;i<Size;i++){
147         Element[i]-=rhs[i];
148       }
149     }
150     return *this;
151   }
152
153   Vector Vector::operator+(const Vector &rhs) const{
154     Vector result=*this;
155     return result+=rhs;
156   }
157
158   Vector Vector::operator-(const Vector &rhs) const{
159     Vector result=*this;
160     return result-=rhs;
161   }
162
163   Vector operator*(double lhs, const Vector &rhs){
164     if(rhs.size()==0){
165       std::cout << "Vector operator*:Size 0" << std::endl;
166       exit(1);
167     }
168     Vector result=rhs;
169     for(int i=0;i<result.size();i++){
170       result[i]*=lhs;
171     }
172     return result;
173   }
174
175   Vector operator/(const Vector &lhs, double rhs){
176     if(lhs.size()==0){
177       std::cout << "Vector operator/:Size 0" << std::endl;
178       exit(1);
```

```
179     }
180     Vector result=lhs;
181     return (result/=rhs);
182   }
183
184
185   std::ostream &operator<<(std::ostream &os, const Vector &rhs){
186     os << "(";
187     if(rhs.size()>0){
188       for(int i=0;;i++){
189         os << rhs[i];
190         if(i>=rhs.size()-1) break;
191         os << ", ";
192       }
193     }
194     os << ')';
195     return os;
196   }
197
198   bool Vector::operator==(const Vector &rhs) const{
199     if(Size!=rhs.size())  return false;
200     for(int i=0;i<Size;i++){
201       if(Element[i]!=rhs[i])      return false;
202     }
203     return true;
204   }
205
206   double max_norm(const Vector &arg){
207     if(arg.size()<1){
208       std::cout << "Can't calculate norm for 0-sized vector" << std::endl;
209       exit(1);
210     }
211     double result=fabs(arg[0]);
212     for(int i=1;i<arg.size();i++){
213       double tmp=fabs(arg[i]);
214       if(result<tmp)      result=tmp;
215     }
216     return result;
217   }
218
219   double squared_norm(const Vector &arg){
220     return sqrt(norm_square(arg));
221   }
222
223   double norm_square(const Vector &arg){
224     double result=0.0;
225     for(int i=0;i<arg.size();i++){
226       result+=arg[i]*arg[i];
227     }
228     return result;
```

```
229  }
230
231  double L1norm_square(const Vector &arg){
232    double result=0.0;
233    for(int i=0;i<arg.size();i++){
234      result+=fabs(arg[i]);
235    }
236    return result;
237  }
238
239  double Vector::operator*(const Vector &rhs) const{
240    if(Size<1 || rhs.size()<1 || Size!=rhs.size()){
241      std::cout << "Can't calculate innerproduct";
242      std::cout << "for 0-sized vector";
243      std::cout << "or for different sized vector";
244      std::cout << std::endl;
245      exit(1);
246    }
247    double result=Element[0]*rhs[0];
248    for(int i=1;i<Size;i++){
249      result+=Element[i]*rhs[i];
250    }
251    return result;
252  }
253
254  bool Vector::operator!=(const Vector &rhs) const{
255    if(Size!=rhs.size())  return true;
256    for(int i=0;i<Size;i++){
257      if(Element[i]!=rhs[i])      return true;
258    }
259    return false;
260  }
261
262  Vector Vector::sub(int begin, int end) const{
263    if(end<begin){
264      std::cerr << "Vector::sub:invalid parameter" << std::endl;
265      exit(1);
266    }
267    Vector result(end-begin+1);
268    for(int i=0;i<result.size();i++){
269      result[i]=Element[begin+i];
270    }
271    return result;
272  }
273
274  void Vector::set_sub(int begin, int end, const Vector &arg){
275    if(end<begin){
276      std::cerr << "Vector::sub:invalid parameter" << std::endl;
277      exit(1);
278    }
```

```
279     if(end-begin+1!=arg.size()){
280       std::cerr << "Vector::sub:invalid parameter" << std::endl;
281       exit(1);
282     }
283     for(int i=0;i<arg.size();i++){
284       Element[begin+i]=arg[i];
285     }
286     return;
287   }
288
289   Vector fraction(const Vector &arg){
290     Vector result(arg.size());
291     for(int i=0;i<result.size();i++){
292       result[i]=1.0/arg[i];
293     }
294     return result;
295   }
```

matrix.h

```
1   #include<iostream>
2   #include<cstring>
3   #include"vector.h"
4
5   #ifndef __MATRIX__
6   #define __MATRIX__
7
8   class Matrix{
9    private:
10    int Rows;
11    Vector *Element;
12   public:
13    //Matrix(int rows=0);
14    Matrix(int rows=0, int cols=0);
15    explicit Matrix(int dim, const char *s);
16    explicit Matrix(const Vector &arg, const char *s);
17    ~Matrix(void);
18    Matrix(const Matrix &arg);
19    Matrix &operator=(const Matrix &arg);
20    Matrix(Matrix &&arg);
21    Matrix &operator=(Matrix &&arg);
22    int rows(void) const;
23    int cols(void) const;
24    Vector operator[](int index) const;
25    Vector &operator[](int index);
26    Matrix operator+(void) const;
27    Matrix operator-(void) const;
28    Matrix &operator+=(const Matrix &rhs);
```

```
29    Matrix &operator-=(const Matrix &rhs);
30    Matrix &operator*=(double rhs);
31    Matrix &operator/=(double rhs);
32    Matrix sub(int row_begin,
33                    int row_end,
34                    int col_begin,
35                    int col_end) const;
36    void set_sub(int row_begin,
37                 int row_end,
38                 int col_begin,
39                 int col_end,
40                 const Matrix &arg);
41  };
42
43  Matrix operator+(const Matrix &lhs, const Matrix &rhs);
44  Matrix operator-(const Matrix &lhs, const Matrix &rhs);
45  Matrix operator*(double lhs, const Matrix &rhs);
46  Vector operator*(const Matrix &lhs, const Vector &rhs);
47  Matrix operator*(const Matrix &lhs, const Matrix &rhs);
48  Matrix operator*(const Matrix &lhs, double rhs);
49  Matrix operator/(const Matrix &lhs, double rhs);
50  std::ostream &operator<<(std::ostream &os, const Matrix &rhs);
51  bool operator==(const Matrix &lhs, const Matrix &rhs);
52  double max_norm(const Matrix &arg);
53  double frobenius_norm(const Matrix &arg);
54  Matrix transpose(const Matrix &arg);
55  Vector diag(const Matrix &arg);
56  Matrix pow(const Matrix &arg, double power);
57  Matrix transpose(const Vector &arg);
58  Matrix operator*(const Vector &lhs, const Matrix &rhs);
59
60  #endif
```

matrix.cxx

```
1   #include<iostream>
2   #include<cstdlib>
3   #include<cmath>
4   #include"vector.h"
5   #include"matrix.h"
6
7   Matrix::Matrix(int rows, int cols) try :
8     Rows(rows), Element(new Vector[Rows]){
9     for(int i=0;i<Rows;i++){
10      Element[i]=Vector(cols);
11    }
12  }
13  catch(std::bad_alloc){
```

```
14      std::cerr << "Out of Memory" << std::endl;
15      throw;
16    }
17
18  Matrix::Matrix(int dim, const char *s) try :
19    Rows(dim), Element(new Vector[Rows]){
20    if(strcmp(s, "I")!=0){
21      std::cerr << "Invalid string parameter" << std::endl;
22      exit(1);
23
24    }
25    for(int i=0;i<Rows;i++){
26      Element[i]=Vector(dim);
27    }
28    for(int i=0;i<Rows;i++){
29      for(int j=0;j<Rows;j++){
30        Element[i][j]=0.0;
31      }
32      Element[i][i]=1.0;
33    }
34  }
35  catch(std::bad_alloc){
36      std::cerr << "Out of Memory" << std::endl;
37      throw;
38    }
39
40  Matrix::Matrix(const Vector &arg, const char *s) try :
41    Rows(arg.size()), Element(new Vector[Rows]){
42    if(strcmp(s, "diag")!=0){
43      std::cerr << "Invalid string parameter" << std::endl;
44      exit(1);
45
46    }
47    for(int i=0;i<Rows;i++){
48      Element[i]=Vector(Rows);
49    }
50    for(int i=0;i<Rows;i++){
51      for(int j=0;j<Rows;j++){
52        Element[i][j]=0.0;
53      }
54      Element[i][i]=arg[i];
55    }
56  }
57  catch(std::bad_alloc){
58      std::cerr << "Out of Memory" << std::endl;
59      throw;
60    }
61
62  Matrix::~Matrix(void){
63    delete []Element;
```

```
64  }
65
66  Matrix::Matrix(const Matrix &arg) try :
67    Rows(arg.Rows), Element(new Vector[Rows]){
68    for(int i=0;i<Rows;i++){
69      Element[i]=arg.Element[i];
70    }
71  }
72  catch(std::bad_alloc){
73      std::cerr << "Out of Memory" << std::endl;
74      throw;
75   }
76
77  Matrix::Matrix(Matrix &&arg)
78    : Rows(arg.Rows), Element(arg.Element){
79    arg.Rows=0;
80    arg.Element=nullptr;
81  }
82
83  Matrix &Matrix::operator=(Matrix &&arg){
84    if(this==&arg){
85      return *this;
86    }
87    else{
88      Rows=arg.Rows;
89      Element=arg.Element;
90      arg.Rows=0;
91      arg.Element=nullptr;
92      return *this;
93    }
94  }
95
96  Matrix &Matrix::operator=(const Matrix &arg){
97    if(this==&arg)        return *this;
98    //Rows=arg.Rows; ここでは Rows を更新してはいけない
99    if(this->Rows != arg.Rows || this->cols() != arg.cols()){
100     Rows=arg.Rows;
101     delete []Element;
102     try{
103       Element=new Vector[Rows];
104     }
105     catch(std::bad_alloc){
106       std::cerr << "Out of Memory" << std::endl;
107       throw;
108     }
109   }
110   for(int i=0;i<Rows;i++){
111     Element[i]=arg.Element[i];
112   }
113   return *this;
```

```
114  }
115
116  int Matrix::rows(void) const{
117    return Rows;
118  }
119
120  int Matrix::cols(void) const{
121    return Element[0].size();
122  }
123
124  Vector Matrix::operator[](int index) const{
125    return Element[index];
126  }
127
128  Vector &Matrix::operator[](int index){
129    return Element[index];
130  }
131
132  Matrix Matrix::operator+(void) const{
133    return *this;
134  }
135
136  Matrix Matrix::operator-(void) const{
137    Matrix result=*this;
138    for(int i=0;i<result.Rows;i++){
139      result[i]=-1.0*result[i];
140    }
141    return result;
142  }
143
144  Matrix &Matrix::operator+=(const Matrix &rhs){
145    if(rhs.Rows==0){
146      std::cout << "Rows 0" << std::endl;
147      exit(1);
148    }
149    else if(Rows!=rhs.Rows){
150      std::cout << "Rows Unmatched" << std::endl;
151      exit(1);
152    }
153    else{
154      for(int i=0;i<Rows;i++){
155        Element[i]+=rhs[i];
156      }
157    }
158    return *this;
159  }
160
161  Matrix &Matrix::operator-=(const Matrix &rhs){
162    if(rhs.Rows==0){
163      std::cout << "Rows 0" << std::endl;
```

```
164       exit(1);
165     }
166     else if(Rows!=rhs.Rows){
167       std::cout << "Rows Unmatched" << std::endl;
168       exit(1);
169     }
170     else{
171       for(int i=0;i<Rows;i++){
172         Element[i]-=rhs[i];
173       }
174     }
175     return *this;
176   }
177
178   Matrix operator+(const Matrix &lhs, const Matrix &rhs){
179     Matrix result=lhs;
180     return result+=rhs;
181   }
182
183   Matrix operator-(const Matrix &lhs, const Matrix &rhs){
184     Matrix result=lhs;
185     return result-=rhs;
186   }
187
188   Matrix operator*(double lhs, const Matrix &rhs){
189     if(rhs.rows()==0){
190       std::cout << "Rows 0" << std::endl;
191       exit(1);
192     }
193     Matrix result=rhs;
194     for(int i=0;i<result.rows();i++){
195       result[i]=lhs*result[i];
196     }
197     return result;
198   }
199
200   Matrix &Matrix::operator/=(double rhs){
201     for(int i=0;i<Rows;i++){
202       Element[i]/=rhs;
203     }
204     return *this;
205   }
206
207   Matrix operator/(const Matrix &lhs, double rhs){
208     Matrix result(lhs);
209     return result/=rhs;
210   }
211
212   std::ostream &operator<<(std::ostream &os, const Matrix &rhs){
213     os << "(";
```

```
214     if(rhs.rows()>0){
215       for(int i=0;;i++){
216         os << rhs[i];
217         if(i>=rhs.rows()-1) break;
218         os << "\n";
219       }
220     }
221     os << ')';
222     return os;
223   }
224
225   bool operator==(const Matrix &lhs, const Matrix &rhs){
226     if(lhs.rows()!=rhs.rows())    return false;
227     for(int i=0;i<lhs.rows();i++){
228       if(lhs[i]!=rhs[i])  return false;
229     }
230     return true;
231   }
232
233   double abssum(const Vector &arg){
234     double result=fabs(arg[0]);
235     for(int i=1;i<arg.size();i++){
236       result+=fabs(arg[i]);
237     }
238     return result;
239   }
240
241   double max_norm(const Matrix &arg){
242     if(arg.rows()<1){
243       std::cout << "Can't calculate norm for 0-sized vector" << std::endl;
244       exit(1);
245     }
246     double result=abssum(arg[0]);
247     for(int i=1;i<arg.rows();i++){
248       double tmp=abssum(arg[i]);
249       if(result<tmp)      result=tmp;
250     }
251     return result;
252   }
253
254   double frobenius_norm(const Matrix &arg){
255     double result=0.0;
256     for(int i=0;i<arg.rows();i++){
257       for(int j=0;j<arg.cols();j++){
258         result+=arg[i][j]*arg[i][j];
259       }}
260     return sqrt(result);
261   }
262
263   Vector operator*(const Matrix &lhs, const Vector &rhs){
```

```
264     if(lhs.rows()<1 || lhs.cols()<1 || rhs.size()<1 || lhs.cols()!=rhs.size()){
265       std::cout << "operator*(const Matrix &, const Vector &):";
266       std::cout << "Can't calculate innerproduct ";
267       std::cout << "for 0-sized vector ";
268       std::cout << "or for different sized vector:";
269       std::cout << "lhs.Cols=" << lhs.cols() << ", ";
270       std::cout << "lhs.Rows=" << lhs.rows() << ", ";
271       std::cout << "rhs.Size=" << rhs.size();
272       std::cout << std::endl;
273       exit(1);
274     }
275     Vector result(lhs.rows());
276     for(int i=0;i<lhs.rows();i++){
277       result[i]=lhs[i]*rhs;
278     }
279     return result;
280   }
281
282   Matrix operator*(const Matrix &lhs, const Matrix &rhs){
283     if(lhs.rows()<1 || rhs.cols()<1 || lhs.cols()!=rhs.rows()){
284       std::cout << "Can't calculate innerproduct";
285       std::cout << "for 0-sized vector";
286       std::cout << "or for different sized vector";
287       std::cout << std::endl;
288       exit(1);
289     }
290     Matrix result(lhs.rows(), rhs.cols());
291     for(int i=0;i<result.rows();i++){
292       for(int j=0;j<result.cols();j++){
293         result[i][j]=0.0;
294         for(int k=0;k<lhs.cols();k++){
295           result[i][j]+=lhs[i][k]*rhs[k][j];
296         }
297       }}
298     return result;
299   }
300
301   Matrix Matrix::sub(int row_begin, int row_end,
302                              int col_begin, int col_end) const{
303
304     if(row_end<row_begin || col_end<col_begin){
305       std::cerr << "Matrix::sub:invalid parameter" << std::endl;
306       std::cerr << "row_begin:" << row_begin << std::endl;
307       std::cerr << "row_end:" << row_end << std::endl;
308       std::cerr << "col_begin:" << col_begin << std::endl;
309       std::cerr << "col_end:" << col_end << std::endl;
310       exit(1);
311     }
312     if(row_end>=this->rows() || col_end>=this->cols()){
313       std::cerr << "Matrix::sub:invalid parameter" << std::endl;
```

```
314       std::cerr << "row_end:" << row_end << std::endl;
315       std::cerr << "Rows:" << this->rows() << std::endl;
316       std::cerr << "col_end:" << col_end << std::endl;
317       std::cerr << "Cols:" << this->cols() << std::endl;
318       exit(1);
319     }
320     if(row_begin<0 || col_begin<0){
321       std::cerr << "Matrix::sub:invalid parameter" << std::endl;
322       std::cerr << "row_begin:" << row_begin << std::endl;
323       std::cerr << "col_begin:" << col_begin << std::endl;
324       exit(1);
325     }
326     Matrix result(row_end-row_begin+1, col_end-col_begin+1);
327     for(int i=0;i<result.rows();i++){
328       for(int j=0;j<result.cols();j++){
329         result[i][j]=Element[i+row_begin][j+col_begin];
330       }}
331     return result;
332   }
333
334   void Matrix::set_sub(int row_begin, int row_end,
335                        int col_begin, int col_end,
336                        const Matrix &arg){
337
338     if(row_end<row_begin || col_end<col_begin){
339       std::cerr << "Matrix::sub:invalid parameter" << std::endl;
340       exit(1);
341     }
342     for(int i=row_begin;i<=row_end;i++){
343       for(int j=col_begin;j<=col_end;j++){
344         Element[i][j]=arg[i-row_begin][j-col_begin];
345       }}
346     return;
347   }
348
349   Matrix transpose(const Matrix &arg){
350     Matrix result(arg.cols(), arg.rows());
351     for(int i=0;i<result.rows();i++){
352       for(int j=0;j<result.cols();j++){
353         result[i][j]=arg[j][i];
354       }}
355     return result;
356   }
357
358   Vector diag(const Matrix &arg){
359     if(arg.rows()!=arg.cols()){
360       std::cerr << "No Diag" << std::endl;
361       exit(1);
362     }
363     Vector result(arg.rows());
```

```
364     for(int i=0;i<result.size();i++){
365       result[i]=arg[i][i];
366     }
367     return result;
368   }
369
370   Matrix pow(const Matrix &arg, double power){
371     Matrix result(arg);
372     for(int i=0;i<result.rows();i++){
373       for(int j=0;j<result.cols();j++){
374         result[i][j]=pow(result[i][j],power);
375       }}
376     return result;
377   }
378
379   Matrix transpose(const Vector &arg){
380     Matrix result(1, arg.size());
381     for(int j=0;j<result.cols();j++){
382       result[0][j]=arg[j];
383     }
384     return result;
385   }
386
387   Matrix operator*(const Vector &lhs, const Matrix &rhs){
388     if(rhs.rows()!=1){
389       std::cerr << "Size unmatched for Vector*Matrix:" << rhs.rows() << ":" << rhs.cols
390       exit(1);
391     }
392     Matrix result(lhs.size(), rhs.cols());
393     for(int i=0;i<result.rows();i++){
394       for(int j=0;j<result.cols();j++){
395         result[i][j]=lhs[i]*rhs[0][j];
396       }}
397     return result;
398   }
```

randGaussianMain.cxx

```
1   #include<random>
2   #include<iostream>
3
4   int main(void){
5     std::random_device rnd;
6     std::mt19937 mt(rnd());
7     std::normal_distribution<> normDist(0.0, 1.0);
8
9     const int dimension=2, eachDataNum=50, clusterNum=2;
10    const double means[clusterNum][dimension]={
```

```
11      {-1,-1},{1,1}};
12    const double stddevs[clusterNum][dimension]={
13      {0.5,0.5},{0.5,0.5}};
14
15    std::cout << eachDataNum*clusterNum << "\t" << dimension << std::endl;
16
17    for(int i=0;i<clusterNum;i++){
18      for(int k=0;k<eachDataNum;k++){
19        for(int ell=0;ell<dimension;ell++){
20          std::cout << normDist(mt)*stddevs[i][ell]+means[i][ell] << "\t";
21        }
22        std::cout << std::endl;
23      }
24    }
25    return 0;
26  }
```

hcm.cxx

```
1   #include"hcm.h"
2   #include <boost/math/special_functions/binomial.hpp>
3
4   Hcm::Hcm(int dimension,
5            int data_number,
6            int centers_number):
7     Data(data_number, dimension),
8     Centers(centers_number, dimension),
9     Tmp_Centers(centers_number, dimension),
10    Membership(centers_number, data_number),
11    Tmp_Membership(centers_number, data_number),
12    Alpha(centers_number),
13    Tmp_Alpha(centers_number),
14    Dissimilarities(centers_number, data_number),
15    CrispMembership(centers_number, data_number),
16    CorrectCrispMembership(centers_number, data_number),
17    ContingencyTable(centers_number+1, centers_number+1),
18    Iterates(0){
19    /***↓収束判定のために DBL_MAX に設定***/
20    for(int i=0;i<centers_number;i++){
21      Centers[i]=Vector(dimension);
22      for(int ell=0;ell<dimension;ell++){
23        Centers[i][ell]=DBL_MAX;
24      }
25    }
26    /***↓収束判定のために DBL_MAX に設定***/
27    for(int i=0;i<centers_number;i++){
28      for(int k=0;k<data_number;k++){
29        Membership[i][k]=DBL_MAX;
```

```
30      }
31    }
32  }
33
34  void Hcm::revise_dissimilarities(void){
35    for(int i=0;i<centers_number();i++){
36      for(int k=0;k<data_number();k++){
37        Dissimilarities[i][k]=norm_square(Data[k]-Centers[i]);
38      }}
39    return;
40  }
41
42  void Hcm::revise_membership(void){
43    Tmp_Membership=Membership;
44    for(int k=0;k<data_number();k++){
45      int min_index=0; double min_dissimilarity=Dissimilarities[0][k];
46      for(int i=1;i<centers_number();i++){
47        if(min_dissimilarity>Dissimilarities[i][k]){
48          min_index=i;
49          min_dissimilarity=Dissimilarities[i][k];
50        }
51      }
52      for(int i=0;i<centers_number();i++){
53        Membership[i][k]=0.0;
54      }
55      Membership[min_index][k]=1.0;
56    }
57    return;
58  }
59
60  void Hcm::revise_centers(void){
61    Tmp_Centers=Centers;
62    for(int i=0;i<centers_number();i++){
63      double denominator=0.0;
64      Vector numerator(Centers[i].size());
65      for(int ell=0;ell<numerator.size();ell++){
66        numerator[ell]=0.0;
67      }
68      for(int k=0;k<data_number();k++){
69        denominator+=Membership[i][k];
70        numerator+=Membership[i][k]*Data[k];
71      }
72      Centers[i]=numerator/denominator;
73    }
74    return;
75  }
76
77  int Hcm::dimension(void) const{
78    return Data[0].size();
79  }
```

```
80
81  int Hcm::data_number(void) const{
82    return Data.rows();
83  }
84
85  int Hcm::centers_number(void) const{
86    return Centers.rows();
87  }
88
89  Matrix Hcm::centers(void) const{
90    return Centers;
91  }
92
93  Matrix Hcm::tmp_centers(void) const{
94    return Tmp_Centers;
95  }
96
97  Matrix Hcm::data(void) const{
98    return Data;
99  }
100
101 Matrix Hcm::membership(void) const{
102   return Membership;
103 }
104
105 Matrix Hcm::tmp_membership(void) const{
106   return Tmp_Membership;
107 }
108
109 int &Hcm::iterates(void){
110   return Iterates;
111 }
112
113 Matrix Hcm::dissimilarities(void) const{
114   return Dissimilarities;
115 }
116
117 double &Hcm::data(int index1, int index2){
118   return Data[index1][index2];
119 }
120
121 double &Hcm::centers(int index1, int index2){
122   return Centers[index1][index2];
123 }
124
125 double &Hcm::membership(int row, int col){
126   return Membership[row][col];
127 }
128
129 double Hcm::objective(void) const{
```

```
130   return Objective;
131 }
132
133 void Hcm::set_objective(void){
134   Objective=0.0;
135   for(int i=0;i<centers_number();i++){
136     for(int k=0;k<data_number();k++){
137       Objective+=Membership[i][k]*Dissimilarities[i][k];
138     }}
139   return;
140 }
141
142 double &Hcm::dissimilarities(int index1, int index2){
143   return Dissimilarities[index1][index2];
144 }
145
146 void Hcm::set_crispMembership(void){
147   for(int k=0;k<data_number();k++){
148     for(int i=0;i<centers_number();i++){
149       CrispMembership[i][k]=0.0;
150     }
151     double max=-DBL_MAX;
152     int max_index=-1;
153     for(int i=0;i<centers_number();i++){
154       if(Membership[i][k]>max){
155         max=Membership[i][k];
156         max_index=i;
157       }
158     }
159     CrispMembership[max_index][k]=1.0;
160   }
161   return;
162 }
163
164 Matrix Hcm::crispMembership(void) const{
165   return CrispMembership;
166 }
167
168 double &Hcm::crispMembership(int index1, int index2){
169   return CrispMembership[index1][index2];
170 }
171
172 Matrix Hcm::correctCrispMembership(void) const{
173   return CorrectCrispMembership;
174 }
175
176 double &Hcm::correctCrispMembership(int index1, int index2){
177   return CorrectCrispMembership[index1][index2];
178 }
179
```

```
180  void Hcm::set_contingencyTable(void){
181    ContingencyTable.set_sub(0,centers_number()-1, 0, centers_number()-1,CrispMembershi
182
183    for(int i=0;i<ContingencyTable.rows()-1;i++){
184      ContingencyTable[i][ContingencyTable.cols()-1]=0.0;
185      for(int j=0;j<ContingencyTable.cols()-1;j++){
186        ContingencyTable[i][ContingencyTable.cols()-1]+=ContingencyTable[i][j];
187      }
188    }
189    for(int j=0;j<ContingencyTable.cols()-1;j++){
190      ContingencyTable[ContingencyTable.rows()-1][j]=0.0;
191      for(int i=0;i<ContingencyTable.rows()-1;i++){
192        ContingencyTable[ContingencyTable.rows()-1][j]+=ContingencyTable[i][j];
193      }
194    }
195    ContingencyTable[ContingencyTable.rows()-1][ContingencyTable.cols()-1]=data_number(
196    return;
197  }
198
199  Matrix Hcm::contingencyTable(void) const{
200    return ContingencyTable;
201  }
202
203  double combination(int n, int k){
204    if(n<k) return 0.0;
205   return boost::math::binomial_coefficient<double>(n, k);
206  }
207
208  double Hcm::ARI(void) const{
209    double Index=0.0;
210    for(int i=0;i<ContingencyTable.rows()-1;i++){
211      for(int j=0;j<ContingencyTable.cols()-1;j++){
212        Index+=ContingencyTable[i][j]*ContingencyTable[i][j];
213      }
214    }
215    Index=0.5*(Index-ContingencyTable[ContingencyTable.rows()-1][ContingencyTable.cols(
216    //  std::cout << "Index:" << Index << std::endl;
217    double ExpectedIndexI=0.0;
218    for(int i=0;i<ContingencyTable.rows()-1;i++){
219      ExpectedIndexI+=combination(ContingencyTable[i][ContingencyTable.cols()-1], 2);
220    }
221    //  std::cout << "ExpectedIndexI:" << ExpectedIndexI << std::endl;
222    double ExpectedIndexJ=0.0;
223    for(int j=0;j<ContingencyTable.cols()-1;j++){
224      ExpectedIndexJ+=combination(ContingencyTable[ContingencyTable.rows()-1][j], 2);
225    }
226    //  std::cout << "ExpectedIndexJ:" << ExpectedIndexJ << std::endl;
227    double ExpectedIndex=ExpectedIndexI*ExpectedIndexJ/combination(ContingencyTable[Con
228    //  std::cout << "Denom:" << combination(ContingencyTable[ContingencyTable.rows()-1
229    double MaxIndex=0.5*(ExpectedIndexI+ExpectedIndexJ);
```

```
230
231     return (Index-ExpectedIndex)/(MaxIndex-ExpectedIndex);
232   }
233
234   Vector &Hcm::data(int index1){
235     return Data[index1];
236   }
237
238   Vector &Hcm::centers(int index1){
239     return Centers[index1];
240   }
241
242   Vector Hcm::alpha(void) const{
243     return Alpha;
244   }
245
246   double &Hcm::alpha(int index1){
247     return Alpha[index1];
248   }
249
250   Vector Hcm::tmp_alpha(void) const{
251     return Tmp_Alpha;
252   }
```

hcm.h

```
 1   #include<cmath>
 2   #include<cfloat>
 3   #include"matrix.h"
 4
 5   #ifndef __HCM__
 6   #define __HCM__
 7
 8   class Hcm{
 9    protected:
10     Matrix Data, Centers, Tmp_Centers;
11     Matrix Membership, Tmp_Membership, Dissimilarities;
12     Matrix CrispMembership, CorrectCrispMembership, ContingencyTable;
13     Vector Alpha,Tmp_Alpha;
14     int Iterates;
15     double Objective;
16    public:
17     Hcm(int dimension,
18         int data_number,
19         int centers_number);
20     virtual void revise_membership(void);
21     virtual void revise_dissimilarities(void);
22     virtual void revise_centers(void);
```

```
23    int dimension(void) const;
24    int data_number(void) const;
25    int centers_number(void) const;
26    Matrix centers(void) const;
27    Matrix tmp_centers(void) const;
28    Matrix data(void) const;
29    Matrix membership(void) const;
30    Matrix tmp_membership(void) const;
31    Vector alpha(void) const;
32    double &alpha(int index);
33    Vector tmp_alpha(void) const;
34    int &iterates(void);
35    Matrix dissimilarities(void) const;
36    double &data(int index1, int index2);
37    Vector &data(int index1);
38    double &centers(int index1, int index2);
39    Vector &centers(int index1);
40    double &membership(int index1, int index2);
41    double &dissimilarities(int index1, int index2);
42    void set_objective(void);
43    double objective(void) const;
44    void set_crispMembership(void);
45    Matrix crispMembership(void) const;
46    double &crispMembership(int index1, int index2);
47    Matrix correctCrispMembership(void) const;
48    double &correctCrispMembership(int index1, int index2);
49    void set_contingencyTable(void);
50    Matrix contingencyTable(void) const;
51    double ARI(void) const;
52  };
53
54  #endif
```

sfcm.h

```
1   #include<cmath>
2   #include<cfloat>
3   #include"matrix.h"
4   #include"hcm.h"
5
6   #ifndef __SFCM__
7   #define __SFCM__
8
9   class Sfcm: virtual public Hcm{
10  protected:
11    double FuzzifierEm;
12  public:
13    Sfcm(int dimension,
```

```
14          int data_number,
15          int centers_number,
16          double fuzzifierEm);
17    double fuzzifierEm(void)const;
18    double &fuzzifierEm(void);
19    virtual void revise_membership(void);
20    virtual void revise_centers(void);
21  };
22
23  #endif
24
```

sfcm.cxx

```
1   #include"sfcm.h"
2
3   Sfcm::Sfcm(int dimension,
4              int data_number,
5              int centers_number,
6              double fuzzifierEm)
7     : Hcm(dimension, data_number, centers_number), FuzzifierEm(fuzzifierEm){
8   }
9
10  double Sfcm::fuzzifierEm(void)const{
11    return FuzzifierEm;
12  }
13
14  double &Sfcm::fuzzifierEm(void){
15    return FuzzifierEm;
16  }
17
18  void Sfcm::revise_membership(void){
19    Tmp_Membership=Membership;
20    for(int k=0;k<data_number();k++){
21      int numZeroDissimilarities=0;
22      Vector indexZeroDissimilarities(centers_number(), 0.0, "all");
23      for(int i=0;i<centers_number();i++){
24        if(Dissimilarities[i][k]==0.0){
25          numZeroDissimilarities++;
26          indexZeroDissimilarities[i]=1.0;
27        }
28      }
29      if(numZeroDissimilarities!=0){
30        for(int i=0;i<centers_number();i++){
31          Membership[i][k]=indexZeroDissimilarities[i]/numZeroDissimilarities;
32        }
33      }
34      else{
```

```
35        for(int i=0;i<centers_number();i++){
36          double denominator=0.0;
37          for(int j=0;j<centers_number();j++){
38            denominator+=pow(Dissimilarities[i][k]/Dissimilarities[j][k], 1.0/(Fuzzifie
39          }
40          Membership[i][k]=1.0/denominator;
41        }
42      }//else
43    }//k
44      return;
45  }
46
47  void Sfcm::revise_centers(void){
48    Tmp_Centers=Centers;
49    for(int i=0;i<centers_number();i++){
50      double denominator=0.0;
51      Vector numerator(dimension(), 0.0, "all");
52      for(int k=0;k<data_number();k++){
53        denominator+=pow(Membership[i][k], FuzzifierEm);
54        numerator+=pow(Membership[i][k], FuzzifierEm)*Data[k];
55      }
56      Centers[i]=numerator/denominator;
57    }
58    return;
59  }
```

efcm.h

```
1   #include<cmath>
2   #include<cfloat>
3   #include"matrix.h"
4   #include"hcm.h"
5
6   #ifndef __EFCM__
7   #define __EFCM__
8
9   class Efcm: virtual public Hcm{
10  protected:
11    double FuzzifierLambda;
12  public:
13    Efcm(int dimension,
14         int data_number,
15         int centers_number,
16         double fuzzifierLambda);
17    double fuzzifierLambda(void)const;
18    double &fuzzifierLambda(void);
19    virtual void revise_membership(void);
20    virtual void revise_centers(void);
```

```
21  };
22
23  #endif
24
```

efcm.cxx

```
1   #include"efcm.h"
2
3   Efcm::Efcm(int dimension,
4              int data_number,
5              int centers_number,
6              double fuzzifierLambda)
7     : Hcm(dimension, data_number, centers_number), FuzzifierLambda(fuzzifierLambda){
8   }
9
10
11  double Efcm::fuzzifierLambda(void)const{
12    return FuzzifierLambda;
13  }
14
15  double &Efcm::fuzzifierLambda(void){
16    return FuzzifierLambda;
17  }
18
19  void Efcm::revise_membership(void){
20    Tmp_Membership=Membership;
21    for(int k=0;k<data_number();k++){
22      int numZeroDissimilarities=0;
23      Vector indexZeroDissimilarities(centers_number(), 0.0, "all");
24      for(int i=0;i<centers_number();i++){
25        if(Dissimilarities[i][k]==0.0){
26          numZeroDissimilarities++;
27          indexZeroDissimilarities[i]=1.0;
28        }
29      }
30      if(numZeroDissimilarities!=0){
31        for(int i=0;i<centers_number();i++){
32          Membership[i][k]=indexZeroDissimilarities[i]/numZeroDissimilarities;
33        }
34      }
35      else{
36        for(int i=0;i<centers_number();i++){
37          double denominator=0.0;
38          for(int j=0;j<centers_number();j++){
39            denominator+=exp(-1.0*FuzzifierLambda*Dissimilarities[j][k])/exp(-1.0*Fuzzi
40          }
41          Membership[i][k]=1.0/denominator;
```

```
42        }
43      }//else
44    }//k
45      return;
46  }
47
48  void Efcm::revise_centers(void){
49    Tmp_Centers=Centers;
50    for(int i=0;i<centers_number();i++){
51      double denominator=0.0;
52      Vector numerator(dimension(), 0.0, "all");
53      for(int k=0;k<data_number();k++){
54        denominator+=Membership[i][k];
55        numerator+=Membership[i][k]*Data[k];
56      }
57      Centers[i]=numerator/denominator;
58    }
59    return;
60  }
```

qfcm.h

```
1   #include<cmath>
2   #include<cfloat>
3   #include"matrix.h"
4   #include"hcm.h"
5   #include"sfcm.h"
6   #include"efcm.h"
7
8   #ifndef __QFCM__
9   #define __QFCM__
10
11  class Qfcm: public Sfcm, public Efcm{
12  public:
13    Qfcm(int dimension,
14         int data_number,
15         int centers_number,
16         double fuzzifierEm,
17         double fuzzifierLambda);
18    void revise_membership(void);
19    void revise_centers(void);
20  };
21
22  #endif
23
```

qfcm.cxx

```
#include"qfcm.h"

Qfcm::Qfcm(int dimension,
           int data_number,
           int centers_number,
           double fuzzifierEm,
           double fuzzifierLambda):
  Hcm(dimension, data_number, centers_number),
  Sfcm(dimension, data_number, centers_number,fuzzifierEm),
  Efcm(dimension, data_number, centers_number,fuzzifierLambda){
}

void Qfcm::revise_membership(void){
  Tmp_Membership=Membership;
  for(int k=0;k<data_number();k++){
    int numZeroDissimilarities=0;
    Vector indexZeroDissimilarities(centers_number(), 0.0, "all");
    for(int i=0;i<centers_number();i++){
      if(Dissimilarities[i][k]==0.0){
        numZeroDissimilarities++;
        indexZeroDissimilarities[i]=1.0;
      }
    }
    if(numZeroDissimilarities!=0){
      for(int i=0;i<centers_number();i++){
        Membership[i][k]=indexZeroDissimilarities[i]/numZeroDissimilarities;
      }
    }
    else{
      for(int i=0;i<centers_number();i++){
        double denominator=0.0;
        for(int j=0;j<centers_number();j++){
          //帰属度
          denominator+=(FuzzifierLambda*(FuzzifierEm-1.0)*Dissimilarities[i][k]+1)/(F
      }
      Membership[i][k]=1.0/pow(denominator,1/(1.0-FuzzifierEm));
      }
    }//else
  }//k
    return;
}

void Qfcm::revise_centers(void){
  Sfcm::revise_centers();
  return;
}
```

sfcma.h

```
#include"hcm.h"
#include"sfcm.h"

#ifndef __SFCMA__
#define __SFCMA__

class Sfcma: virtual public Hcm, public Sfcm{
 public:
  Sfcma(const int &dimension,
        const int &data_number,
        const int &centers_number,
        const double &fuzzifierEm);
  virtual void revise_membership(void);
  virtual void revise_centers(void);
  virtual void revise_alpha(void);
};
#endif
```

sfcma.cxx

```
#include"sfcma.h"

Sfcma::Sfcma(const int &dimension,
             const int &data_number,
             const int &centers_number,
             const double &fuzzifierEm) :
  Hcm(dimension, data_number, centers_number),
  Sfcm(dimension, data_number, centers_number,fuzzifierEm){
}

void Sfcma::revise_membership(void){
  Tmp_Membership=Membership;
  for(int k=0;k<data_number();k++){
    int numZeroDissimilarities=0;
    Vector indexZeroDissimilarities(centers_number(), 0.0, "all");
    for(int i=0;i<centers_number();i++){
      if(Dissimilarities[i][k]==0.0){
        numZeroDissimilarities++;
        indexZeroDissimilarities[i]=1.0;
      }
    }
    if(numZeroDissimilarities!=0){
      for(int i=0;i<centers_number();i++){
        Membership[i][k]=indexZeroDissimilarities[i]/numZeroDissimilarities;
```

```
25        }
26      }
27      else{
28        for(int i=0;i<centers_number();i++){
29          double denominator=0.0;
30          for(int j=0;j<centers_number();j++){
31            denominator+=Alpha[j]/Alpha[i]
32              *pow(Dissimilarities[i][k]/Dissimilarities[j][k],
33              1.0/(FuzzifierEm-1.0));
34          }
35          Membership[i][k]=1.0/denominator;
36        }
37      }
38    }
39    return;
40  }
41
42  void Sfcma::revise_centers(void){
43    Sfcm::revise_centers();
44    return;
45  }
46
47  void Sfcma::revise_alpha(void){
48    Tmp_Alpha=Alpha;
49    double denominator=0.0;
50    for(int j=0;j<centers_number();j++){
51      double tmp1=0.0;
52      for(int k=0;k<data_number();k++){
53        tmp1+=pow(Membership[j][k],FuzzifierEm)*Dissimilarities[j][k];
54      }
55      denominator+=pow(tmp1,1.0/FuzzifierEm);
56    }
57    for(int i=0;i<centers_number();i++){
58      double tmp2=0.0;
59      for(int k=0;k<data_number();k++){
60        tmp2+=pow(Membership[i][k],FuzzifierEm)*Dissimilarities[i][k];
61      }
62      Alpha[i]=pow(tmp2,1.0/FuzzifierEm)/denominator;
63    }
64    return;
65  }
```

efcma.h

```
1
2   #include"efcm.h"
3
4   #ifndef __EFCMA__
```

```
5   #define __EFCMA__
6
7   class Efcma: public Efcm {
8   public:
9     Efcma(
10         int dimension,
11         int data_number,
12         int centers_number,
13         double fuzzifierLambda);
14    void revise_membership(void);
15    void revise_alpha(void);
16  };
17
18  #endif
19
```

efcma.cxx

```
1
2   #include"efcma.h"
3
4   Efcma::Efcma(int dimension,
5              int data_number,
6              int centers_number,
7              double fuzzifierLambda)
8     : Hcm(dimension, data_number, centers_number),
9       Efcm(dimension, data_number, centers_number, fuzzifierLambda){
10  }
11
12  void Efcma::revise_membership(void){
13    Tmp_Membership=Membership;
14    for(int k=0;k<data_number();k++){
15      for(int i=0;i<centers_number();i++){
16        double denominator=0.0;
17        for(int j=0;j<centers_number();j++){
18          denominator+=(Alpha[j]/Alpha[i])*exp(FuzzifierLambda*(Dissimilarities[i][k]-D
19        }
20        Membership[i][k]=1.0/denominator;
21      }
22    }
23    return;
24  }
25
26  void Efcma::revise_alpha(void){
27    Tmp_Alpha=Alpha;
28    for(int i=0;i<centers_number();i++){
29      double numerator=0;
30      for(int k=0;k<data_number();k++){
```

```
31        numerator+=Membership[i][k];
32      }
33      Alpha[i]=numerator/data_number();
34    }
35    return;
36  }
```

qfcma.h

```
1   #include"efcma.h"
2   #include"sfcma.h"
3
4   #ifndef __QFCMA__
5   #define __QFCMA__
6
7   class Qfcma: public Efcma, public Sfcma{
8
9   public:
10    Qfcma(int dimension,
11          int data_number,
12          int centers_number,
13          double fuzzifierEm,
14          double fuzzifierLambda);
15    virtual void revise_membership(void);
16    virtual void revise_centers(void);
17    virtual void revise_alpha(void);
18  };
19
20  #endif
21
```

qfcma.cxx

```
1   #include"qfcma.h"
2
3   Qfcma::Qfcma(int dimension,
4                int data_number,
5                int centers_number,
6                double fuzzifierEm,
7                double fuzzifierLambda) :
8     Hcm(dimension, data_number, centers_number),
9     Sfcma(dimension, data_number, centers_number,fuzzifierEm),
10    Efcma(dimension, data_number, centers_number,fuzzifierLambda){
11  }
12
```

```
13  void Qfcma::revise_membership(void){
14    Tmp_Membership=Membership;
15    for(int k=0;k<data_number();k++){
16      int numZeroDissimilarities=0;
17      Vector indexZeroDissimilarities(centers_number(), 0.0, "all");
18      for(int i=0;i<centers_number();i++){
19        if(Dissimilarities[i][k]==0.0){
20          numZeroDissimilarities++;
21          indexZeroDissimilarities[i]=1.0;
22        }
23      }
24      if(numZeroDissimilarities!=0){
25        for(int i=0;i<centers_number();i++){
26          Membership[i][k]=indexZeroDissimilarities[i]/numZeroDissimilarities;
27        }
28      }
29      else{
30        for(int i=0;i<centers_number();i++){
31          double denominator=0.0;
32          for(int j=0;j<centers_number();j++){
33            denominator+=Alpha[j]/Alpha[i]
34              *pow((1.0-FuzzifierLambda*(1.0-FuzzifierEm)
35                    *Dissimilarities[j][k])
36                  /(1.0-FuzzifierLambda*(1.0-FuzzifierEm)
37                    *Dissimilarities[i][k])
38                   ,1.0/(1.0-FuzzifierEm));
39          }
40          Membership[i][k]=1.0/denominator;
41        }
42      }//else
43    }//k
44    return;
45  }
46
47  void Qfcma::revise_centers(void){
48    Sfcma::revise_centers();
49    return;
50  }
51
52  void Qfcma::revise_alpha(void){
53    Tmp_Alpha=Alpha;
54    double denominator=0.0;
55    for(int j=0;j<centers_number();j++){
56      double tmp1=0.0;
57      for(int k=0;k<data_number();k++){
58        tmp1+=pow(Membership[j][k],FuzzifierEm)
59          *(1.0-FuzzifierLambda*(1.0-FuzzifierEm)*Dissimilarities[j][k]);
60      }
61      denominator+=pow(tmp1,1.0/FuzzifierEm);
62    }
```

```
63    for(int i=0;i<centers_number();i++){
64      double tmp2=0.0;
65      for(int k=0;k<data_number();k++){
66        tmp2+=pow(Membership[i][k],FuzzifierEm)
67          *(1.0-FuzzifierLambda*(1.0-FuzzifierEm))*Dissimilarities[i][k];
68      }
69      Alpha[i]=pow(tmp2,1/FuzzifierEm)/denominator;
70    }
71    return;
72  }
```

sfcm_main_2d-Gaussian-2clusters.cxx

```
1   #include<iostream>
2   #include<fstream>
3   #include<cstdlib>
4   #include<random>
5   #include"sfcm.h"
6
7   #define MAX_ITERATES 100000
8   #define DIFF_FOR_STOP 1.0E-10
9
10  const int centers_number=2;
11
12  int main(void){
13    std::string filenameData("2d-Gaussian-2clusters.dat");
14  #ifdef CHECK_ANSWER
15    std::string filenameCorrectCrispMembership("2d-Gaussian-2clusters.correctCrispMembe
16  #endif
17
18    std::string::size_type filenameDataDotPosition=filenameData.find_last_of(".");
19    if(filenameDataDotPosition==std::string::npos){
20      std::cerr << "File:" << filenameData
21                << " needs \".\" and filename-extention." << std::endl;
22      exit(1);
23    }
24
25    std::ifstream ifs(filenameData);
26    if(!ifs){
27      std::cerr << "File:" << filenameData
28                << " could not open." << std::endl;
29      exit(1);
30    }
31    int data_number, data_dimension;
32    ifs >> data_number;
33    ifs >> data_dimension;
34
35    Sfcm test(data_dimension, data_number, centers_number, 2.0);
```

```
36
37    for(int cnt=0;cnt<data_number;cnt++){
38      for(int ell=0;ell<data_dimension;ell++){
39        ifs >> test.data(cnt, ell);
40      }
41    }
42
43    /***Initial Centers Setting***/
44    std::random_device rnd;
45    std::mt19937 mt(rnd());
46    std::uniform_int_distribution<> randDataNumber(0,test.data_number()-1);
47    for(int i=0;i<test.centers_number();i++){
48      test.centers(i)=test.data()[randDataNumber(mt)];
49    }
50  #ifdef VERBOSE
51    std::cout << "v:\n" << test.centers() << std::endl;
52  #endif
53
54    test.iterates()=0;
55    while(1){
56      test.revise_dissimilarities();
57  #ifdef VERBOSE
58      std::cout << "d:\n" << test.dissimilarities() << std::endl;
59  #endif
60      test.revise_membership();
61  #ifdef VERBOSE
62      std::cout << "u:\n" << test.membership() << std::endl;
63  #endif
64      test.revise_centers();
65  #ifdef VERBOSE
66      std::cout << "v:\n" << test.centers() << std::endl;
67  #endif
68
69      double diff_u=max_norm(test.tmp_membership()-test.membership());
70      double diff_v=max_norm(test.tmp_centers()-test.centers());
71      double diff=diff_u+diff_v;
72  #ifdef DIFF
73      std::cout << "#diff:" << diff << "\t";
74      std::cout << "#diff_u:" << diff_u << "\t";
75      std::cout << "#diff_v:" << diff_v << "\n";
76  #endif
77      if(diff<DIFF_FOR_STOP)break;
78      if(test.iterates()>=MAX_ITERATES)break;
79      test.iterates()++;
80    }
81  #ifdef VERBOSE
82    std::cout << "v:\n" << test.centers() << std::endl;
83  #endif
84
85  #ifdef CHECK_ANSWER
```

```
86    test.set_crispMembership();
87
88    std::ifstream ifs_correctCrispMembership(filenameCorrectCrispMembership);
89    if(!ifs_correctCrispMembership){
90      std::cerr << "File:" << filenameCorrectCrispMembership
91                << " could not open." << std::endl;
92      exit(1);
93    }
94    for(int i=0;i<test.centers_number();i++){
95      for(int k=0;k<test.data_number();k++){
96        ifs_correctCrispMembership >> test.correctCrispMembership(i, k);
97      }
98    }
99    test.set_contingencyTable();
100   std::cout << "Contingency Table:\n" << test.contingencyTable() << std::endl;
101   std::cout << "ARI:" << test.ARI() << std::endl;
102 #endif
103
104   std::string filenameResultMembership
105     =std::string("sFCM-Em")+std::to_string(test.fuzzifierEm())+std::string("-")
106     +filenameData.substr(0, filenameDataDotPosition)
107     +std::string(".result_membership");
108   std::ofstream ofs_membership(filenameResultMembership);
109   if(!ofs_membership){
110     std::cerr << "File:" << filenameResultMembership
111               << "could not open." << std::endl;
112     exit(1);
113   }
114
115   for(int k=0;k<test.data_number();k++){
116     for(int ell=0;ell<test.dimension();ell++){
117       ofs_membership << test.data()[k][ell] << "\t";
118     }
119     for(int i=0;i<test.centers_number();i++){
120       ofs_membership << test.membership()[i][k] << "\t";
121     }
122     ofs_membership << std::endl;
123   }
124   ofs_membership.close();
125
126   std::string filenameResultCenters
127     =std::string("sFCM-Em")+std::to_string(test.fuzzifierEm())+std::string("-")
128     +filenameData.substr(0, filenameDataDotPosition)
129     +std::string(".result_centers");
130   std::ofstream ofs_centers(filenameResultCenters);
131   if(!ofs_centers){
132     std::cerr << "File:" << filenameResultCenters
133               << "could not open." << std::endl;
134     exit(1);
135   }
```

```
136     for(int i=0;i<test.centers_number();i++){
137       for(int ell=0;ell<test.dimension();ell++){
138         ofs_centers << test.centers()[i][ell] << "\t";
139       }
140       ofs_centers << std::endl;
141     }
142     ofs_centers.close();
143
144   #ifdef CLASSIFICATION_FUNCTION
145     //Classification Function
146     if(test.dimension()>2){
147       std::cerr << "Dimension:" << test.dimension()
148                 << "is too high for classification function visualization."
149                 << std::endl;
150       exit(1);
151     }
152     Sfcm ClassFunction(test.dimension(), 1, test.centers_number(), test.fuzzifierEm());
153     std::string filenameClassificationFunction
154       =std::string("sFCM-Em")+std::to_string(test.fuzzifierEm())+std::string("-")
155       +filenameData.substr(0, filenameDataDotPosition)
156       +std::string(".result_classificationFunction");
157     std::ofstream ofs_classificationFunction(filenameClassificationFunction);
158     if(!ofs_classificationFunction){
159       std::cerr << "File:" << filenameClassificationFunction
160                 << "could not open." << std::endl;
161       exit(1);
162     }
163     for(int i=0;i<test.centers_number();i++){
164       ClassFunction.centers(i)=test.centers(i);
165     }
166     Vector Min(test.dimension(), DBL_MAX, "all");
167     Vector Max(test.dimension(), -DBL_MAX, "all");
168     for(int k=0;k<test.data_number();k++){
169       for(int ell=0;ell<test.dimension();ell++){
170         if(Min[ell]>test.data(k, ell)){
171           Min[ell]=test.data(k, ell);
172         }
173         if(Max[ell]<test.data(k, ell)){
174           Max[ell]=test.data(k, ell);
175         }
176       }
177     }
178     Vector Mid=0.5*(Max+Min);
179     Vector Width=Max-Min;
180     Min=Mid-Width;
181     Max=Mid+Width;
182
183     for(double x0=Min[0];x0<=Max[0];x0+=Width[0]/10.0){
184       for(double x1=Min[1];x1<=Max[1];x1+=Width[1]/10.0){
185   #ifdef VERBOSE
```

```
186         std::cout << "x0:" << x0 << "\t" << "x1:" << x1 << std::endl;
187   #endif
188         ClassFunction.data(0,0)=x0;
189         ClassFunction.data(0,1)=x1;
190         while(1){
191           ClassFunction.revise_dissimilarities();
192           ClassFunction.revise_membership();
193           double diff_u=frobenius_norm(ClassFunction.tmp_membership()-ClassFunction.mem
194   #ifdef DIFF
195           std::cout << "diff_u:" << diff_u << std::endl;
196   #endif
197           if(diff_u<DIFF_FOR_STOP)break;
198         }
199         for(int ell=0;ell<ClassFunction.dimension();ell++){
200           ofs_classificationFunction << ClassFunction.data()[0][ell] << "\t";
201         }
202         for(int i=0;i<ClassFunction.centers_number();i++){
203           ofs_classificationFunction << ClassFunction.membership()[i][0] << "\t";
204         }
205         double max=0.0;
206         for(int i=0;i<ClassFunction.centers_number();i++){
207           if(max<ClassFunction.membership()[i][0]){
208             max=ClassFunction.membership()[i][0];
209           }
210         }
211         ofs_classificationFunction << max << "\t";
212         ofs_classificationFunction << std::endl;
213       }
214       ofs_classificationFunction << std::endl;
215     }
216
217   #endif
218
219     return 0;
220   }
```

efcm_main_2d-Gaussian-2clusters.cxx

```
1   #include<iostream>
2   #include<fstream>
3   #include<cstdlib>
4   #include<random>
5   #include"efcm.h"
6
7   #define MAX_ITERATES 100000
8   #define DIFF_FOR_STOP 1.0E-10
9
10  const int centers_number=2;
```

```
11
12  int main(void){
13    std::string filenameData("2d-Gaussian-2clusters.dat");
14  #ifdef CHECK_ANSWER
15    std::string filenameCorrectCrispMembership("2d-Gaussian-2clusters.correctCrispMembe
16  #endif
17
18    std::string::size_type filenameDataDotPosition=filenameData.find_last_of(".");
19    if(filenameDataDotPosition==std::string::npos){
20      std::cerr << "File:" << filenameData
21                << " needs \".\" and filename-extention." << std::endl;
22      exit(1);
23    }
24
25    std::ifstream ifs(filenameData);
26    if(!ifs){
27      std::cerr << "File:" << filenameData
28                << " could not open." << std::endl;
29      exit(1);
30    }
31    int data_number, data_dimension;
32    ifs >> data_number;
33    ifs >> data_dimension;
34
35    Efcm test(data_dimension, data_number, centers_number, 10.0);
36
37    for(int cnt=0;cnt<data_number;cnt++){
38      for(int ell=0;ell<data_dimension;ell++){
39        ifs >> test.data(cnt, ell);
40      }
41    }
42
43    /***Initial Centers Setting***/
44    std::random_device rnd;
45    std::mt19937 mt(rnd());
46    std::uniform_int_distribution<> randDataNumber(0,test.data_number()-1);
47    for(int i=0;i<test.centers_number();i++){
48      test.centers(i)=test.data()[randDataNumber(mt)];
49    }
50  #ifdef VERBOSE
51    std::cout << "v:\n" << test.centers() << std::endl;
52  #endif
53
54    test.iterates()=0;
55    while(1){
56      test.revise_dissimilarities();
57  #ifdef VERBOSE
58      std::cout << "d:\n" << test.dissimilarities() << std::endl;
59  #endif
60      test.revise_membership();
```

```
61  #ifdef VERBOSE
62      std::cout << "u:\n" << test.membership() << std::endl;
63  #endif
64      test.revise_centers();
65  #ifdef VERBOSE
66      std::cout << "v:\n" << test.centers() << std::endl;
67  #endif
68
69      double diff_u=max_norm(test.tmp_membership()-test.membership());
70      double diff_v=max_norm(test.tmp_centers()-test.centers());
71      double diff=diff_u+diff_v;
72  #ifdef DIFF
73      std::cout << "#diff:" << diff << "\t";
74      std::cout << "#diff_u:" << diff_u << "\t";
75      std::cout << "#diff_v:" << diff_v << "\n";
76  #endif
77      if(diff<DIFF_FOR_STOP)break;
78      if(test.iterates()>=MAX_ITERATES)break;
79      test.iterates()++;
80    }
81  #ifdef VERBOSE
82    std::cout << "v:\n" << test.centers() << std::endl;
83  #endif
84
85  #ifdef CHECK_ANSWER
86    test.set_crispMembership();
87
88    std::ifstream ifs_correctCrispMembership(filenameCorrectCrispMembership);
89    if(!ifs_correctCrispMembership){
90      std::cerr << "File:" << filenameCorrectCrispMembership
91                << " could not open." << std::endl;
92      exit(1);
93    }
94    for(int i=0;i<test.centers_number();i++){
95      for(int k=0;k<test.data_number();k++){
96        ifs_correctCrispMembership >> test.correctCrispMembership(i, k);
97      }
98    }
99    test.set_contingencyTable();
100   std::cout << "Contingency Table:\n" << test.contingencyTable() << std::endl;
101   std::cout << "ARI:" << test.ARI() << std::endl;
102 #endif
103
104   std::string filenameResultMembership
105     =std::string("eFCM-Lambda")+std::to_string(test.fuzzifierLambda())+std::string("-
106     +filenameData.substr(0, filenameDataDotPosition)
107     +std::string(".result_membership");
108   std::ofstream ofs_membership(filenameResultMembership);
109   if(!ofs_membership){
110     std::cerr << "File:" << filenameResultMembership
```

```
111                 << "could not open." << std::endl;
112       exit(1);
113     }
114
115     for(int k=0;k<test.data_number();k++){
116       for(int ell=0;ell<test.dimension();ell++){
117         ofs_membership << test.data()[k][ell] << "\t";
118       }
119       for(int i=0;i<test.centers_number();i++){
120         ofs_membership << test.membership()[i][k] << "\t";
121       }
122       ofs_membership << std::endl;
123     }
124     ofs_membership.close();
125
126     std::string filenameResultCenters
127       =std::string("eFCM-Lambda")+std::to_string(test.fuzzifierLambda())+std::string("-
128       +filenameData.substr(0, filenameDataDotPosition)
129       +std::string(".result_centers");
130     std::ofstream ofs_centers(filenameResultCenters);
131     if(!ofs_centers){
132       std::cerr << "File:" << filenameResultCenters
133                 << "could not open." << std::endl;
134       exit(1);
135     }
136     for(int i=0;i<test.centers_number();i++){
137       for(int ell=0;ell<test.dimension();ell++){
138         ofs_centers << test.centers()[i][ell] << "\t";
139       }
140       ofs_centers << std::endl;
141     }
142     ofs_centers.close();
143
144   #ifdef CLASSIFICATION_FUNCTION
145     //Classification Function
146     if(test.dimension()>2){
147       std::cerr << "Dimension:" << test.dimension()
148                 << "is too high for classification function visualization."
149                 << std::endl;
150       exit(1);
151     }
152     Efcm ClassFunction(test.dimension(), 1, test.centers_number(), test.fuzzifierEm());
153     std::string filenameClassificationFunction
154       =std::string("eFCM-Lambda")+std::to_string(test.fuzzifierLambda())+std::string("-
155       +filenameData.substr(0, filenameDataDotPosition)
156       +std::string(".result_classificationFunction");
157     std::ofstream ofs_classificationFunction(filenameClassificationFunction);
158     if(!ofs_classificationFunction){
159       std::cerr << "File:" << filenameClassificationFunction
160                 << "could not open." << std::endl;
```

```
161       exit(1);
162     }
163     for(int i=0;i<test.centers_number();i++){
164       ClassFunction.centers(i)=test.centers(i);
165     }
166     Vector Min(test.dimension(), DBL_MAX, "all");
167     Vector Max(test.dimension(), -DBL_MAX, "all");
168     for(int k=0;k<test.data_number();k++){
169       for(int ell=0;ell<test.dimension();ell++){
170         if(Min[ell]>test.data(k, ell)){
171           Min[ell]=test.data(k, ell);
172         }
173         if(Max[ell]<test.data(k, ell)){
174           Max[ell]=test.data(k, ell);
175         }
176       }
177     }
178     Vector Mid=0.5*(Max+Min);
179     Vector Width=Max-Min;
180     Min=Mid-Width;
181     Max=Mid+Width;
182
183     for(double x0=Min[0];x0<=Max[0];x0+=Width[0]/10.0){
184       for(double x1=Min[1];x1<=Max[1];x1+=Width[1]/10.0){
185   #ifdef VERBOSE
186         std::cout << "x0:" << x0 << "\t" << "x1:" << x1 << std::endl;
187   #endif
188         ClassFunction.data(0,0)=x0;
189         ClassFunction.data(0,1)=x1;
190         while(1){
191           ClassFunction.revise_dissimilarities();
192           ClassFunction.revise_membership();
193           double diff_u=frobenius_norm(ClassFunction.tmp_membership()-ClassFunction.mem
194   #ifdef DIFF
195           std::cout << "diff_u:" << diff_u << std::endl;
196   #endif
197           if(diff_u<DIFF_FOR_STOP)break;
198         }
199         for(int ell=0;ell<ClassFunction.dimension();ell++){
200           ofs_classificationFunction << ClassFunction.data()[0][ell] << "\t";
201         }
202         for(int i=0;i<ClassFunction.centers_number();i++){
203           ofs_classificationFunction << ClassFunction.membership()[i][0] << "\t";
204         }
205         double max=0.0;
206         for(int i=0;i<ClassFunction.centers_number();i++){
207           if(max<ClassFunction.membership()[i][0]){
208             max=ClassFunction.membership()[i][0];
209           }
210         }
```

```
211         ofs_classificationFunction << max << "\t";
212         ofs_classificationFunction << std::endl;
213       }
214       ofs_classificationFunction << std::endl;
215     }
216
217   #endif
218
219     return 0;
220   }
```

qfcm_main_2d-Gaussian-2clusters.cxx

```
1   #include<iostream>
2   #include<fstream>
3   #include<cstdlib>
4   #include<random>
5   #include"qfcm.h"
6
7
8   #define MAX_ITERATES 100000
9   #define DIFF_FOR_STOP 1.0E-10
10
11  const int centers_number=2;
12
13  int main(void){
14
15    double fuzzifierEm = 2.0;
16    double fuzzifierLambda = 0.2;
17
18    std::string filenameData("2d-Gaussian-2clusters.dat");
19  #ifdef CHECK_ANSWER
20    std::string filenameCorrectCrispMembership("2d-Gaussian-2clusters.correctCrispMembe
21  #endif
22
23    std::string::size_type filenameDataDotPosition=filenameData.find_last_of(".");
24    if(filenameDataDotPosition==std::string::npos){
25      std::cerr << "File:" << filenameData
26                << " needs \".\" and filename-extention." << std::endl;
27      exit(1);
28    }
29
30    std::ifstream ifs(filenameData);
31    if(!ifs){
32      std::cerr << "File:" << filenameData
33                << " could not open." << std::endl;
34      exit(1);
35    }
```

```
36    int data_number, data_dimension;
37    ifs >> data_number;
38    ifs >> data_dimension;
39
40    Qfcm test(data_dimension, data_number, centers_number, fuzzifierEm, fuzzifierLambda
41
42    for(int cnt=0;cnt<data_number;cnt++){
43      for(int ell=0;ell<data_dimension;ell++){
44        ifs >> test.data(cnt, ell);
45      }
46    }
47
48    /***Initial Centers Setting***/
49    std::random_device rnd;
50    std::mt19937 mt(rnd());
51    std::uniform_int_distribution<> randDataNumber(0,test.data_number()-1);
52    for(int i=0;i<test.centers_number();i++){
53      test.centers(i)=test.data()[randDataNumber(mt)];
54    }
55  #ifdef VERBOSE
56    std::cout << "v:\n" << test.centers() << std::endl;
57  #endif
58
59    test.iterates()=0;
60    while(1){
61      test.revise_dissimilarities();
62  #ifdef VERBOSE
63      std::cout << "d:\n" << test.dissimilarities() << std::endl;
64  #endif
65      test.revise_membership();
66  #ifdef VERBOSE
67      std::cout << "u:\n" << test.membership() << std::endl;
68  #endif
69      test.revise_centers();
70  #ifdef VERBOSE
71      std::cout << "v:\n" << test.centers() << std::endl;
72  #endif
73
74      double diff_u=max_norm(test.tmp_membership()-test.membership());
75      double diff_v=max_norm(test.tmp_centers()-test.centers());
76      double diff=diff_u+diff_v;
77  #ifdef DIFF
78      std::cout << "#diff:" << diff << "\t";
79      std::cout << "#diff_u:" << diff_u << "\t";
80      std::cout << "#diff_v:" << diff_v << "\n";
81  #endif
82      if(diff<DIFF_FOR_STOP)break;
83      if(test.iterates()>=MAX_ITERATES)break;
84      test.iterates()++;
85    }
```

```
86  #ifdef VERBOSE
87    std::cout << "v:\n" << test.centers() << std::endl;
88  #endif
89
90  #ifdef CHECK_ANSWER
91    test.set_crispMembership();
92
93    std::ifstream ifs_correctCrispMembership(filenameCorrectCrispMembership);
94    if(!ifs_correctCrispMembership){
95      std::cerr << "File:" << filenameCorrectCrispMembership
96                << " could not open." << std::endl;
97      exit(1);
98    }
99    for(int i=0;i<test.centers_number();i++){
100     for(int k=0;k<test.data_number();k++){
101       ifs_correctCrispMembership >> test.correctCrispMembership(i, k);
102     }
103   }
104   test.set_contingencyTable();
105   std::cout << "Contingency Table:\n" << test.contingencyTable() << std::endl;
106   std::cout << "ARI:" << test.ARI() << std::endl;
107 #endif
108
109   std::string filenameResultMembership
110     =std::string("qFCM-Em")+std::to_string(test.fuzzifierEm())
111     +std::string("-Lambda")+std::to_string(test.fuzzifierLambda())
112     +std::string("-")
113     +filenameData.substr(0, filenameDataDotPosition)
114     +std::string(".result_membership");
115   std::ofstream ofs_membership(filenameResultMembership);
116   if(!ofs_membership){
117     std::cerr << "File:" << filenameResultMembership
118               << "could not open." << std::endl;
119     exit(1);
120   }
121
122   for(int k=0;k<test.data_number();k++){
123     for(int ell=0;ell<test.dimension();ell++){
124       ofs_membership << test.data()[k][ell] << "\t";
125     }
126     for(int i=0;i<test.centers_number();i++){
127       ofs_membership << test.membership()[i][k] << "\t";
128     }
129     ofs_membership << std::endl;
130   }
131   ofs_membership.close();
132
133   std::string filenameResultCenters
134     =std::string("qFCM-Em")+std::to_string(test.fuzzifierEm())
135     +std::string("-Lambda")+std::to_string(test.fuzzifierLambda())
```

```
136       +std::string("-")
137       +filenameData.substr(0, filenameDataDotPosition)
138       +std::string(".result_centers");
139     std::ofstream ofs_centers(filenameResultCenters);
140     if(!ofs_centers){
141       std::cerr << "File:" << filenameResultCenters
142                 << "could not open." << std::endl;
143       exit(1);
144     }
145     for(int i=0;i<test.centers_number();i++){
146       for(int ell=0;ell<test.dimension();ell++){
147         ofs_centers << test.centers()[i][ell] << "\t";
148       }
149       ofs_centers << std::endl;
150     }
151     ofs_centers.close();
152
153   #ifdef CLASSIFICATION_FUNCTION
154     //Classification Function
155     if(test.dimension()>2){
156       std::cerr << "Dimension:" << test.dimension()
157                 << "is too high for classification function visualization."
158                 << std::endl;
159       exit(1);
160     }
161     Qfcm ClassFunction(test.dimension(), 1, test.centers_number(), test.fuzzifierEm(),t
162     std::string filenameClassificationFunction
163       =std::string("qFCM-Em")+std::to_string(test.fuzzifierEm())
164       +std::string("-Lambda")+std::to_string(test.fuzzifierLambda())
165       +std::string("-")
166       +filenameData.substr(0, filenameDataDotPosition)
167       +std::string(".result_classificationFunction");
168     std::ofstream ofs_classificationFunction(filenameClassificationFunction);
169     if(!ofs_classificationFunction){
170       std::cerr << "File:" << filenameClassificationFunction
171                 << "could not open." << std::endl;
172       exit(1);
173     }
174     for(int i=0;i<test.centers_number();i++){
175       ClassFunction.centers(i)=test.centers(i);
176     }
177     Vector Min(test.dimension(), DBL_MAX, "all");
178     Vector Max(test.dimension(), -DBL_MAX, "all");
179     for(int k=0;k<test.data_number();k++){
180       for(int ell=0;ell<test.dimension();ell++){
181         if(Min[ell]>test.data(k, ell)){
182           Min[ell]=test.data(k, ell);
183         }
184         if(Max[ell]<test.data(k, ell)){
185           Max[ell]=test.data(k, ell);
```

```
186         }
187       }
188     }
189     Vector Mid=0.5*(Max+Min);
190     Vector Width=Max-Min;
191     Min=Mid-Width;
192     Max=Mid+Width;
193
194     for(double x0=Min[0];x0<=Max[0];x0+=Width[0]/10.0){
195       for(double x1=Min[1];x1<=Max[1];x1+=Width[1]/10.0){
196   #ifdef VERBOSE
197         std::cout << "x0:" << x0 << "\t" << "x1:" << x1 << std::endl;
198   #endif
199         ClassFunction.data(0,0)=x0;
200         ClassFunction.data(0,1)=x1;
201         while(1){
202           ClassFunction.revise_dissimilarities();
203           ClassFunction.revise_membership();
204           double diff_u=frobenius_norm(ClassFunction.tmp_membership()-ClassFunction.mem
205   #ifdef DIFF
206           std::cout << "diff_u:" << diff_u << std::endl;
207   #endif
208           if(diff_u<DIFF_FOR_STOP)break;
209         }
210         for(int ell=0;ell<ClassFunction.dimension();ell++){
211           ofs_classificationFunction << ClassFunction.data()[0][ell] << "\t";
212         }
213         for(int i=0;i<ClassFunction.centers_number();i++){
214           ofs_classificationFunction << ClassFunction.membership()[i][0] << "\t";
215         }
216         double max=0.0;
217         for(int i=0;i<ClassFunction.centers_number();i++){
218           if(max<ClassFunction.membership()[i][0]){
219             max=ClassFunction.membership()[i][0];
220           }
221         }
222         ofs_classificationFunction << max << "\t";
223         ofs_classificationFunction << std::endl;
224       }
225       ofs_classificationFunction << std::endl;
226     }
227
228   #endif
229
230     return 0;
231   }
```

sfcma_main_2d-Gaussian-2clusters.cxx

```
#include<iostream>
#include<fstream>
#include<cstdlib>
#include<random>
#include"sfcma.h"

#define MAX_ITERATES 100000
#define DIFF_FOR_STOP 1.0E-10
#define EM 1.01

const int centers_number=2;

int main(void){
  double Em=EM;

  std::string filenameData("2d-Gaussian-2clusters.dat");
#ifdef CHECK_ANSWER
  std::string filenameCorrectCrispMembership("2d-Gaussian-2clusters.correctCrispMembe
#endif

  std::string::size_type filenameDataDotPosition=filenameData.find_last_of(".");
  if(filenameDataDotPosition==std::string::npos){
    std::cerr << "File:" << filenameData
              << " needs \".\" and filename-extention." << std::endl;
    exit(1);
  }

  std::ifstream ifs(filenameData);
  if(!ifs){
    std::cerr << "File:" << filenameData
              << " could not open." << std::endl;
    exit(1);
  }
  int data_number, data_dimension;
  ifs >> data_number;
  ifs >> data_dimension;

  Sfcma test(data_dimension, data_number, centers_number, Em);

  for(int cnt=0;cnt<data_number;cnt++){
    for(int ell=0;ell<data_dimension;ell++){
      ifs >> test.data(cnt, ell);
    }
  }

  /***Initial Centers Setting***/
```

```
47    std::random_device rnd;
48    std::mt19937 mt(rnd());
49    std::uniform_int_distribution<> randDataNumber(0,test.data_number()-1);
50    for(int i=0;i<test.centers_number();i++){
51      test.centers(i)=test.data()[randDataNumber(mt)];
52      test.alpha(i)=1.0/centers_number;
53    }
54    test.iterates()=0;
55    while(1){
56      test.revise_dissimilarities();
57  #ifdef VERBOSE
58      std::cout << "d:\n" << test.dissimilarities() << std::endl;
59  #endif
60      test.revise_membership();
61  #ifdef VERBOSE
62      std::cout << "u:\n" << test.membership() << std::endl;
63  #endif
64      test.revise_centers();
65  #ifdef VERBOSE
66      std::cout << "v:\n" << test.centers() << std::endl;
67  #endif
68      test.revise_alpha();
69  #ifdef VERBOSE
70      std::cout << "a:\n" << test.alpha() << std::endl;
71  #endif
72
73      double diff_u=max_norm(test.tmp_membership()-test.membership());
74      double diff_v=max_norm(test.tmp_centers()-test.centers());
75      double diff_a=max_norm(test.tmp_alpha()-test.alpha());
76      double diff=diff_u+diff_v+diff_a;
77  #ifdef DIFF
78      std::cout << "#diff:" << diff << "\t";
79      std::cout << "#diff_u:" << diff_u << "\t";
80      std::cout << "#diff_v:" << diff_v << "\t";
81      std::cout << "#diff_a:" << diff_a << "\n";
82  #endif
83      if(diff<DIFF_FOR_STOP)break;
84      if(test.iterates()>=MAX_ITERATES)break;
85      test.iterates()++;
86    }
87  #ifdef VERBOSE
88    std::cout << "v:\n" << test.centers() << std::endl;
89  #endif
90
91  #ifdef CHECK_ANSWER
92    test.set_crispMembership();
93
94    std::ifstream ifs_correctCrispMembership(filenameCorrectCrispMembership);
95    if(!ifs_correctCrispMembership){
96      std::cerr << "File:" << filenameCorrectCrispMembership
```

```
97                << " could not open." << std::endl;
98      exit(1);
99    }
100   for(int i=0;i<test.centers_number();i++){
101     for(int k=0;k<test.data_number();k++){
102       ifs_correctCrispMembership >> test.correctCrispMembership(i, k);
103     }
104   }
105   test.set_contingencyTable();
106   std::cout << "Contingency Table:\n" << test.contingencyTable() << std::endl;
107   std::cout << "ARI:" << test.ARI() << std::endl;
108 #endif
109
110   std::string filenameResultMembership
111     =std::string("sFCMA-Em")
112     +std::to_string(test.fuzzifierEm())+std::string("-")
113     +filenameData.substr(0, filenameDataDotPosition)
114     +std::string(".result_membership");
115   std::ofstream ofs_membership(filenameResultMembership);
116   if(!ofs_membership){
117     std::cerr << "File:" << filenameResultMembership
118               << "could not open." << std::endl;
119     exit(1);
120   }
121
122   for(int k=0;k<test.data_number();k++){
123     for(int ell=0;ell<test.dimension();ell++){
124       ofs_membership << test.data()[k][ell] << "\t";
125     }
126     for(int i=0;i<test.centers_number();i++){
127       ofs_membership << test.membership()[i][k] << "\t";
128     }
129     ofs_membership << std::endl;
130   }
131   ofs_membership.close();
132
133   std::string filenameResultCenters
134     =std::string("sFCMA-Em")
135     +std::to_string(test.fuzzifierEm())+std::string("-")
136     +filenameData.substr(0, filenameDataDotPosition)
137     +std::string(".result_centers");
138   std::ofstream ofs_centers(filenameResultCenters);
139   if(!ofs_centers){
140     std::cerr << "File:" << filenameResultCenters
141               << "could not open." << std::endl;
142     exit(1);
143   }
144   for(int i=0;i<test.centers_number();i++){
145     for(int ell=0;ell<test.dimension();ell++){
146       ofs_centers << test.centers()[i][ell] << "\t";
```

```
147       }
148       ofs_centers << std::endl;
149     }
150     ofs_centers.close();
151
152   #ifdef CLASSIFICATION_FUNCTION
153     //Classification Function
154     if(test.dimension()>2){
155       std::cerr << "Dimension:" << test.dimension()
156                 << "is too high for classification function visualization."
157                 << std::endl;
158       exit(1);
159     }
160     Sfcma ClassFunction(test.dimension(), 1, test.centers_number(), test.fuzzifierEm())
161     std::string filenameClassificationFunction
162       =std::string("sFCMA-Em")
163       +std::to_string(test.fuzzifierEm())+std::string("-")
164       +filenameData.substr(0, filenameDataDotPosition)
165       +std::string(".result_classificationFunction");
166     std::ofstream ofs_classificationFunction(filenameClassificationFunction);
167     if(!ofs_classificationFunction){
168       std::cerr << "File:" << filenameClassificationFunction
169                 << "could not open." << std::endl;
170       exit(1);
171     }
172     for(int i=0;i<test.centers_number();i++){
173       ClassFunction.centers(i)=test.centers(i);
174     }
175     Vector Min(test.dimension(), DBL_MAX, "all");
176     Vector Max(test.dimension(), -DBL_MAX, "all");
177     for(int k=0;k<test.data_number();k++){
178       for(int ell=0;ell<test.dimension();ell++){
179         if(Min[ell]>test.data(k, ell)){
180           Min[ell]=test.data(k, ell);
181         }
182         if(Max[ell]<test.data(k, ell)){
183           Max[ell]=test.data(k, ell);
184         }
185       }
186     }
187     Vector Mid=0.5*(Max+Min);
188     Vector Width=Max-Min;
189     Min=Mid-Width;
190     Max=Mid+Width;
191
192     for(double x0=Min[0];x0<=Max[0];x0+=Width[0]/10.0){
193       for(double x1=Min[1];x1<=Max[1];x1+=Width[1]/10.0){
194   #ifdef VERBOSE
195         std::cout << "x0:" << x0 << "\t" << "x1:" << x1 << std::endl;
196   #endif
```

```
197         ClassFunction.data(0,0)=x0;
198         ClassFunction.data(0,1)=x1;
199         while(1){
200           ClassFunction.revise_dissimilarities();
201           ClassFunction.revise_membership();
202           double diff_u=frobenius_norm(ClassFunction.tmp_membership()-ClassFunction.mem
203   #ifdef DIFF
204           std::cout << "diff_u:" << diff_u << std::endl;
205   #endif
206           if(diff_u<DIFF_FOR_STOP)break;
207         }
208         for(int ell=0;ell<ClassFunction.dimension();ell++){
209           ofs_classificationFunction << ClassFunction.data()[0][ell] << "\t";
210         }
211         for(int i=0;i<ClassFunction.centers_number();i++){
212           ofs_classificationFunction << ClassFunction.membership()[i][0] << "\t";
213         }
214         double max=0.0;
215         for(int i=0;i<ClassFunction.centers_number();i++){
216           if(max<ClassFunction.membership()[i][0]){
217             max=ClassFunction.membership()[i][0];
218           }
219         }
220         ofs_classificationFunction << max << "\t";
221         ofs_classificationFunction << std::endl;
222       }
223       ofs_classificationFunction << std::endl;
224     }
225
226   #endif
227
228     return 0;
229   }
```

efcma_main_2d-Gaussian-2clusters.cxx

```
1   #include<iostream>
2   #include<fstream>
3   #include<cstdlib>
4   #include<random>
5   #include"efcma.h"
6
7   #define MAX_ITERATES 100000
8   #define DIFF_FOR_STOP 1.0E-10
9   #define LAMBDA 1
10
11  const int centers_number=2;
12
```

```
13  int main(void){
14    double Lambda = LAMBDA;
15
16    std::string filenameData("2d-Gaussian-2clusters.dat");
17  #ifdef CHECK_ANSWER
18    std::string filenameCorrectCrispMembership("2d-Gaussian-2clusters.correctCrispMembe
19  #endif
20
21    std::string::size_type filenameDataDotPosition=filenameData.find_last_of(".");
22    if(filenameDataDotPosition==std::string::npos){
23      std::cerr << "File:" << filenameData
24                << " needs \".\" and filename-extention." << std::endl;
25      exit(1);
26    }
27
28    std::ifstream ifs(filenameData);
29    if(!ifs){
30      std::cerr << "File:" << filenameData
31                << " could not open." << std::endl;
32      exit(1);
33    }
34    int data_number, data_dimension;
35    ifs >> data_number;
36    ifs >> data_dimension;
37
38    Efcma test(data_dimension, data_number, centers_number, Lambda);
39
40    for(int cnt=0;cnt<data_number;cnt++){
41      for(int ell=0;ell<data_dimension;ell++){
42        ifs >> test.data(cnt, ell);
43      }
44    }
45
46    /***Initial Centers Setting***/
47    std::random_device rnd;
48    std::mt19937 mt(rnd());
49    std::uniform_int_distribution<> randDataNumber(0,test.data_number()-1);
50    for(int i=0;i<test.centers_number();i++){
51      test.centers(i)=test.data()[randDataNumber(mt)];
52      test.alpha(i)=1.0/centers_number;
53    }
54
55    test.iterates()=0;
56    while(1){
57      test.revise_dissimilarities();
58  #ifdef VERBOSE
59      std::cout << "d:\n" << test.dissimilarities() << std::endl;
60  #endif
61      test.revise_membership();
62  #ifdef VERBOSE
```

```
63      std::cout << "u:\n" << test.membership() << std::endl;
64  #endif
65      test.revise_centers();
66  #ifdef VERBOSE
67      std::cout << "v:\n" << test.centers() << std::endl;
68  #endif
69      test.revise_alpha();
70  #ifdef VERBOSE
71      std::cout << "a:\n" << test.alpha() << std::endl;
72  #endif
73      double diff_u=max_norm(test.tmp_membership()-test.membership());
74      double diff_v=max_norm(test.tmp_centers()-test.centers());
75      double diff_a=max_norm(test.tmp_alpha()-test.alpha());
76      double diff=diff_u+diff_v+diff_a;
77  #ifdef DIFF
78      std::cout << "#diff:" << diff << "\t";
79      std::cout << "#diff_u:" << diff_u << "\t";
80      std::cout << "#diff_v:" << diff_v << "\n";
81  #endif
82      if(diff<DIFF_FOR_STOP)break;
83      if(test.iterates()>=MAX_ITERATES)break;
84      test.iterates()++;
85    }
86  #ifdef VERBOSE
87    std::cout << "v:\n" << test.centers() << std::endl;
88  #endif
89
90  #ifdef CHECK_ANSWER
91    test.set_crispMembership();
92    std::ifstream ifs_correctCrispMembership(filenameCorrectCrispMembership);
93    if(!ifs_correctCrispMembership){
94      std::cerr << "File:" << filenameCorrectCrispMembership
95                << " could not open." << std::endl;
96      exit(1);
97    }
98    for(int i=0;i<test.centers_number();i++){
99      for(int k=0;k<test.data_number();k++){
100       ifs_correctCrispMembership >> test.correctCrispMembership(i, k);
101     }
102   }
103   test.set_contingencyTable();
104   std::cout << "Contingency Table:\n" << test.contingencyTable() << std::endl;
105   std::cout << "ARI:" << test.ARI() << std::endl;
106 #endif
107
108   std::string filenameResultMembership
109     =std::string("eFCMA-Lambda")+std::to_string(test.fuzzifierLambda())+std::string("
110     +filenameData.substr(0, filenameDataDotPosition)
111     +std::string(".result_membership");
112   std::ofstream ofs_membership(filenameResultMembership);
```

```
113     if(!ofs_membership){
114       std::cerr << "File:" << filenameResultMembership
115                 << "could not open." << std::endl;
116       exit(1);
117     }
118
119     for(int k=0;k<test.data_number();k++){
120       for(int ell=0;ell<test.dimension();ell++){
121         ofs_membership << test.data()[k][ell] << "\t";
122       }
123       for(int i=0;i<test.centers_number();i++){
124         ofs_membership << test.membership()[i][k] << "\t";
125       }
126       ofs_membership << std::endl;
127     }
128     ofs_membership.close();
129
130     std::string filenameResultCenters
131       =std::string("eFCMA-Lambda")+std::to_string(test.fuzzifierLambda())+std::string("
132       +filenameData.substr(0, filenameDataDotPosition)
133       +std::string(".result_centers");
134     std::ofstream ofs_centers(filenameResultCenters);
135     if(!ofs_centers){
136       std::cerr << "File:" << filenameResultCenters
137                 << "could not open." << std::endl;
138       exit(1);
139     }
140     for(int i=0;i<test.centers_number();i++){
141       for(int ell=0;ell<test.dimension();ell++){
142         ofs_centers << test.centers()[i][ell] << "\t";
143       }
144       ofs_centers << std::endl;
145     }
146     ofs_centers.close();
147
148   #ifdef CLASSIFICATION_FUNCTION
149     //Classification Function
150     if(test.dimension()>2){
151       std::cerr << "Dimension:" << test.dimension()
152                 << "is too high for classification function visualization."
153                 << std::endl;
154       exit(1);
155     }
156     Efcma ClassFunction(test.dimension(), 1, test.centers_number(), test.fuzzifierLambd
157     std::string filenameClassificationFunction
158       =std::string("eFCMA-Lambda")+std::to_string(test.fuzzifierLambda())+std::string("
159       +filenameData.substr(0, filenameDataDotPosition)
160       +std::string(".result_classificationFunction");
161     std::ofstream ofs_classificationFunction(filenameClassificationFunction);
162     if(!ofs_classificationFunction){
```

```
163       std::cerr << "File:" << filenameClassificationFunction
164                 << "could not open." << std::endl;
165       exit(1);
166     }
167     for(int i=0;i<test.centers_number();i++){
168       ClassFunction.centers(i)=test.centers(i);
169     }
170     Vector Min(test.dimension(), DBL_MAX, "all");
171     Vector Max(test.dimension(), -DBL_MAX, "all");
172     for(int k=0;k<test.data_number();k++){
173       for(int ell=0;ell<test.dimension();ell++){
174         if(Min[ell]>test.data(k, ell)){
175           Min[ell]=test.data(k, ell);
176         }
177         if(Max[ell]<test.data(k, ell)){
178           Max[ell]=test.data(k, ell);
179         }
180       }
181     }
182     Vector Mid=0.5*(Max+Min);
183     Vector Width=Max-Min;
184     Min=Mid-Width;
185     Max=Mid+Width;
186
187     for(double x0=Min[0];x0<=Max[0];x0+=Width[0]/10.0){
188       for(double x1=Min[1];x1<=Max[1];x1+=Width[1]/10.0){
189   #ifdef VERBOSE
190         std::cout << "x0:" << x0 << "\t" << "x1:" << x1 << std::endl;
191   #endif
192         ClassFunction.data(0,0)=x0;
193         ClassFunction.data(0,1)=x1;
194         while(1){
195           ClassFunction.revise_dissimilarities();
196           ClassFunction.revise_membership();
197           double diff_u=frobenius_norm(ClassFunction.tmp_membership()-ClassFunction.mem
198   #ifdef DIFF
199           std::cout << "diff_u:" << diff_u << std::endl;
200   #endif
201           if(diff_u<DIFF_FOR_STOP)break;
202         }
203         for(int ell=0;ell<ClassFunction.dimension();ell++){
204           ofs_classificationFunction << ClassFunction.data()[0][ell] << "\t";
205         }
206         for(int i=0;i<ClassFunction.centers_number();i++){
207           ofs_classificationFunction << ClassFunction.membership()[i][0] << "\t";
208         }
209         double max=0.0;
210         for(int i=0;i<ClassFunction.centers_number();i++){
211           if(max<ClassFunction.membership()[i][0]){
212             max=ClassFunction.membership()[i][0];
```

```
213           }
214         }
215         ofs_classificationFunction << max << "\t";
216         ofs_classificationFunction << std::endl;
217       }
218       ofs_classificationFunction << std::endl;
219     }
220
221   #endif
222
223     return 0;
224   }
```

qfcma_main_2d-Gaussian-2clusters.cxx

```
1   #include<iostream>
2   #include<fstream>
3   #include<cstdlib>
4   #include<random>
5   #include"qfcma.h"
6
7   #define MAX_ITERATES 100000
8   #define DIFF_FOR_STOP 1.0E-10
9   #define EM 2.5
10  #define LAMBDA 1
11
12  const int centers_number=2;
13
14  int main(void){
15    double Em=EM;
16    double Lambda=LAMBDA;
17
18    std::string filenameData("2d-Gaussian-2clusters.dat");
19  #ifdef CHECK_ANSWER
20    std::string filenameCorrectCrispMembership("2d-Gaussian-2clusters.correctCrispMembe
21  #endif
22
23    std::string::size_type filenameDataDotPosition=filenameData.find_last_of(".");
24    if(filenameDataDotPosition==std::string::npos){
25      std::cerr << "File:" << filenameData
26                << " needs \".\" and filename-extention." << std::endl;
27      exit(1);
28    }
29
30    std::ifstream ifs(filenameData);
31    if(!ifs){
32      std::cerr << "File:" << filenameData
33                << " could not open." << std::endl;
```

```
34      exit(1);
35    }
36    int data_number, data_dimension;
37    ifs >> data_number;
38    ifs >> data_dimension;
39
40    Qfcma test(data_dimension, data_number, centers_number, Em, Lambda);
41
42    for(int cnt=0;cnt<data_number;cnt++){
43      for(int ell=0;ell<data_dimension;ell++){
44        ifs >> test.data(cnt, ell);
45      }
46    }
47
48    /***Initial Centers Setting***/
49    std::random_device rnd;
50    std::mt19937 mt(rnd());
51    std::uniform_int_distribution<> randDataNumber(0,test.data_number()-1);
52    for(int i=0;i<test.centers_number();i++){
53      test.centers(i)=test.data()[randDataNumber(mt)];
54      test.alpha(i)=1.0/centers_number;
55    }
56    test.iterates()=0;
57    while(1){
58      test.revise_dissimilarities();
59  #ifdef VERBOSE
60      std::cout << "d:\n" << test.dissimilarities() << std::endl;
61  #endif
62      test.revise_membership();
63  #ifdef VERBOSE
64      std::cout << "u:\n" << test.membership() << std::endl;
65  #endif
66      test.revise_centers();
67  #ifdef VERBOSE
68      std::cout << "v:\n" << test.centers() << std::endl;
69  #endif
70      test.revise_alpha();
71  #ifdef VERBOSE
72      std::cout << "a:\n" << test.alpha() << std::endl;
73  #endif
74
75      double diff_u=max_norm(test.tmp_membership()-test.membership());
76      double diff_v=max_norm(test.tmp_centers()-test.centers());
77      double diff_a=max_norm(test.tmp_alpha()-test.alpha());
78      double diff=diff_u+diff_v+diff_a;
79  #ifdef DIFF
80      std::cout << "#diff:" << diff << "\t";
81      std::cout << "#diff_u:" << diff_u << "\t";
82      std::cout << "#diff_v:" << diff_v << "\t";
83      std::cout << "#diff_a:" << diff_a << "\n";
```

```
84  #endif
85
86      if(diff<DIFF_FOR_STOP)break;
87      if(test.iterates()>=MAX_ITERATES)break;
88      test.iterates()++;
89    }
90  #ifdef VERBOSE
91    std::cout << "v:\n" << test.centers() << std::endl;
92  #endif
93
94  #ifdef CHECK_ANSWER
95    test.set_crispMembership();
96    std::ifstream ifs_correctCrispMembership(filenameCorrectCrispMembership);
97    if(!ifs_correctCrispMembership){
98      std::cerr << "File:" << filenameCorrectCrispMembership
99                << " could not open." << std::endl;
100     exit(1);
101   }
102   for(int i=0;i<test.centers_number();i++){
103     for(int k=0;k<test.data_number();k++){
104       ifs_correctCrispMembership >> test.correctCrispMembership(i, k);
105     }
106   }
107   test.set_contingencyTable();
108   std::cout << "Contingency Table:\n" << test.contingencyTable() << std::endl;
109   std::cout << "ARI:" << test.ARI() << std::endl;
110 #endif
111
112   std::string filenameResultMembership
113     =std::string("qFCMA-Em")+std::to_string(test.fuzzifierEm())
114     +std::string("-Lambda")+std::to_string(test.fuzzifierLambda())
115     +std::string("-")
116     +filenameData.substr(0, filenameDataDotPosition)
117     +std::string(".result_membership");
118   std::ofstream ofs_membership(filenameResultMembership);
119   if(!ofs_membership){
120     std::cerr << "File:" << filenameResultMembership
121               << "could not open." << std::endl;
122     exit(1);
123   }
124
125   for(int k=0;k<test.data_number();k++){
126     for(int ell=0;ell<test.dimension();ell++){
127       ofs_membership << test.data()[k][ell] << "\t";
128     }
129     for(int i=0;i<test.centers_number();i++){
130       ofs_membership << test.membership()[i][k] << "\t";
131     }
132     ofs_membership << std::endl;
133   }
```

```
134     ofs_membership.close();
135
136     std::string filenameResultCenters
137       =std::string("qFCMA-Em")+std::to_string(test.fuzzifierEm())
138       +std::string("-Lambda")+std::to_string(test.fuzzifierLambda())
139       +std::string("-")
140       +filenameData.substr(0, filenameDataDotPosition)
141       +std::string(".result_centers");
142     std::ofstream ofs_centers(filenameResultCenters);
143     if(!ofs_centers){
144       std::cerr << "File:" << filenameResultCenters
145                 << "could not open." << std::endl;
146       exit(1);
147     }
148     for(int i=0;i<test.centers_number();i++){
149       for(int ell=0;ell<test.dimension();ell++){
150         ofs_centers << test.centers()[i][ell] << "\t";
151       }
152       ofs_centers << std::endl;
153     }
154     ofs_centers.close();
155
156   #ifdef CLASSIFICATION_FUNCTION
157     //Classification Function
158     if(test.dimension()>2){
159       std::cerr << "Dimension:" << test.dimension()
160                 << "is too high for classification function visualization."
161                 << std::endl;
162       exit(1);
163     }
164     Qfcma ClassFunction(test.dimension(), 1, test.centers_number(), test.fuzzifierEm(),
165     std::string filenameClassificationFunction
166       =std::string("qFCMA-Em")+std::to_string(test.fuzzifierEm())
167       +std::string("-Lambda")+std::to_string(test.fuzzifierLambda())
168       +std::string("-")
169       +filenameData.substr(0, filenameDataDotPosition)
170       +std::string(".result_classificationFunction");
171     std::ofstream ofs_classificationFunction(filenameClassificationFunction);
172     if(!ofs_classificationFunction){
173       std::cerr << "File:" << filenameClassificationFunction
174                 << "could not open." << std::endl;
175       exit(1);
176     }
177     for(int i=0;i<test.centers_number();i++){
178       ClassFunction.centers(i)=test.centers(i);
179     }
180     Vector Min(test.dimension(), DBL_MAX, "all");
181     Vector Max(test.dimension(), -DBL_MAX, "all");
182     for(int k=0;k<test.data_number();k++){
183       for(int ell=0;ell<test.dimension();ell++){
```

```
184         if(Min[ell]>test.data(k, ell)){
185           Min[ell]=test.data(k, ell);
186         }
187         if(Max[ell]<test.data(k, ell)){
188           Max[ell]=test.data(k, ell);
189         }
190       }
191     }
192     Vector Mid=0.5*(Max+Min);
193     Vector Width=Max-Min;
194     Min=Mid-Width;
195     Max=Mid+Width;
196
197     for(double x0=Min[0];x0<=Max[0];x0+=Width[0]/10.0){
198       for(double x1=Min[1];x1<=Max[1];x1+=Width[1]/10.0){
199   #ifdef VERBOSE
200         std::cout << "x0:" << x0 << "\t" << "x1:" << x1 << std::endl;
201   #endif
202         ClassFunction.data(0,0)=x0;
203         ClassFunction.data(0,1)=x1;
204         while(1){
205           ClassFunction.revise_dissimilarities();
206           ClassFunction.revise_membership();
207           double diff_u=frobenius_norm(ClassFunction.tmp_membership()-ClassFunction.mem
208   #ifdef DIFF
209           std::cout << "diff_u:" << diff_u << std::endl;
210   #endif
211           if(diff_u<DIFF_FOR_STOP)break;
212         }
213         for(int ell=0;ell<ClassFunction.dimension();ell++){
214           ofs_classificationFunction << ClassFunction.data()[0][ell] << "\t";
215         }
216         for(int i=0;i<ClassFunction.centers_number();i++){
217           ofs_classificationFunction << ClassFunction.membership()[i][0] << "\t";
218         }
219         double max=0.0;
220         for(int i=0;i<ClassFunction.centers_number();i++){
221           if(max<ClassFunction.membership()[i][0]){
222             max=ClassFunction.membership()[i][0];
223           }
224         }
225         ofs_classificationFunction << max << "\t";
226         ofs_classificationFunction << std::endl;
227       }
228       ofs_classificationFunction << std::endl;
229     }
230
231   #endif
232
233     return 0;
```

```
234  }
```

sfcm_main_user_knowledge.cxx

efcm_main_user_knowledge.cxx

qfcm_main_user_knowledge.cxx

sfcma_main_user_knowledge.cxx

```
1   #include<iostream>
2   #include<fstream>
3   #include<cstdlib>
4   #include<random>
5   #include"sfcma.h"
6
7   #define MAX_ITERATES 100000
8   #define DIFF_FOR_STOP 1.0E-10
9
10  const int centers_number=2;
11
12  int main(void){
13    double max_ARI_Em, max_ARI;
14
15    std::ofstream outputfile("sfcma_user_knowledge_ARI.txt");
16
17    std::string filenameData("user_knowledge.dat");
18    std::string filenameCorrectCrispMembership("user_knowledge.correctCrispMembership")
19
20    std::string::size_type filenameDataDotPosition=filenameData.find_last_of(".");
21    if(filenameDataDotPosition==std::string::npos){
22      std::cerr << "File:" << filenameData
23                << " needs \".\" and filename-extention." << std::endl;
24      exit(1);
25    }
```

```
26    for(double Em=3.0;Em>1.0;Em-=0.1){
27      std::ifstream ifs(filenameData);
28      if(!ifs){
29        std::cerr << "File:" << filenameData
30                  << " could not open." << std::endl;
31        exit(1);
32      }
33      int data_number, data_dimension;
34      ifs >> data_number;
35      ifs >> data_dimension;
36
37      Sfcma test(data_dimension, data_number, centers_number, Em);
38
39      for(int cnt=0;cnt<data_number;cnt++){
40        for(int ell=0;ell<data_dimension;ell++){
41          ifs >> test.data(cnt, ell);
42        }
43      }
44
45      /***Initial Centers Setting***/
46      std::random_device rnd;
47      std::mt19937 mt(rnd());
48      std::uniform_int_distribution<> randDataNumber(0,test.data_number()-1);
49      std::ifstream ifs_correctCrispMembership(filenameCorrectCrispMembership);
50      if(!ifs_correctCrispMembership){
51        std::cerr << "File:" << filenameCorrectCrispMembership
52                  << " could not open." << std::endl;
53        exit(1);
54      }
55      for(int i=0;i<test.centers_number();i++){
56        for(int k=0;k<test.data_number();k++){
57          ifs_correctCrispMembership >> test.correctCrispMembership(i, k);
58        }
59      }
60      for(int i=0;i<test.centers_number();i++){
61        test.centers(i)=test.data()[randDataNumber(mt)];
62        test.alpha(i)=1.0/centers_number;
63        for(int k=0;k<test.data_number();k++){
64          test.membership(i,k)=test.correctCrispMembership(i, k);
65        }
66      }
67
68      test.iterates()=0;
69      while(1){
70        test.revise_centers();
71  #ifdef VERBOSE
72        std::cout << "v:\n" << test.centers() << std::endl;
73  #endif
74        test.revise_dissimilarities();
75  #ifdef VERBOSE
```

```
76        std::cout << "d:\n" << test.dissimilarities() << std::endl;
77  #endif
78        test.revise_membership();
79  #ifdef VERBOSE
80        std::cout << "u:\n" << test.membership() << std::endl;
81  #endif
82        test.revise_alpha();
83  #ifdef VERBOSE
84        std::cout << "a:\n" << test.alpha() << std::endl;
85  #endif
86
87        double diff_u=max_norm(test.tmp_membership()-test.membership());
88        double diff_v=max_norm(test.tmp_centers()-test.centers());
89        double diff_a=max_norm(test.tmp_alpha()-test.alpha());
90        double diff=diff_u+diff_v+diff_a;
91  #ifdef DIFF
92        std::cout << "#diff:" << diff << "\t";
93        std::cout << "#diff_u:" << diff_u << "\t";
94        std::cout << "#diff_v:" << diff_v << "\t";
95        std::cout << "#diff_a:" << diff_a << "\n";
96  #endif
97        if(diff<DIFF_FOR_STOP)break;
98        if(test.iterates()>=MAX_ITERATES)break;
99        test.iterates()++;
100     }
101 #ifdef VERBOSE
102     std::cout << "v:\n" << test.centers() << std::endl;
103 #endif
104
105 #ifdef CHECK_ANSWER
106     test.set_crispMembership();
107     test.set_contingencyTable();
108     //std::cout << "Contingency Table:\n" << test.contingencyTable() << std::endl;
109     std::cout << "Em:" << Em  << "\tARI:" << test.ARI() << std::endl;
110     outputfile<<Em<<"\t";
111     outputfile<<test.ARI()<<"\t";
112     outputfile<<"\n";
113 #endif
114
115     if(max_ARI<test.ARI()){
116       max_ARI_Em=Em;
117       max_ARI=test.ARI();
118     }
119   }
120
121   outputfile.close();
122
123   std::cout << "max_ARI_Em:" << max_ARI_Em << std::endl;
124   std::cout << "max_ARI:" << max_ARI << std::endl;
125
```

```
126     return 0;
127   }
```

efcma_main_user_knowledge.cxx

```
  1   #include<iostream>
  2   #include<fstream>
  3   #include<cstdlib>
  4   #include<random>
  5   #include"efcma.h"
  6
  7   #define MAX_ITERATES 100000
  8   #define DIFF_FOR_STOP 1.0E-10
  9
 10   const int centers_number=4;
 11
 12
 13   int main(void){
 14
 15     double max_ARI_Lambda, max_ARI;
 16
 17     std::ofstream outputfile("efcma_user_knowledge_ARI.txt");
 18
 19     std::string filenameData("user_knowledge.dat");
 20     std::string filenameCorrectCrispMembership("user_knowledge.correctCrispMembership")
 21
 22     std::string::size_type filenameDataDotPosition=filenameData.find_last_of(".");
 23     if(filenameDataDotPosition==std::string::npos){
 24       std::cerr << "File:" << filenameData
 25                 << " needs \".\" and filename-extention." << std::endl;
 26       exit(1);
 27     }
 28
 29     for(double Lambda=1;Lambda<=100;Lambda+=1){
 30       std::ifstream ifs(filenameData);
 31       if(!ifs){
 32         std::cerr << "File:" << filenameData
 33                   << " could not open." << std::endl;
 34         exit(1);
 35       }
 36       int data_number, data_dimension;
 37       ifs >> data_number;
 38       ifs >> data_dimension;
 39
 40       Efcma test(data_dimension, data_number, centers_number, Lambda);
 41
 42       for(int cnt=0;cnt<data_number;cnt++){
 43         for(int ell=0;ell<data_dimension;ell++){
```

```
44          ifs >> test.data(cnt, ell);
45        }
46      }
47
48      /***Initial Centers Setting***/
49      std::random_device rnd;
50      std::mt19937 mt(rnd());
51      std::uniform_int_distribution<> randDataNumber(0,test.data_number()-1);
52      std::ifstream ifs_correctCrispMembership(filenameCorrectCrispMembership);
53      if(!ifs_correctCrispMembership){
54        std::cerr << "File:" << filenameCorrectCrispMembership
55                  << " could not open." << std::endl;
56        exit(1);
57      }
58
59      for(int i=0;i<test.centers_number();i++){
60        for(int k=0;k<test.data_number();k++){
61          ifs_correctCrispMembership >> test.correctCrispMembership(i, k);
62        }
63      }
64      for(int i=0;i<test.centers_number();i++){
65        test.centers(i)=test.data()[randDataNumber(mt)];
66        test.alpha(i)=1.0/centers_number;
67        for(int k=0;k<test.data_number();k++){
68          test.membership(i,k) = test.correctCrispMembership(i,k);
69        }
70      }
71
72      test.iterates()=0;
73      while(1){
74        test.revise_centers();
75  #ifdef VERBOSE
76        std::cout << "v:\n" << test.centers() << std::endl;
77  #endif
78        test.revise_dissimilarities();
79  #ifdef VERBOSE
80        std::cout << "d:\n" << test.dissimilarities() << std::endl;
81  #endif
82        test.revise_membership();
83  #ifdef VERBOSE
84        std::cout << "u:\n" << test.membership() << std::endl;
85  #endif
86        test.revise_alpha();
87  #ifdef VERBOSE
88        std::cout << "a:\n" << test.alpha() << std::endl;
89  #endif
90        double diff_u=max_norm(test.tmp_membership()-test.membership());
91        double diff_v=max_norm(test.tmp_centers()-test.centers());
92        double diff_a=max_norm(test.tmp_alpha()-test.alpha());
93        double diff=diff_u+diff_v+diff_a;
```

```
94  #ifdef DIFF
95        std::cout << "#diff:" << diff << "\t";
96        std::cout << "#diff_u:" << diff_u << "\t";
97        std::cout << "#diff_v:" << diff_v << "\n";
98  #endif
99        if(diff<DIFF_FOR_STOP)break;
100       if(test.iterates()>=MAX_ITERATES)break;
101       test.iterates()++;
102     }
103 #ifdef VERBOSE
104     std::cout << "v:\n" << test.centers() << std::endl;
105 #endif
106
107 #ifdef CHECK_ANSWER
108     test.set_crispMembership();
109     test.set_contingencyTable();
110     //std::cout << "Contingency Table:\n" << test.contingencyTable() << std::endl;
111     std::cout << "Lambda:" << Lambda << "\tARI:" << test.ARI() << std::endl;
112     outputfile<<Lambda<<"\t";
113     outputfile<<test.ARI()<<"\t";
114     outputfile<<"\n";
115 #endif
116
117     if(max_ARI<test.ARI()){
118       max_ARI_Lambda=Lambda;
119       max_ARI=test.ARI();
120     }
121   }
122
123   outputfile.close();
124
125   std::cout << "max_ARI_Lambda:" << max_ARI_Lambda << std::endl;
126   std::cout << "max_ARI:" << max_ARI << std::endl;
127
128   return 0;
129 }
```

qfcma_main_user_knowledge.cxx

```
1  #include<iostream>
2  #include<fstream>
3  #include<cstdlib>
4  #include<random>
5  #include"qfcma.h"
6
7  #define MAX_ITERATES 100000
8  #define DIFF_FOR_STOP 1.0E-2
9
```

```
10  const int centers_number=4;
11
12  int main(void){
13
14    double max_ARI_Em, max_ARI_Lambda, max_ARI;
15
16    std::ofstream outputfile("qfcma_user_knowledge_ARI.txt");
17
18    std::string filenameData("user_knowledge.dat");
19    std::string filenameCorrectCrispMembership("user_knowledge.correctCrispMembership")
20
21    std::string::size_type filenameDataDotPosition=filenameData.find_last_of(".");
22    if(filenameDataDotPosition==std::string::npos){
23      std::cerr << "File:" << filenameData
24                << " needs \".\" and filename-extention." << std::endl;
25      exit(1);
26    }
27
28    for(double Lambda=100;Lambda>0;Lambda-=10){
29      for(double Em=3.0;Em>1.0;Em-=0.1){
30
31        std::ifstream ifs(filenameData);
32        if(!ifs){
33          std::cerr << "File:" << filenameData
34                    << " could not open." << std::endl;
35          exit(1);
36        }
37        int data_number, data_dimension;
38        ifs >> data_number;
39        ifs >> data_dimension;
40
41        Qfcma test(data_dimension, data_number, centers_number, Em, Lambda);
42
43        for(int cnt=0;cnt<data_number;cnt++){
44          for(int ell=0;ell<data_dimension;ell++){
45            ifs >> test.data(cnt, ell);
46          }
47        }
48
49        /***Initial Centers Setting***/
50        std::random_device rnd;
51        std::mt19937 mt(rnd());
52        std::uniform_int_distribution<> randDataNumber(0,test.data_number()-1);
53        std::ifstream ifs_correctCrispMembership(filenameCorrectCrispMembership);
54        if(!ifs_correctCrispMembership){
55          std::cerr << "File:" << filenameCorrectCrispMembership
56                    << " could not open." << std::endl;
57          exit(1);
58        }
59        for(int i=0;i<test.centers_number();i++){
```

```
60          for(int k=0;k<test.data_number();k++){
61            ifs_correctCrispMembership >> test.correctCrispMembership(i, k);
62          }
63        }
64        for(int i=0;i<test.centers_number();i++){
65          //test.centers(i)=test.data()[randDataNumber(mt)];
66          test.alpha(i)=1.0/centers_number;
67          for(int k=0;k<test.data_number();k++){
68            test.membership(i,k)=test.correctCrispMembership(i, k);
69          }
70        }
71
72        test.iterates()=0;
73        while(1){
74          test.revise_centers();
75  #ifdef VERBOSE
76        std::cout << "v:\n" << test.centers() << std::endl;
77  #endif
78          test.revise_dissimilarities();
79  #ifdef VERBOSE
80          std::cout << "d:\n" << test.dissimilarities() << std::endl;
81  #endif
82          test.revise_membership();
83  #ifdef VERBOSE
84          std::cout << "u:\n" << test.membership() << std::endl;
85  #endif
86          test.revise_alpha();
87  #ifdef VERBOSE
88          std::cout << "a:\n" << test.alpha() << std::endl;
89  #endif
90
91          double diff_u=max_norm(test.tmp_membership()-test.membership());
92          double diff_v=max_norm(test.tmp_centers()-test.centers());
93          double diff_a=max_norm(test.tmp_alpha()-test.alpha());
94          double diff=diff_u+diff_v+diff_a;
95  #ifdef DIFF
96          std::cout << "#diff:" << diff << "\t";
97          std::cout << "#diff_u:" << diff_u << "\t";
98          std::cout << "#diff_v:" << diff_v << "\t";
99          std::cout << "#diff_a:" << diff_a << "\n";
100 #endif
101
102         if(diff<DIFF_FOR_STOP)break;
103         if(test.iterates()>=MAX_ITERATES)break;
104         test.iterates()++;
105       }
106 #ifdef VERBOSE
107       std::cout << "v:\n" << test.centers() << std::endl;
108 #endif
109
```

```
110   #ifdef CHECK_ANSWER
111         test.set_crispMembership();
112         test.set_contingencyTable();
113         //std::cout << "Contingency Table:\n" << test.contingencyTable() << std::endl;
114         std::cout << "Lambda:" << Lambda << "\tEm:" << Em << "\tARI:" << test.ARI() <<
115         outputfile<<Lambda<<"\t";
116         outputfile<<Em<<"\t";
117         outputfile<<test.ARI()<<"\t";
118         outputfile<<"\n";
119   #endif
120
121         if(max_ARI<test.ARI()){
122           max_ARI_Em=Em;
123           max_ARI_Lambda=Lambda;
124           max_ARI=test.ARI();
125         }
126         outputfile<<"\n";
127       }
128     }
129
130     outputfile.close();
131
132     std::cout << "max_ARI_Em:" << max_ARI_Em << std::endl;
133     std::cout << "max_ARI_Lambda:" << max_ARI_Lambda << std::endl;
134     std::cout << "max_ARI:" << max_ARI << std::endl;
135
136     return 0;
137   }
```