CS 545: Machine Learning, Spring 2020

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Algorithm #2: Fuzzy C-Means

The standard version of fuzzy c means (FCM) is implemented here. The centroid update formula and membership values update formulas are used as explained in the lecture. The fuzzifier (m) value is take as 1.1

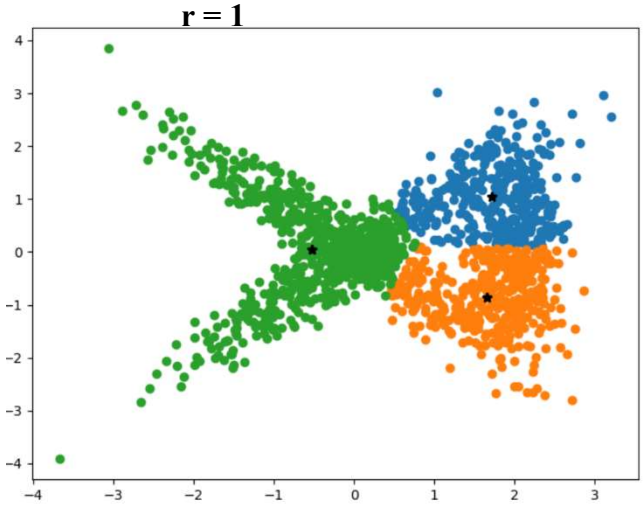
Just like k-means, this algorithm is also ran for 'r' number of times (here r = 10) for each 'c' value. (number of cluster denoted by 'c')

For each 'r' the algorithm begins by initiating the centroids, and the membership grades of each data point with respect to 'c' clusters. the data points are placed in the clusters based on membership grades and then centroids are updated, and weights are recalculated. We repeat this until the centroids are converged or till it reaches maximum number of iterations.

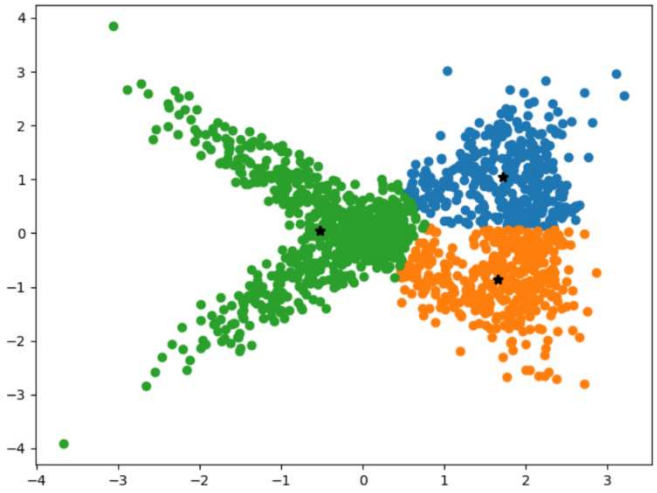
Observations:

1. **Number of clusters c = 3**

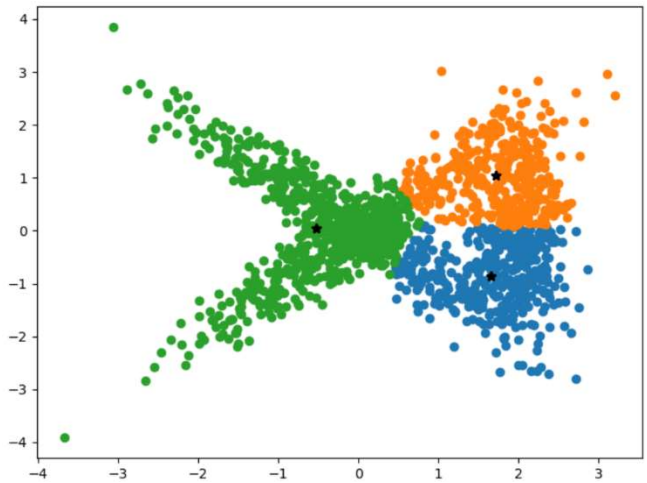
r = 1



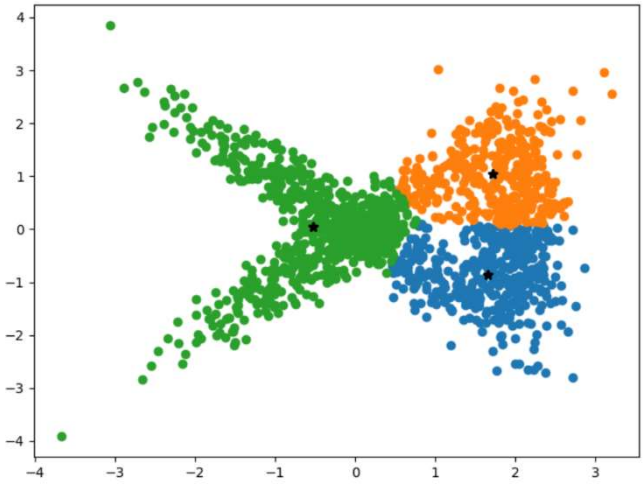
r = 2



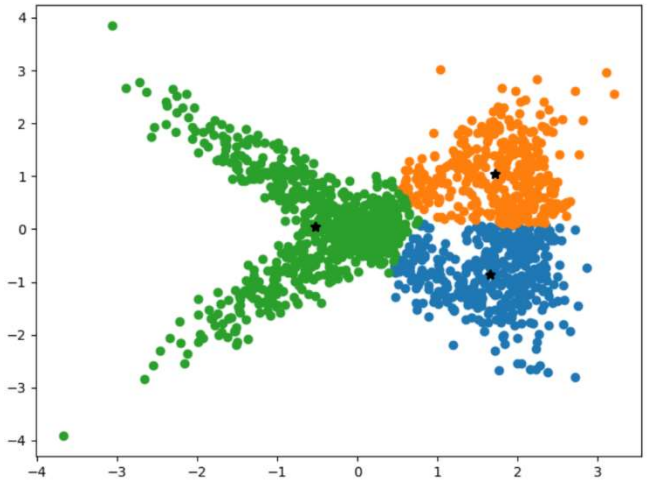
r = 3



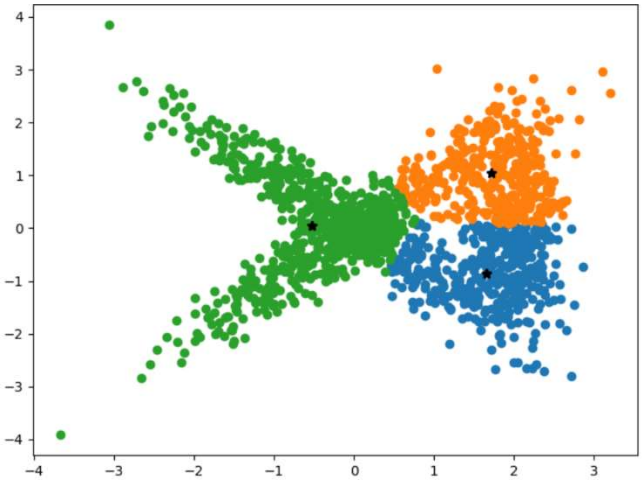
r = 4



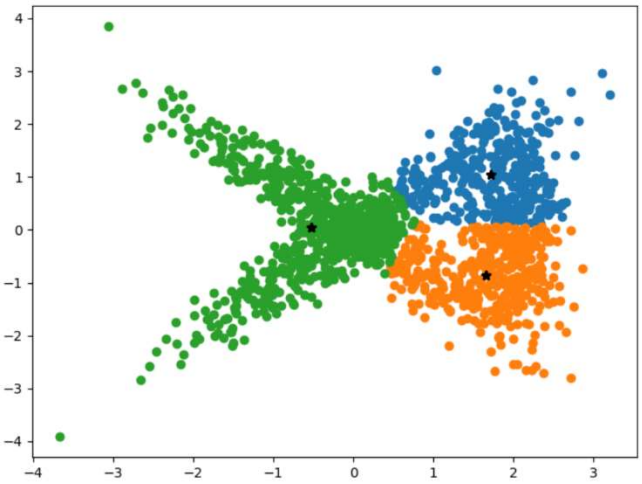
r = 5



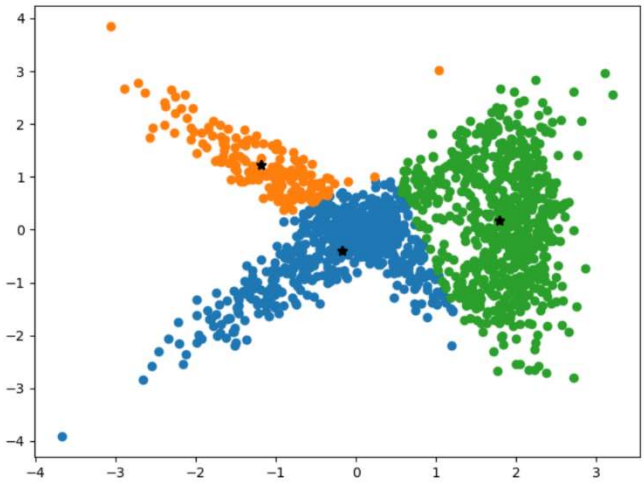
r = 6



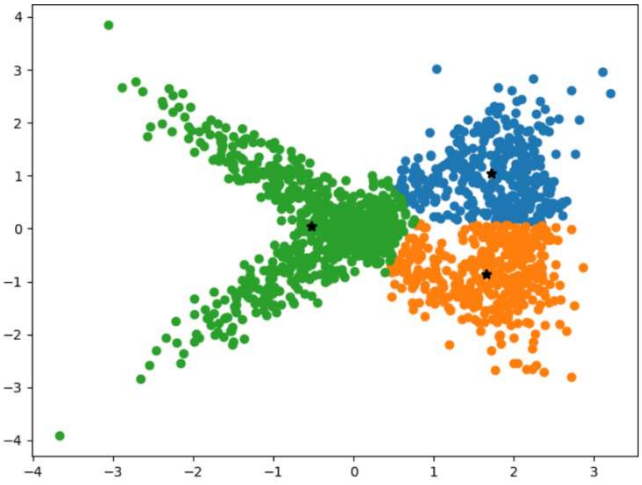
r = 7



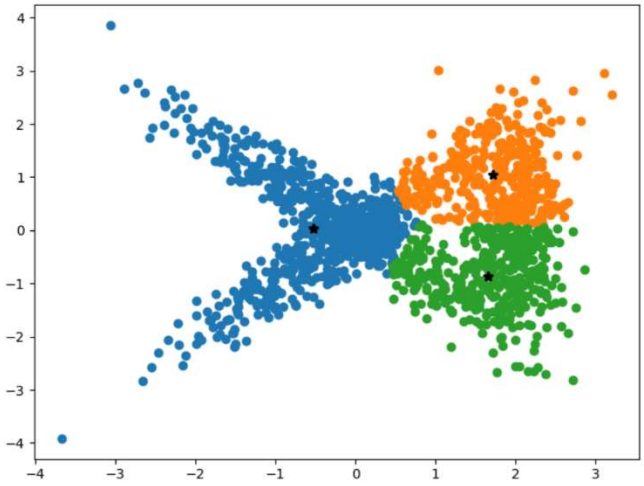
r = 8



r = 9



r = 10



Below is the pic showing sum square error at each ‘r’ with different initial centroids (initial centroid indexes = data point index, which is randomly selected to be centroid)

```
C:\Users\SreeV\anaconda3\envs\tensor\pythonw.exe '
c =  3
initial centroid indexes =  [271 309 971]
centroids converged, breaking the loop
r =  1 sum-square-error =  1536.7930379676216

initial centroid indexes =  [1102 1106 1435]
centroids converged, breaking the loop
r =  2 sum-square-error =  1536.7930378174142

initial centroid indexes =  [ 109 1450  860]
centroids converged, breaking the loop
r =  3 sum-square-error =  1536.793037781081

initial centroid indexes =  [1372 1037  794]
centroids converged, breaking the loop
r =  4 sum-square-error =  1536.7930378054925

initial centroid indexes =  [957  15 827]
centroids converged, breaking the loop
r =  5 sum-square-error =  1536.793037893329

initial centroid indexes =  [1218 1398 1148]
centroids converged, breaking the loop
r =  6 sum-square-error =  1536.7930377642442

initial centroid indexes =  [1218 1398 1148]
centroids converged, breaking the loop
r =  6 sum-square-error =  1536.7930377642442

initial centroid indexes =  [ 786 1380  412]
centroids converged, breaking the loop
r =  7 sum-square-error =  1536.7930377955236

initial centroid indexes =  [767 103 297]
centroids converged, breaking the loop
r =  8 sum-square-error =  1761.9549451764349

initial centroid indexes =  [1030   98  215]
centroids converged, breaking the loop
r =  9 sum-square-error =  1536.7930377931084

initial centroid indexes =  [977 615 855]
centroids converged, breaking the loop
r =  10 sum-square-error =  1536.7930376967197

errors =  [1536.7930379676216, 1536.7930378174142, 1
min error when r = 10
error =  1536.7930376967197

Process finished with exit code 0
```

Sum-square-error at each ‘r’

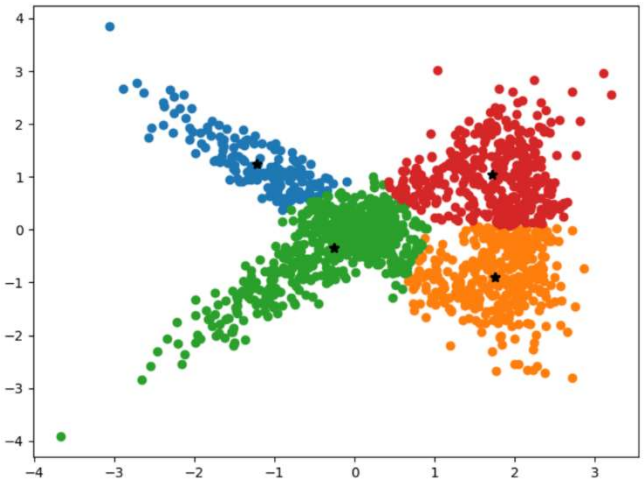
errors = [1536.7930379676216, 1536.7930378174142, 1536.793037781081, 1536.7930378054925, 1536.793037893329, 1536.7930377642442, 1536.7930377955236, 1761.9549451764349, 1536.7930377931084, 1536.7930376967197]

min error when r = 10

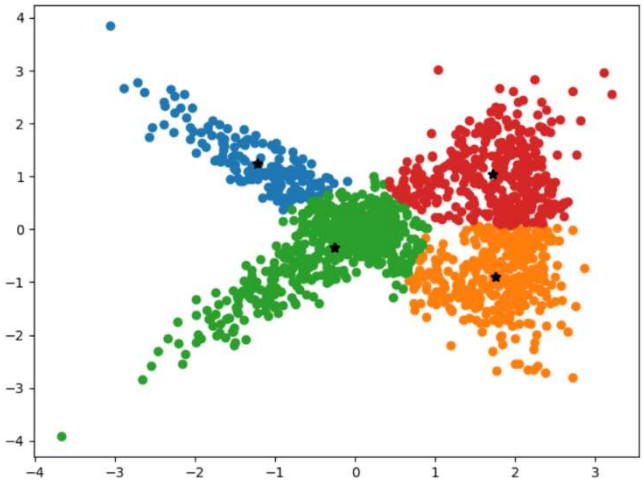
error = 1536.793

2. **Number of clusters c = 4**

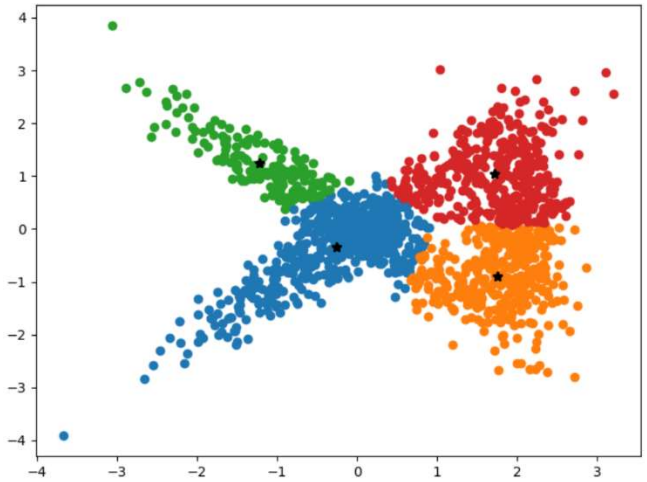
r = 1



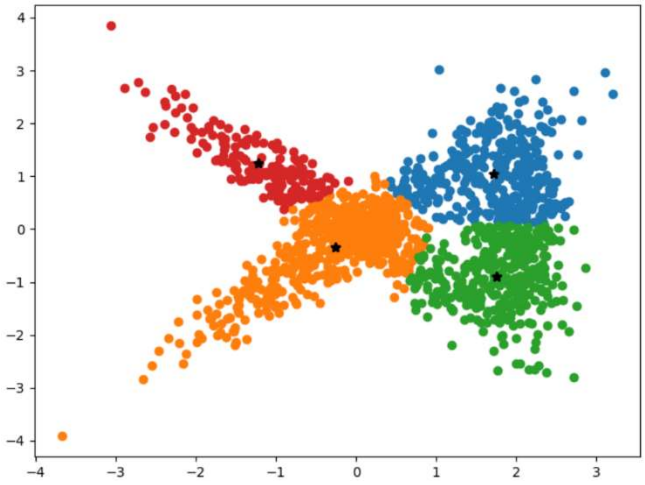
r = 2



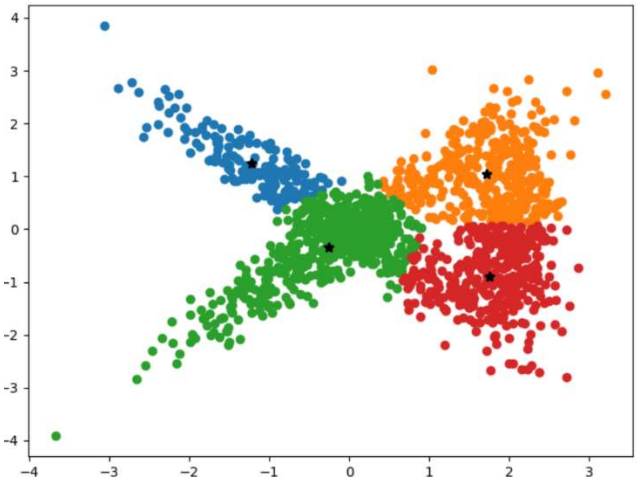
r = 3



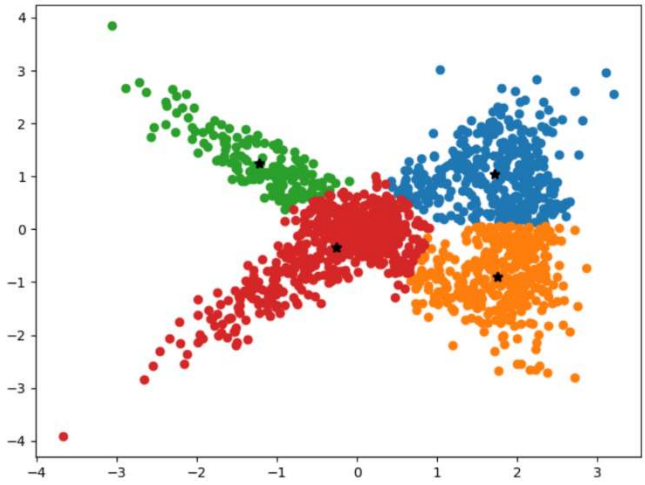
r = 4



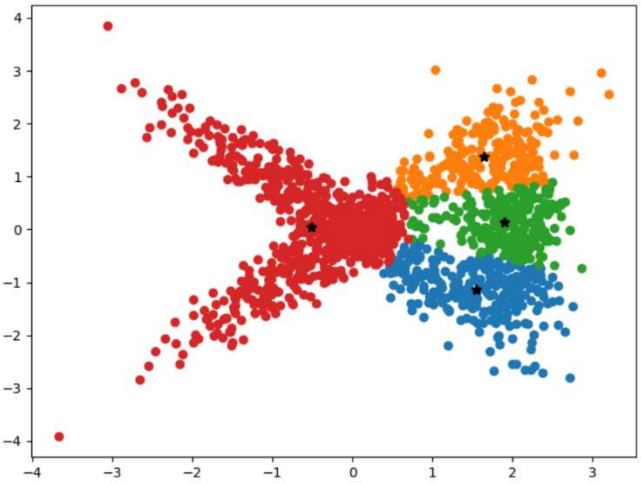
r = 5



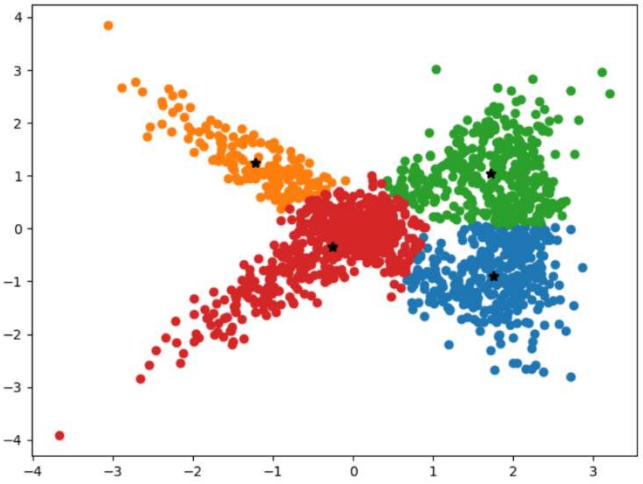
r = 6



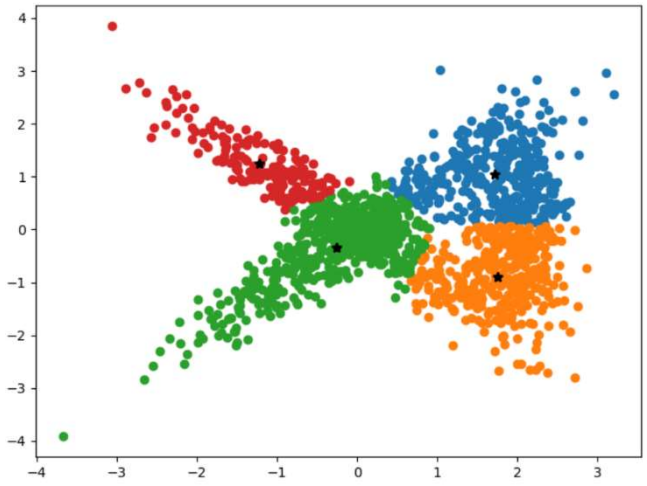
r = 7



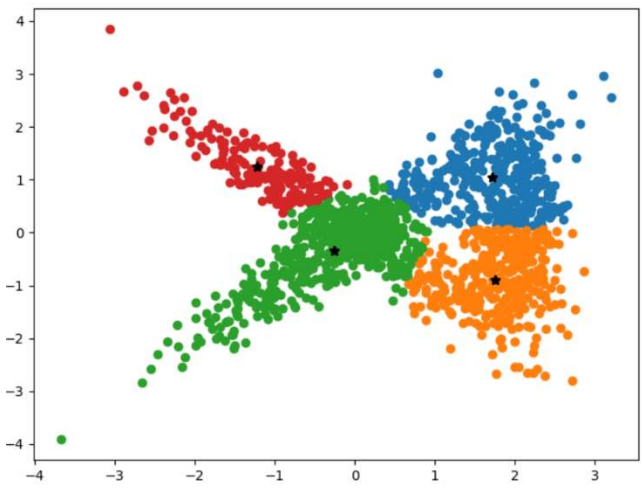
r = 8



r = 9



r =10



```
C:\Users\SreeV\anaconda3\envs\tensor\pythonw.exe "C:/U
c =  4
initial centroid indexes =  [ 386 1257  970  245]
centroids converged, breaking the loop
r =  1 sum-square-error =  1100.4321184208413

initial centroid indexes =  [1342  838 1203  324]
centroids converged, breaking the loop
r =  2 sum-square-error =  1100.432118565212

initial centroid indexes =  [1297 1344 1421 1311]
centroids converged, breaking the loop
r =  3 sum-square-error =  1100.4321186244697

initial centroid indexes =  [ 459 1358  651  728]
centroids converged, breaking the loop
r =  4 sum-square-error =  1100.4321185295241

initial centroid indexes =  [1067 1134 1007 1187]
centroids converged, breaking the loop
r =  5 sum-square-error =  1100.4321184176038

initial centroid indexes =  [439 787 789  19]
centroids converged, breaking the loop
r =  6 sum-square-error =  1100.4321191258987
```

```
initial centroid indexes =  [439 787 789  19]
centroids converged, breaking the loop
r =  6 sum-square-error =  1100.4321191258987

initial centroid indexes =  [1186  984 1128 1182]
centroids converged, breaking the loop
r =  7 sum-square-error =  1392.130015344025

initial centroid indexes =  [1315  222 1133  450]
centroids converged, breaking the loop
r =  8 sum-square-error =  1100.4321184540684

initial centroid indexes =  [109 681 820 712]
centroids converged, breaking the loop
r =  9 sum-square-error =  1100.432118448563

initial centroid indexes =  [1322  784 1034 1243]
centroids converged, breaking the loop
r =  10 sum-square-error =  1100.4321184450678

errors =  [1100.4321184208413, 1100.432118565212, 110(
min error when r = 5
error =  1100.4321184176038

Process finished with exit code 0
```

Sum-square-error at each ‘r’

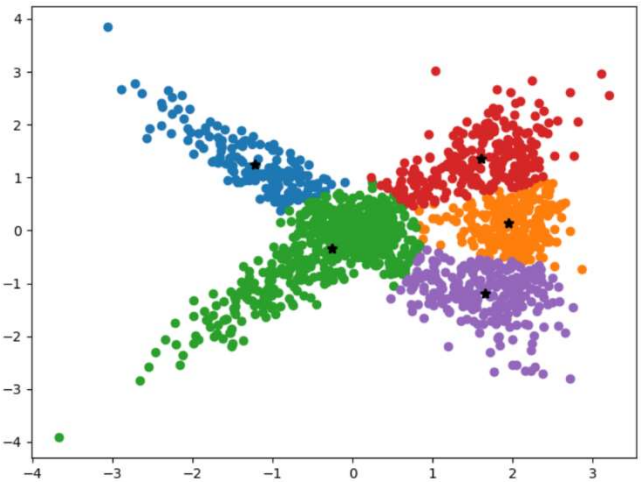
errors = [1100.4321184208413, 1100.432118565212, 1100.4321186244697, 1100.4321185295241, 1100.4321184176038, 1100.4321191258987, 1392.130015344025, 1100.4321184540684, 1100.432118448563, 1100.4321184450678]

min error when r = 5

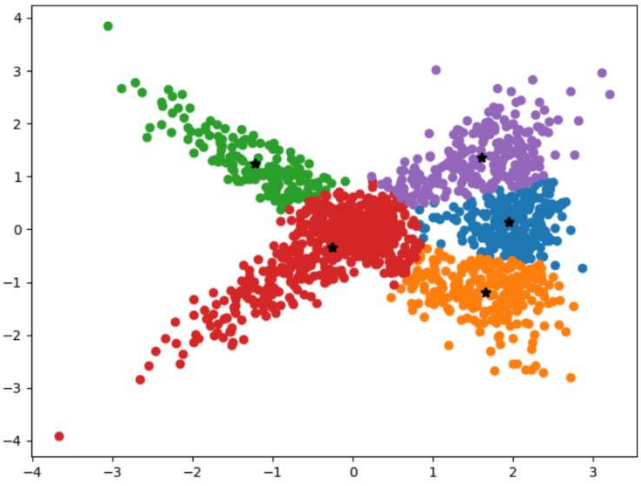
error = 1100.432

3. Number of Clusters c = 5

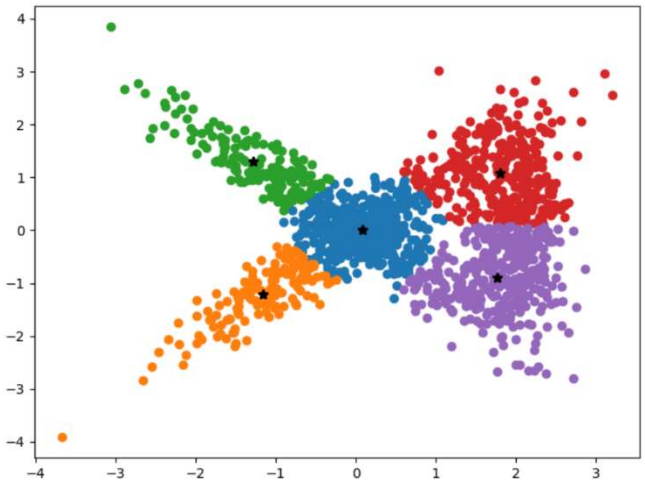
r = 1



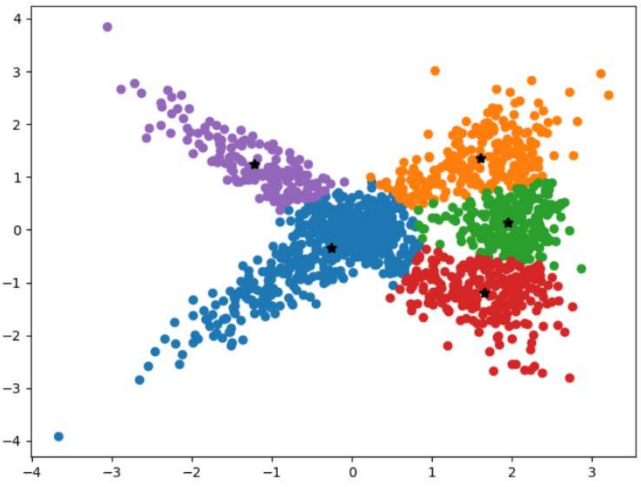
r = 2



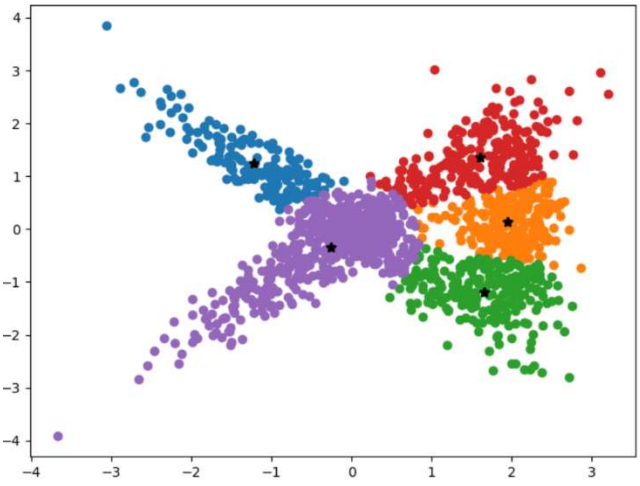
r = 3



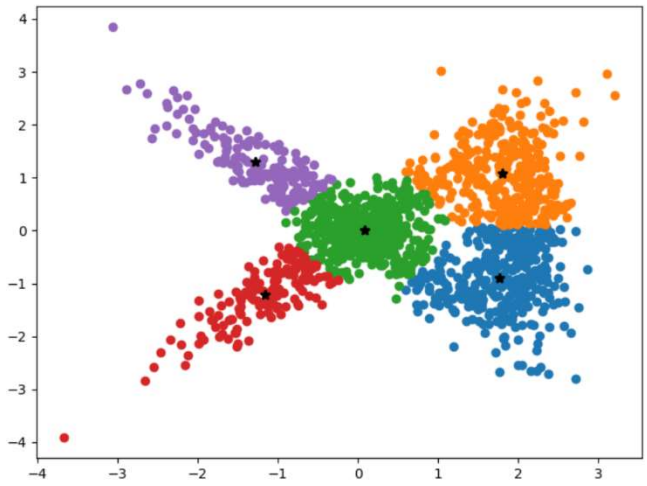
r = 4



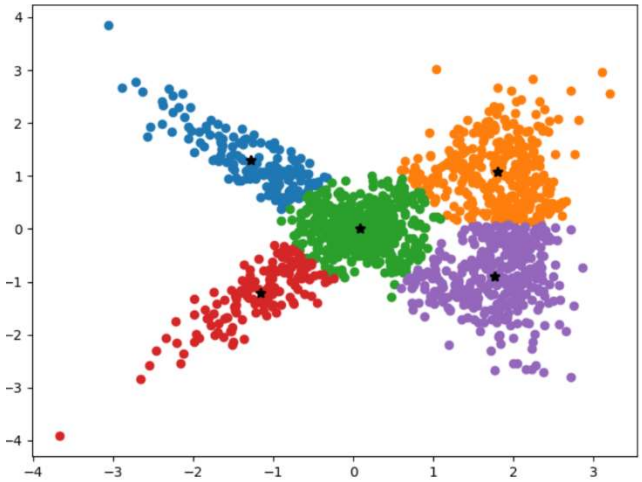
r = 5



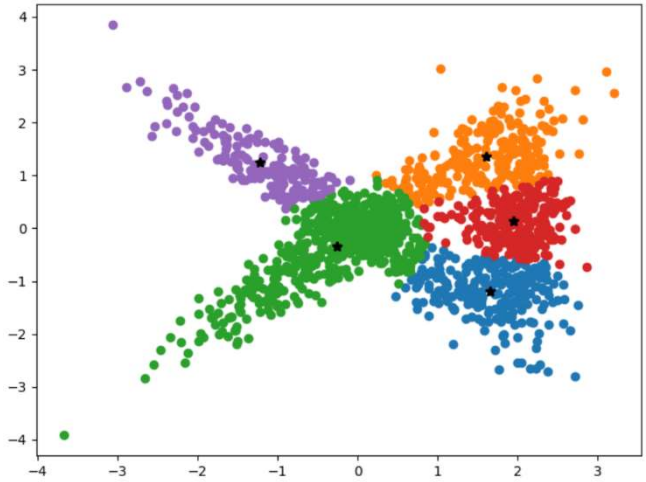
r = 6



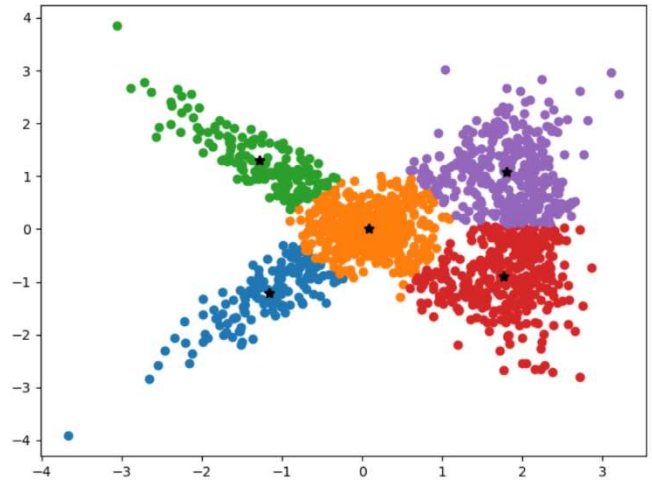
r = 7



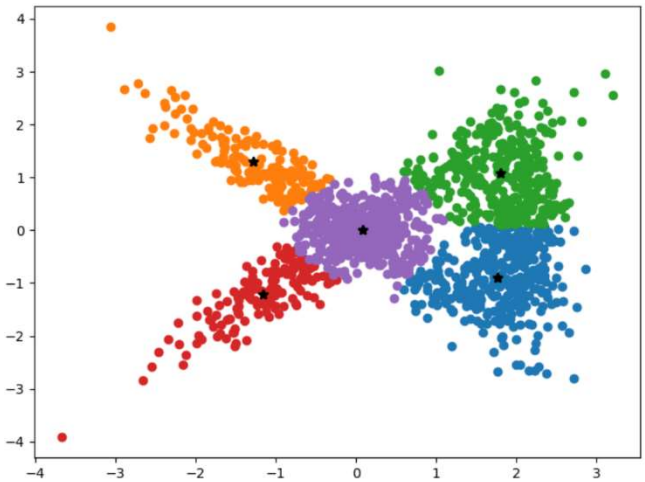
r = 8



r = 9



r = 10



```
C:\Users\SreeV\anaconda3\envs\tensor\pythonw.exe "C:/User
c =  5
initial centroid indexes =  [ 336  197 1184 1013 1062]
centroids converged, breaking the loop
r =  1 sum-square-error =  956.1808534054811

initial centroid indexes =  [1028 1316 1346  969  550]
centroids converged, breaking the loop
r =  2 sum-square-error =  956.1808527413785

initial centroid indexes =  [ 437  123  383  610 1017]
centroids converged, breaking the loop
r =  3 sum-square-error =  770.8956870769562

initial centroid indexes =  [ 861 1186 1326 1072 1105]
centroids converged, breaking the loop
r =  4 sum-square-error =  956.1808539644348

initial centroid indexes =  [1433 1477  385 1164  729]
centroids converged, breaking the loop
r =  5 sum-square-error =  956.1808534000768

initial centroid indexes =  [ 555 1186  355  603 1310]
centroids converged, breaking the loop
r =  6 sum-square-error =  770.8956868959972
```

```
initial centroid indexes =  [ 555 1186  355  603 1310]
centroids converged, breaking the loop
r =  6 sum-square-error =  770.8956868959972

initial centroid indexes =  [ 402  430  725 1357  777]
centroids converged, breaking the loop
r =  7 sum-square-error =  770.895686959511

initial centroid indexes =  [ 443  705 1338 1492 1425]
centroids converged, breaking the loop
r =  8 sum-square-error =  956.1808532428789

initial centroid indexes =  [1159  500 1321  486  535]
centroids converged, breaking the loop
r =  9 sum-square-error =  770.8956871040886

initial centroid indexes =  [ 657 1249  764  462 1368]
centroids converged, breaking the loop
r =  10 sum-square-error =  770.8956870883532

errors =  [956.1808534054811, 956.1808527413785, 770.895
min error when r = 6
error =  770.8956868959972

Process finished with exit code 0
```

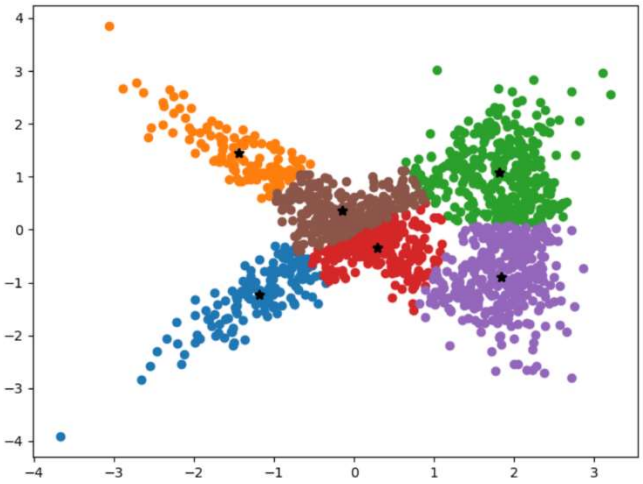
errors = [956.1808534054811, 956.1808527413785, 770.8956870769562, 956.1808539644348, 956.1808534000768, 770.8956868959972, 770.895686959511, 956.1808532428789, 770.8956871040886, 770.8956870883532]

min error when r = 6

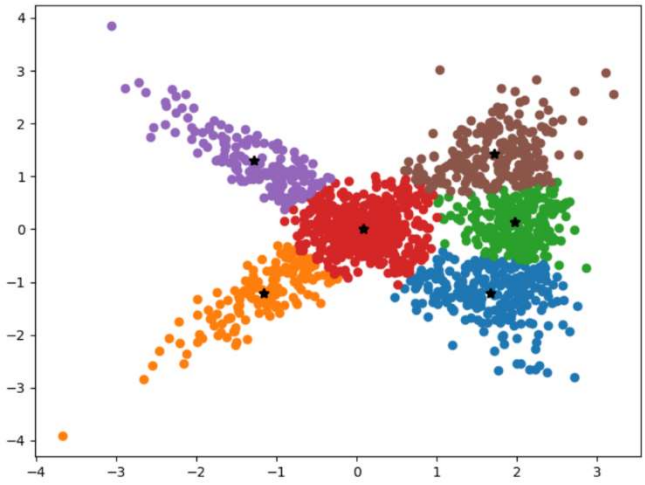
error = 770.895

4. **Number of clusters c = 6**

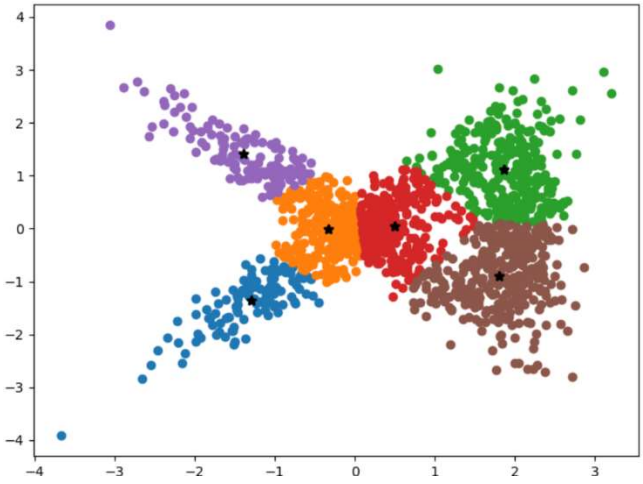
r = 1



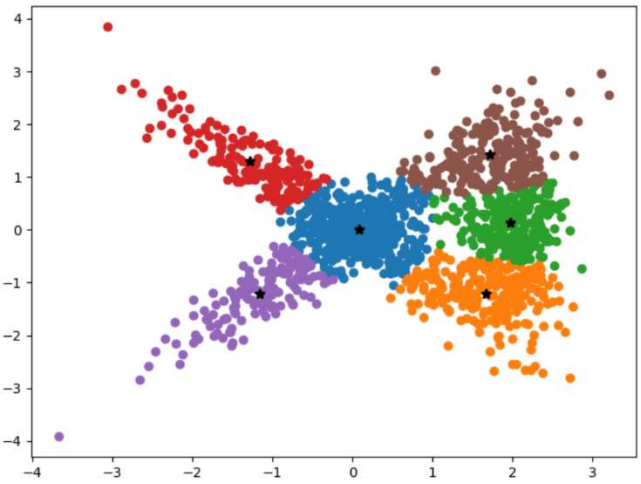
r =2



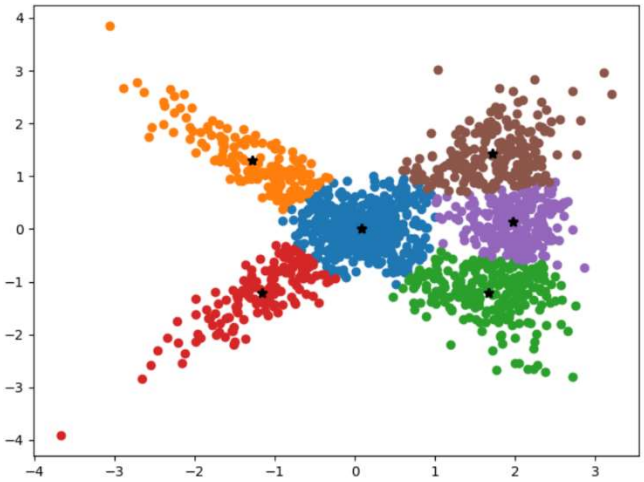
r = 3



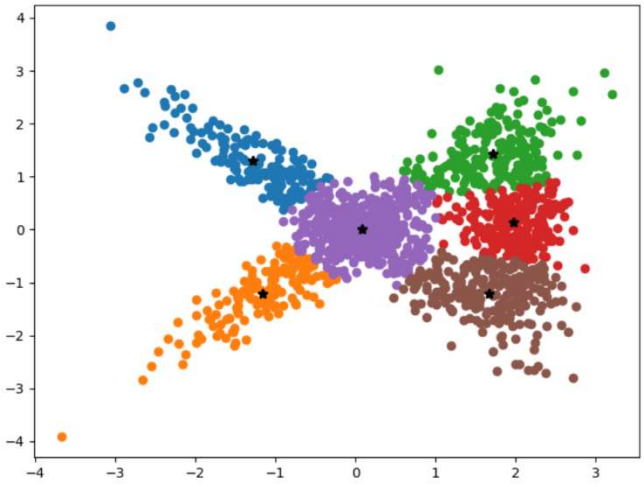
r = 4



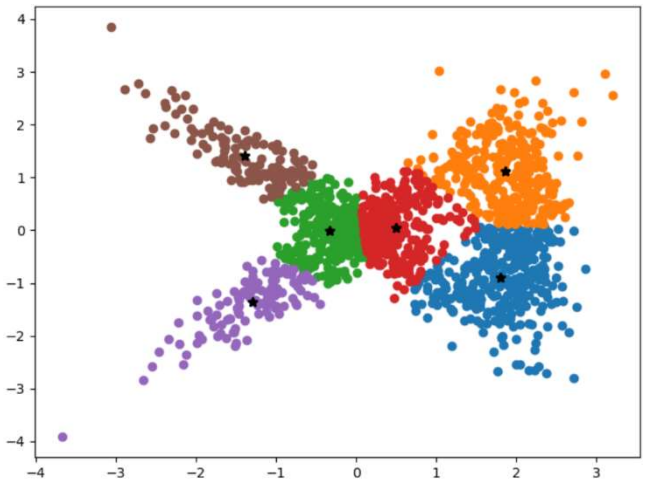
r = 5



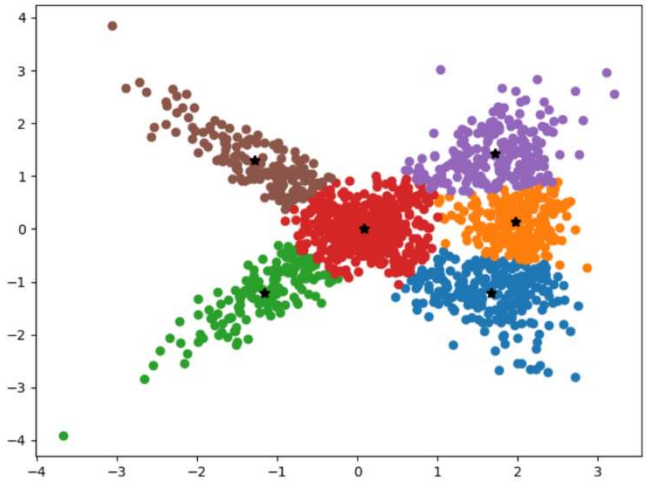
r = 6



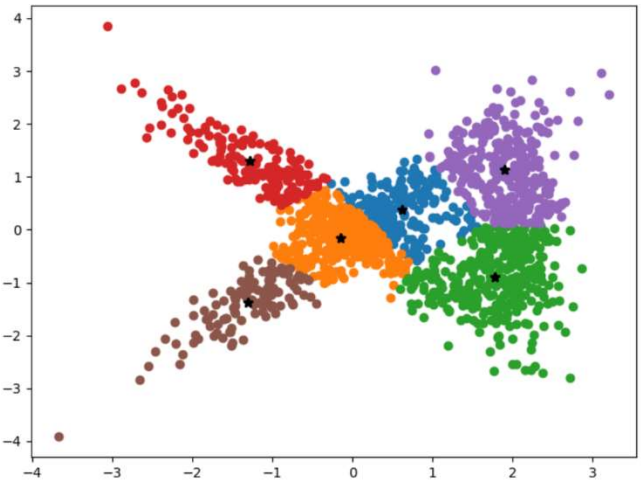
r = 7



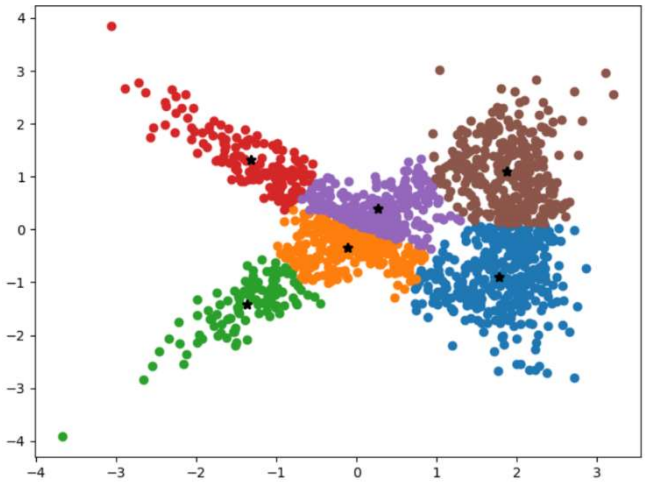
r = 8



r = 9



r = 10



```
C:\Users\SreeV\anaconda3\envs\tensor\pythonw.exe "C:/Users/Sree
c =  6
initial centroid indexes =  [ 984 1342 1471  127 1260  357]
r =  1 sum-square-error =  699.9069563150022

initial centroid indexes =  [ 252  898  178 1339  137  443]
centroids converged, breaking the loop
r =  2 sum-square-error =  624.6070466107832

initial centroid indexes =  [177 262 876 745 336 441]
centroids converged, breaking the loop
r =  3 sum-square-error =  694.0441957521407

initial centroid indexes =  [  3 460 676 406 537  44]
centroids converged, breaking the loop
r =  4 sum-square-error =  624.6070467945203

initial centroid indexes =  [ 115 1175 1193  988 1316  748]
centroids converged, breaking the loop
r =  5 sum-square-error =  624.6070467749153

initial centroid indexes =  [ 197 1154 1158  920  523  238]
centroids converged, breaking the loop
r =  6 sum-square-error =  624.6070468443941
```

```
initial centroid indexes =  [ 197 1154 1158  920  523  238]
centroids converged, breaking the loop
r =  6 sum-square-error =  624.6070468443941

initial centroid indexes =  [1490  245  516 1305  786 1064]
r =  7 sum-square-error =  694.0465738469659

initial centroid indexes =  [1177 1018 1374  988  453   56]
centroids converged, breaking the loop
r =  8 sum-square-error =  624.607046503125

initial centroid indexes =  [1129  456 1110 1026 1216 1033]
r =  9 sum-square-error =  696.6570181863143

initial centroid indexes =  [ 298  293 1424  205  227  971]
r =  10 sum-square-error =  697.6056009573701

errors =  [699.9069563150022, 624.6070466107832, 694.044195752
min error when r = 8
error =  624.607046503125

Process finished with exit code 0
```

Sum-square-error at each ‘r’

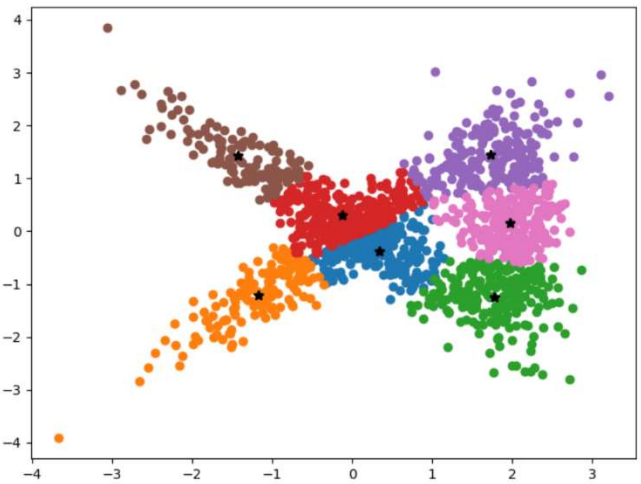
errors = [699.9069563150022, 624.6070466107832, 694.0441957521407, 624.6070467945203, 624.6070467749153, 624.6070468443941, 694.0465738469659, 624.607046503125, 696.6570181863143, 697.6056009573701]

min error when r = 8

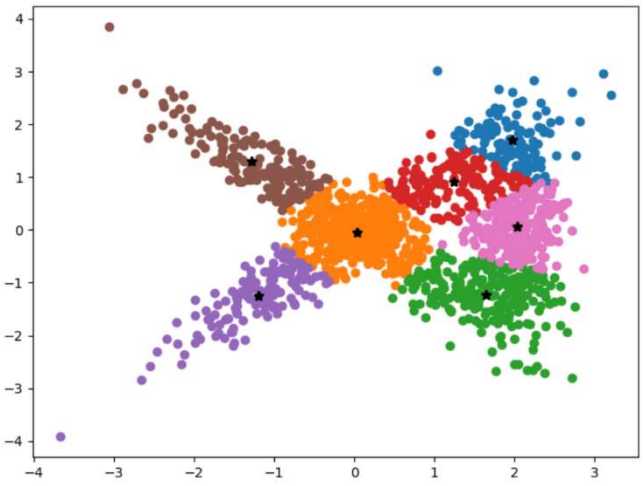
error = 624.607

5. Number of Clusters c = 7

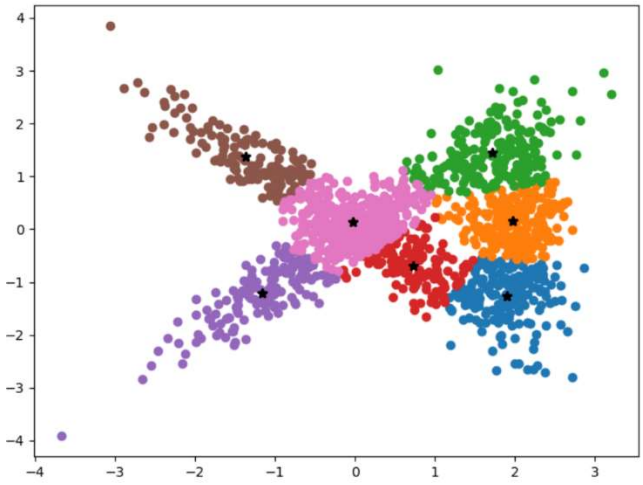
r = 1



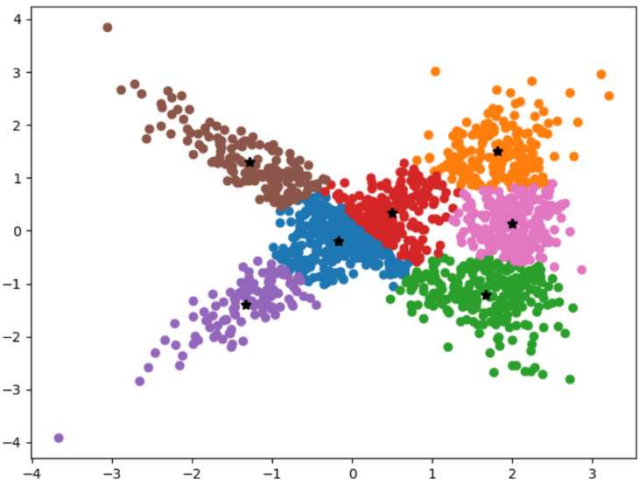
r = 2



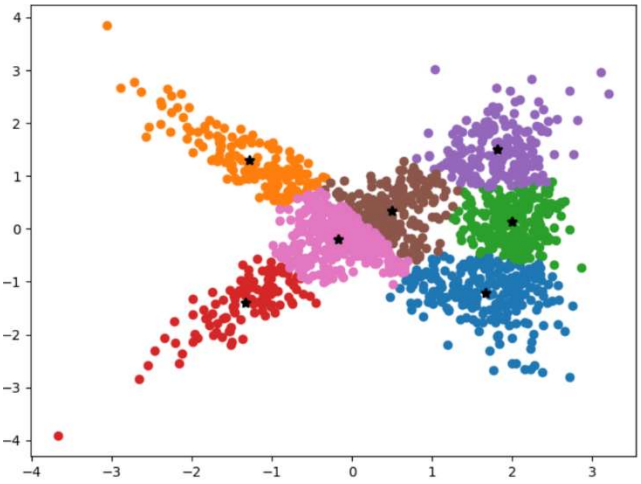
r = 3



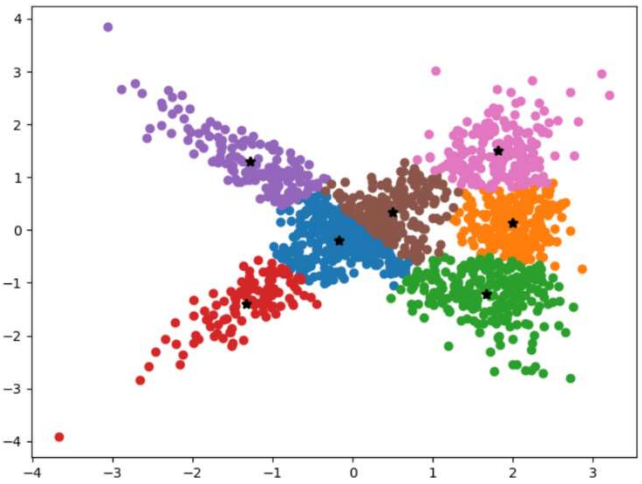
r = 4



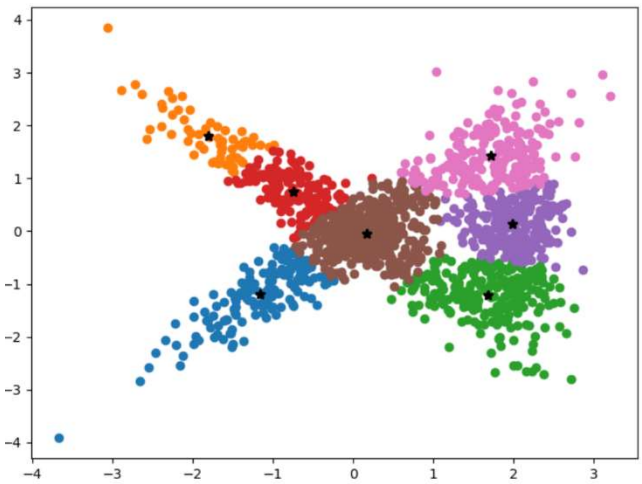
r = 5



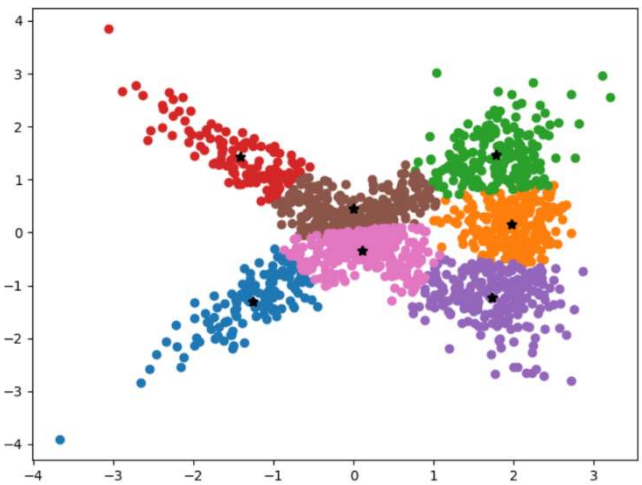
r = 6



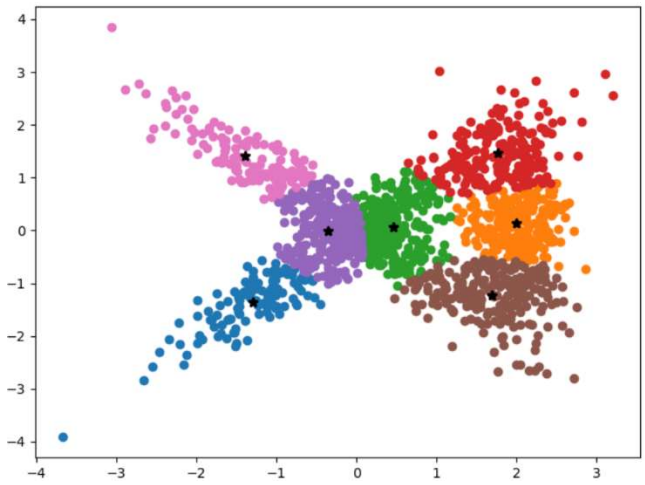
r = 7



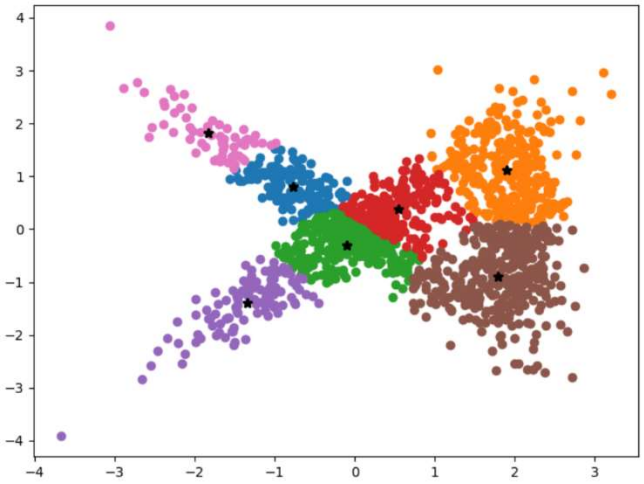
r = 8



r = 9



r = 10



```
C:\Users\SreeV\anaconda3\envs\tensor\pythonw.exe "C:/Users/SreeV/
c =  7
initial centroid indexes =  [ 304  474 1224  774  703  185  912]
r =  1 sum-square-error =  555.3647543266103

initial centroid indexes =  [ 123  892 1397  665 1064  954 1416]
r =  2 sum-square-error =  563.7519828480494

initial centroid indexes =  [ 512  460 1208  372 1121  326 1082]
r =  3 sum-square-error =  558.3549725330115

initial centroid indexes =  [  57  794  661  559  857 1298  506]
r =  4 sum-square-error =  551.0542409587613

initial centroid indexes =  [  50  670 1062  289  667  143 1423]
r =  5 sum-square-error =  551.0597524007748

initial centroid indexes =  [1022  738 1377 1166 1369  362  470]
r =  6 sum-square-error =  551.0349344054191

initial centroid indexes =  [1202 1230  647  236  338  735  890]
centroids converged, breaking the loop
r =  7 sum-square-error =  549.7452459702632

initial centroid indexes =  [1202 1230  647  236  338  735  890]
centroids converged, breaking the loop
r =  7 sum-square-error =  549.7452459702632

initial centroid indexes =  [ 341  873 1389  174  654  112  842]
r =  8 sum-square-error =  553.7463108224292

initial centroid indexes =  [1202 1323 1082  246  306 1260 1276]
r =  9 sum-square-error =  548.4686375549801

initial centroid indexes =  [  10  843  132 1029 1192  952  573]
r =  10 sum-square-error =  621.9494436549519

errors =  [555.3647543266103, 563.7519828480494, 558.3549725330115
min error when r = 9
error =  548.4686375549801

Process finished with exit code 0
```

Sum-square-errors at each r

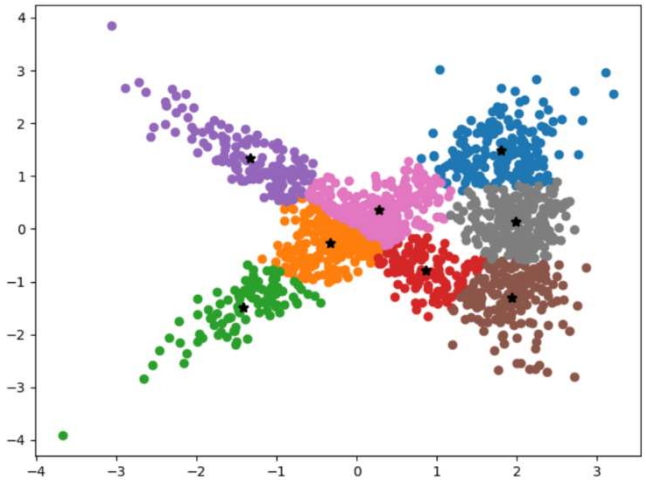
errors = [555.3647543266103, 563.7519828480494, 558.3549725330115, 551.0542409587613, 551.0597524007748, 551.0349344054191, 549.7452459702632, 553.7463108224292, 548.4686375549801, 621.9494436549519]

min error when r = 9

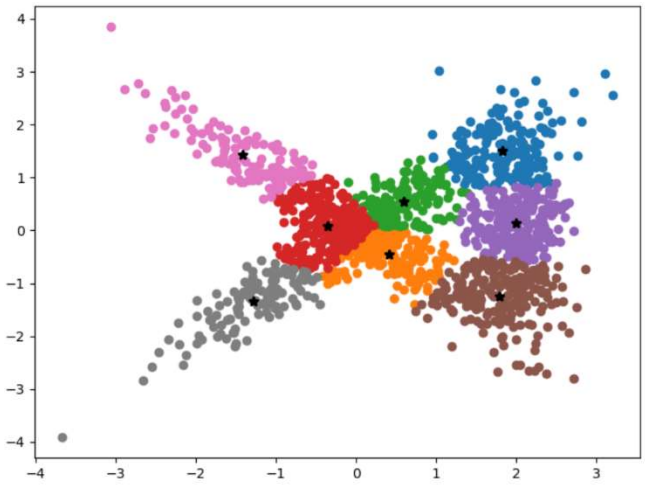
error = 548.468

6. Number of clusters c = 8

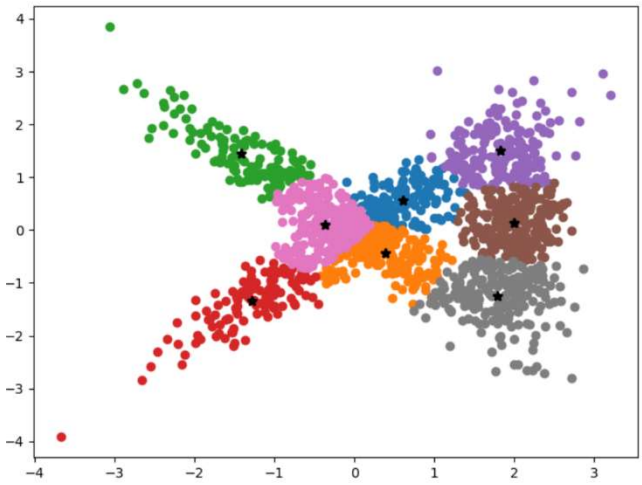
r = 1



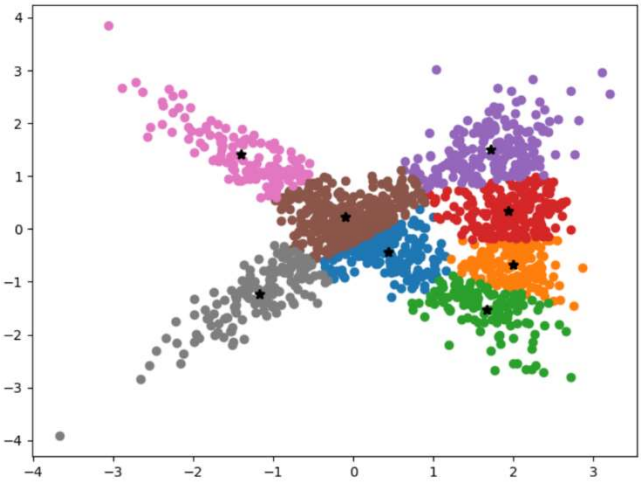
r = 2



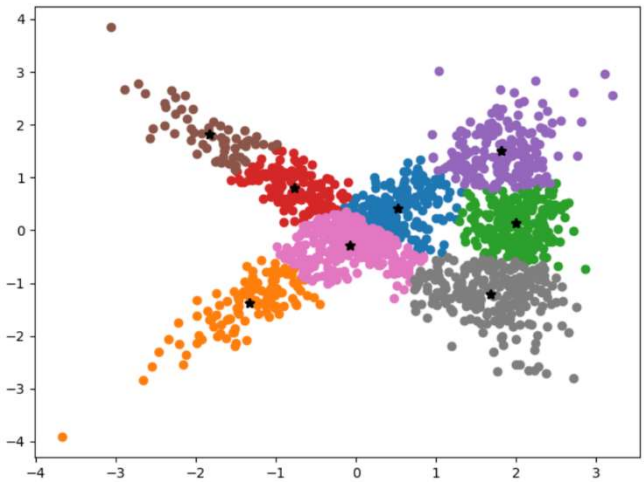
r = 3



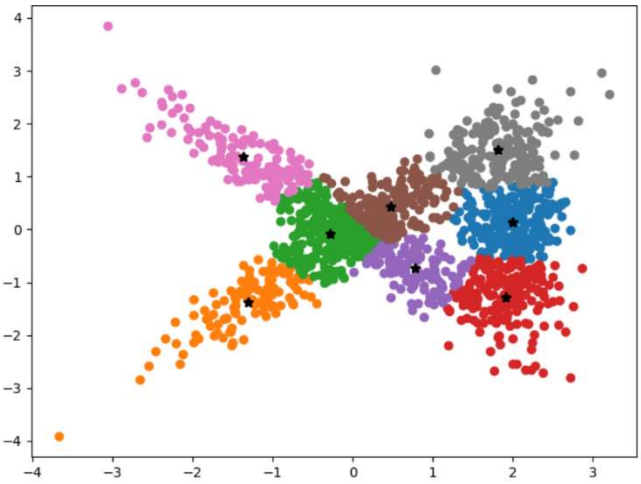
r = 4



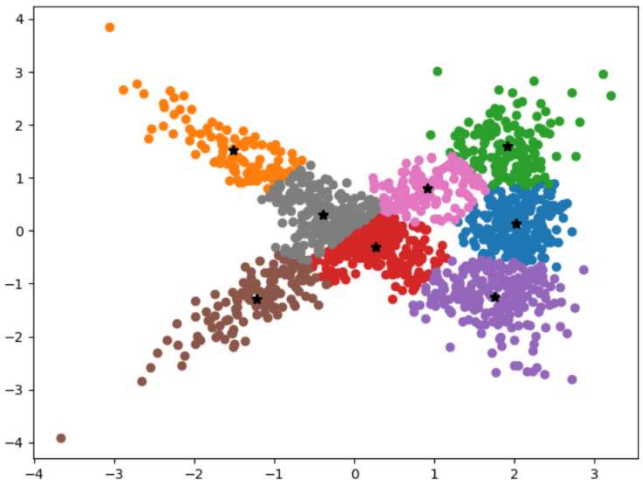
r = 5



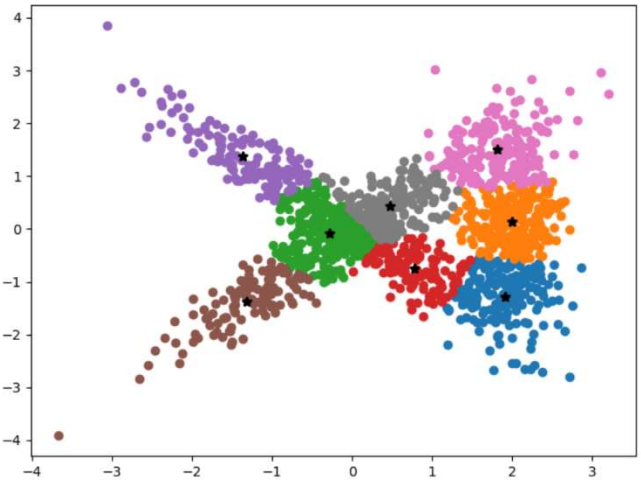
r =6



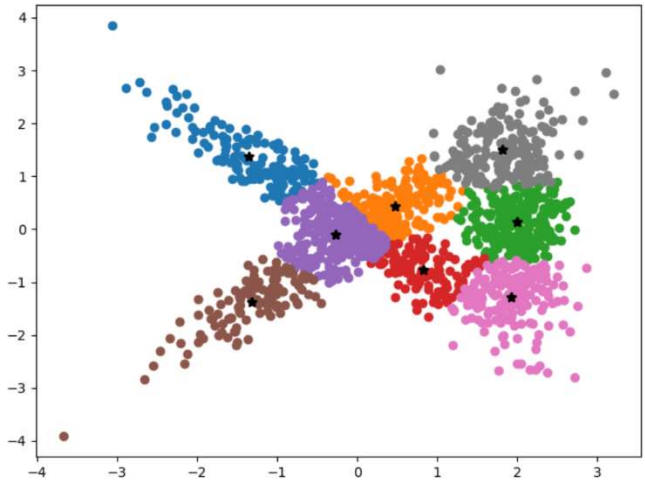
r = 7



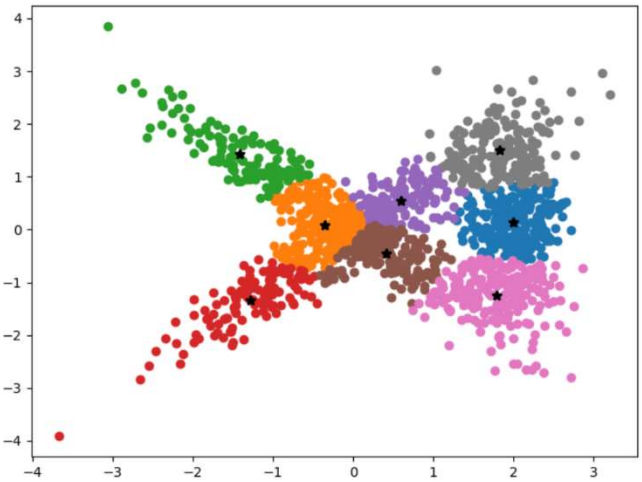
r = 8



r = 9



r =10



```
C:\Users\SreeV\anaconda3\envs\tensor\pythonw.exe "C:/Users/SreeV/Pycharm
c =  8
initial centroid indexes =  [ 443 1490  131  494 1231 1367  542  730]
r =  1 sum-square-error =  486.3925913111946

initial centroid indexes =  [1313  572   44  412  456  965  401 1207]
r =  2 sum-square-error =  484.2298996072921

initial centroid indexes =  [1224 1213 1167  524   93  511  986 1340]
r =  3 sum-square-error =  484.25913295844225

initial centroid indexes =  [ 967 1115 1058  558 1225 1300  294 1286]
r =  4 sum-square-error =  520.3886634289895

initial centroid indexes =  [ 533  408 1042 1493  291  737 1325 1099]
r =  5 sum-square-error =  477.01098960314926

initial centroid indexes =  [ 346 1067  288 1043 1405  248   33  384]
r =  6 sum-square-error =  485.6107591223442

initial centroid indexes =  [ 325 1330  384 1062  187  763  718   55]
r =  7 sum-square-error =  486.83061355181144

initial centroid indexes =  [ 169  578  465  249  237  624 1132  204]
centroids converged, breaking the loop
r =  8 sum-square-error =  485.60886053223834
```

```
initial centroid indexes =  [ 169  578  465  249  237  624 1132  204]
centroids converged, breaking the loop
r =  8 sum-square-error =  485.60886053223834

initial centroid indexes =  [ 608  883   55  569  594 1041  596 1027]
r =  9 sum-square-error =  485.66132909418036

initial centroid indexes =  [ 108  618 1072  711 1497   52  239 1149]
r =  10 sum-square-error =  484.22900236252883

errors =  [486.3925913111946, 484.2298996072921, 484.25913295844225, 52
min error when r = 5
error =  477.01098960314926

Process finished with exit code 0
```

Sum-square-error at each ‘r’

errors = [486.3925913111946, 484.2298996072921, 484.25913295844225, 520.3886634289895, 477.01098960314926, 485.6107591223442, 486.83061355181144, 485.60886053223834, 485.66132909418036, 484.22900236252883]

min error when r = 5

error = 477.010

I ran this algorithm for different number of clusters ‘c’ (c = 3 to 8). And for each ‘c’ value it is ran for ‘r’ (10) times. Below table shows selected models sum-square-error for each ‘c’ value and ‘r’ value at which that model occurred.

C Value	**Minimum Sum-Square Error**	**Model occurred at ‘r’**
C = 3	1536.793	10
C = 4	1100.432	5
C = 5	770.895	6
C = 6	624.607	8
C = 7	548.468	9
C = 8	477.010	5