Unsupervised Learning: PSet 4

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```
#Setups
library(haven)
library(tidyverse)
library(dplyr)
library(lattice)
library(psych)
library(GPArotation)
library(ggplot2)
library(gridExtra)
library(ggfortify)
```

```
## Warning: package 'ggfortify' was built under R version 3.5.3
```

```
library(sparsepca)
```

```
## Warning: package 'sparsepca' was built under R version 3.5.3
```

Factor analysis

1.

How do CFA and EFA differ?

The main difference between CFA and EFA is the existance of a pre-established theory of factors that could explain the data.

CFA, on one hand, pre-establishes a theory related to an amount of factors that could explain the covariation on an input feature loading, and then tries to test that hypothesis.

EFA, on the other hand, does not rely on an initial theory, but rather use factor loading to intuit the factor structure of the data. I.e, it tries to discover how many latent dimensions are needed to account for the covariation among the indicators, rather than testing a certain specific amount.

2.

Fit three exploratory factor analysis models initialized at 2, 3, and 4 factors. Present the loadings from these solutions and discuss in substantive terms. How does each fit? What sense does this give you of the underlying dimensionality of the space? And so on.

```
# Load the data
countries <- read.csv(file.choose(), header = TRUE)

#Standarize data. All columns but the first one.
countries[, -c(1)] <- scale(countries[, -c(1)])
```

```r
# Fit the factor analysis model with 2,3 and 4 factors
factan.1 <- fa(countries[-1],
               nfactors = 2)
factan.2 <- fa(countries[-1],
               nfactors = 3)
factan.3 <- fa(countries[-1],
               nfactors = 4)
```

```r
# Inspect loadings
factan.1$loadings
```

```
##
## Loadings:
##            MR1    MR2
## idealpoint  0.449  0.429
## polity      0.995
## polity2     0.995
## democ       0.931
## autoc      -0.969  0.159
## unreg       0.412 -0.131
## physint             0.782
## speech      0.631  0.154
## new_empinx  0.802  0.197
## wecon               0.509
## wopol       0.551
## wosoc       0.286  0.497
## elecsd      0.852
## gdp.pc.wdi          0.673
## gdp.pc.un           0.671
## pop.wdi     0.204 -0.476
## amnesty            -0.821
## statedept          -0.849
## milper      0.158 -0.468
## cinc        0.211 -0.366
## domestic9   0.288 -0.479
##
##                  MR1   MR2
## SS loadings    6.523 4.527
## Proportion Var 0.311 0.216
## Cumulative Var 0.311 0.526
```

```r
factan.2$loadings
```

```
##
## Loadings:
##            MR1    MR2    MR3
## idealpoint  0.432  0.468
## polity      0.992
## polity2     0.992
## democ       0.910  0.144
## autoc      -0.994  0.191
```

```
## unreg       0.413 -0.129
## physint            0.737 -0.136
## speech      0.646  0.128
## new_empinx  0.840  0.131 -0.125
## wecon              0.518
## wopol       0.552
## wosoc       0.263  0.547
## elecsd      0.858
## gdp.pc.wdi         0.856  0.158
## gdp.pc.un          0.853  0.157
## pop.wdi                   0.892
## amnesty           -0.715  0.243
## statedept         -0.803  0.144
## milper                    0.949
## cinc                      0.999
## domestic9   0.269 -0.443
##
##                  MR1   MR2   MR3
## SS loadings    6.466 4.275 2.881
## Proportion Var 0.308 0.204 0.137
## Cumulative Var 0.308 0.512 0.649
```

```
factan.3$loadings
```

```
##
## Loadings:
##            MR1    MR3    MR4    MR2
## idealpoint  0.467         0.214 -0.294
## polity      0.995
## polity2     0.995
## democ       0.922         0.127
## autoc      -0.986         0.146
## unreg       0.405                 0.165
## physint     0.119                -0.761
## speech      0.658                -0.109
## new_empinx  0.855                -0.145
## wecon       0.105         0.390 -0.170
## wopol       0.555
## wosoc       0.300         0.350 -0.239
## elecsd      0.865
## gdp.pc.wdi                0.986
## gdp.pc.un                 0.979
## pop.wdi            0.923
## amnesty            0.177 -0.197  0.602
## statedept  -0.137         -0.139  0.783
## milper             0.965
## cinc               0.981  0.111
## domestic9   0.247         0.204  0.757
##
##                  MR1   MR3   MR4   MR2
## SS loadings    6.605 2.811 2.426 2.370
## Proportion Var 0.315 0.134 0.116 0.113
## Cumulative Var 0.315 0.448 0.564 0.677
```

The factor loadings discovered are the coefficients that relate the different latent variables discovered with each of the observed features.

$$Observed\_feature_j = \sum_{i}^{n\_factors} factor\_loading_{ij} * factor_{ij}$$

We can notice that in all the models the SS loadings - i.e. eigenvalues - of each factor are high (all over 1), and hence, all are helping to explain the variance in the variables.

Numerically, the total proportion of variance that models with 2,3 and 4 factors explain are 0.527, 0.649 and 0.678 respectively. We can then observe how the introduction of the 4th factor did not actually help to improve too much the amount of variance in the data. It seems then that a model with 3 factors would be more appropiate.

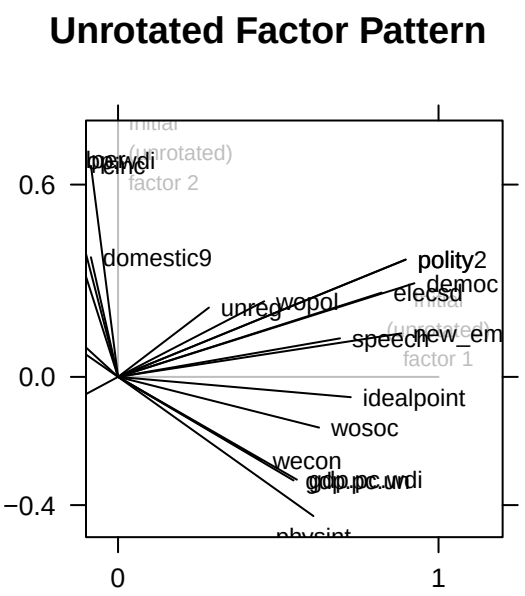
Lastly, it is also important to mention that we can observe some cross loadings on many variables, for all models. This means that, for those variables, it is not possible to explain their variance only with one factor, and hence we use a combination of them. i.e. there is not a clear unobserved factor that sufficiently describe the data.

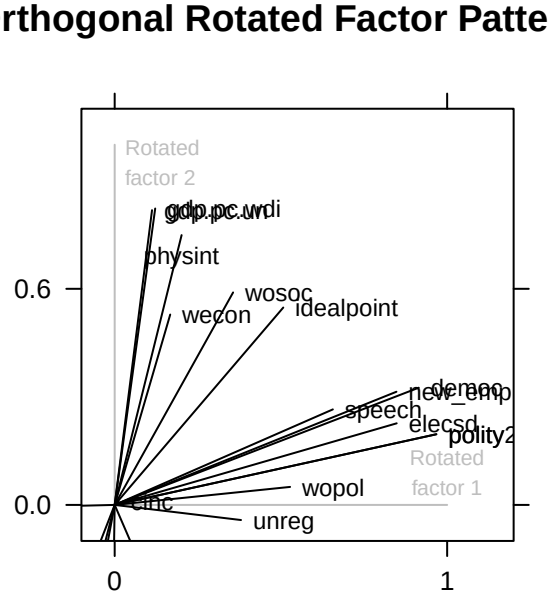
3.

Rotate the 3-factor solution using any oblique method you would like and present a visual of the unrotated and rotated versions side-by-side. How do these differ and why does this matter (or not)?_

```
r.factan.3 <- fa(countries[,-1],
                 nfactors = 3,
                 rotate = "varimax")

## Initial (unrotated) factor solution
nonrotated.factors <- fa(cor(countries[,-1]),
        fm = "pa", # communalities along the diagonal (total variation across features)
        nfactors = 3,
        rotate = "none",
        residuals = TRUE)

# Store a dataframe of loadings to build out a plot
nonrot.pattern <- as.data.frame(nonrotated.factors$loadings[1:21,])

# Save plot unrotated factor pattern
unrotated.plot <- xyplot(PA2 ~ PA1, data = nonrot.pattern,
       aspect = 1,
       xlim = c(-.1, 1.2),
       ylim = c(-.5, .8),
       panel = function (x, y) {
         panel.segments(c(0, 0), c(0, 0),
             c(1, 0), c(0, 1), col = "gray")
         panel.text(1, 0, labels = "Initial\n(unrotated)\nfactor 1",
                    cex = .65, pos = 3, col = "gray")
         panel.text(0, .7, labels = "Initial\n(unrotated)\nfactor 2",
                    cex = .65, pos = 4, col = "gray")
         panel.segments(rep(0, 8), rep(0, 8), x, y,
            col = "black")
         panel.text(x[-7], y[-7], labels = rownames(nonrot.pattern)[-7],
            pos = 4, cex = .75)
```

```
        panel.text(x[7], y[7], labels = rownames(nonrot.pattern)[7],
                   pos = 1, cex = .75)
      },
      main = "Unrotated Factor Pattern",
      xlab = "",
      ylab = "",
      scales = list(x = list(at = c(0, 1)),
                    y = list(at = c(-.4, 0, .6)))
)


# Orthogonal (varimax) rotated factor solution
varimax.factors <- fa(cor(countries[,-1]),
                      fm = "pa",
                      nfactors = 3,
                      rotate = "varimax",
                      smc = TRUE)

# Plot the factor pattern
orthog.pattern <- as.data.frame(varimax.factors$loadings[1:21,])

rotated.plot <-xyplot(PA2 ~ PA1, data = orthog.pattern,
      aspect = 1,
      xlim = c(-.1, 1.2),
      ylim = c(-.1, 1.1),
      panel = function (x, y) {
        panel.segments(c(0, 0), c(0, 0),
                       c(1, 0), c(0, 1), col = "gray")
        panel.text(1, 0, labels = "Rotated\nfactor 1",
                   cex = .65, pos = 3, col = "gray")
        panel.text(0, .95, labels = "Rotated\nfactor 2",
                   cex = .65, pos = 4, col = "gray")
        panel.segments(rep(0, 8), rep(0, 8), x, y,
                       col = "black")
        panel.text(x[-7], y[-7], labels = rownames(orthog.pattern)[-7],
                   pos = 4, cex = .75)
        panel.text(x[7], y[7], labels = rownames(orthog.pattern)[7],
                   pos = 1, cex = .75)
      },
      main = "Orthogonal Rotated Factor Pattern",
      xlab = "",
      ylab = "",
      scales = list(x = list(at = c(0, 1)),
                    y = list(at = c(-.4, 0, .6)))
)


grid.arrange(unrotated.plot, rotated.plot, ncol=2)
```





When we rotate, we move the factors around in space so they can explain the same amount of variance. At the same time, we are able to create a more interpretable version. As a matter of fact, the rotated version allows us to have a more clear visual representation of how close are the variables to the different axes (assumed latent factors). What we we are doing by rotation is changing the reference axes, which are arbitrary anyway; the goal is merely to make patterns more obvious, rather than change patterns.

From our plots we can observe how the second rotated one allowa us to identify more easily which variables are together and to which fator. This matter a lot because it helps interpretability an also as a means of sanity check (if we have previous knolwedge of factor that usually represent the same amount of variation, we would expect them to be together.)

Principal Components Analysis

1.

What is the statistical difference between PCA and FA? Describe the basic construction of each approach using equations and then point to differences that exist across these two widely used methods for reducing dimensionality.

In Factor Analysis, we try to find the underlying/hidden factors(components) that are assumed to be the cause of the observed indicators. Mathematically, this can be expressed as

$$X_1 = b_1 F + d_1 U_1$$

where X_1 is our observed variables, and F and U_1 are the factors to be discovered.

In Principal Components Analysis, a different approach is used. Here, we get the components/factors that are outcomes built from combinations of the items. Mathematically, we can express this idea as

$$Comp_1 = L_1X_1 + L_2X_2 + \cdots + L_kX_k$$

Where $Comp_1$ is the component we are trying to find, based on the combinations of the observables X_1, X_2, etc.

A significant different is that in FA, in contrast with PCA, we make assumptions on the latent structure, number of components, rotations, etc. In addition, FA assumes that the latent variables are Gaussian. In contrast, PCA, because it does not impose any distributional assumptions on the latent factors, allows for true statistical independence.

Whenever there are good reasons to assume Gaussian latent variables, FA might be worth considering over PCA. In all other cases, PCA seems to be more reliable.

2.

Fit a PCA model. Present the proportion of explained variance across the first 10 components. What do these values tell you substantively (e.g., how many components likely characterize these data?)?

```
countries_pca <- countries

#Move X column to index and remove it as a column
rownames(countries_pca) <- countries_pca$X

countries_pca <- countries_pca[, -c(1)]

pca.out <- prcomp(countries_pca, scale = TRUE)

summary(pca.out)
```

```
## Importance of components:
##                           PC1    PC2    PC3     PC4     PC5     PC6
## Standard deviation     2.9173 1.8600 1.6439 1.10713 1.07631 0.91289
## Proportion of Variance 0.4053 0.1648 0.1287 0.05837 0.05516 0.03968
## Cumulative Proportion  0.4053 0.5700 0.6987 0.75708 0.81225 0.85193
##                           PC7     PC8     PC9    PC10    PC11    PC12
## Standard deviation     0.78181 0.72948 0.64421 0.58703 0.55164 0.49341
## Proportion of Variance 0.02911 0.02534 0.01976 0.01641 0.01449 0.01159
## Cumulative Proportion  0.88104 0.90638 0.92614 0.94255 0.95704 0.96864
##                           PC13   PC14    PC15    PC16    PC17    PC18
## Standard deviation     0.46337 0.3995 0.32765 0.29011 0.24347 0.18215
## Proportion of Variance 0.01022 0.0076 0.00511 0.00401 0.00282 0.00158
## Cumulative Proportion  0.97886 0.9865 0.99157 0.99558 0.99840 0.99998
##                           PC19      PC20      PC21
## Standard deviation     0.01990 5.378e-16 2.786e-16
## Proportion of Variance 0.00002 0.000e+00 0.000e+00
## Cumulative Proportion  1.00000 1.000e+00 1.000e+00
```

From the previous summary we can observe the proportion of variance explained by the first 10 components:

$$\begin{bmatrix} 0.4053 \\ 0.1648 \\ 0.1287 \\ 0.05837 \\ 0.05516 \\ 0.03968 \\ 0.02911 \\ 0.02534 \\ 0.01976 \\ 0.01641 \end{bmatrix}$$

adding up to a total of 0.95263. These values explain how much of the variance in the data can be explained by each of these 10 principal components.

We can also observe that the proportion of variance explained by the first components is significantly bigger than the rest. In addition, only the first 5 components add up to 0.81 of the proportion of variance explained. It seems like 5 is a reasonable number of components to characterize these data.

3.

Present a biplot of the PCA fit from the previous question. Describe what you see (e.g., which countries are clustered together? Which input features are doing the bulk of the explaining? How do you know this?

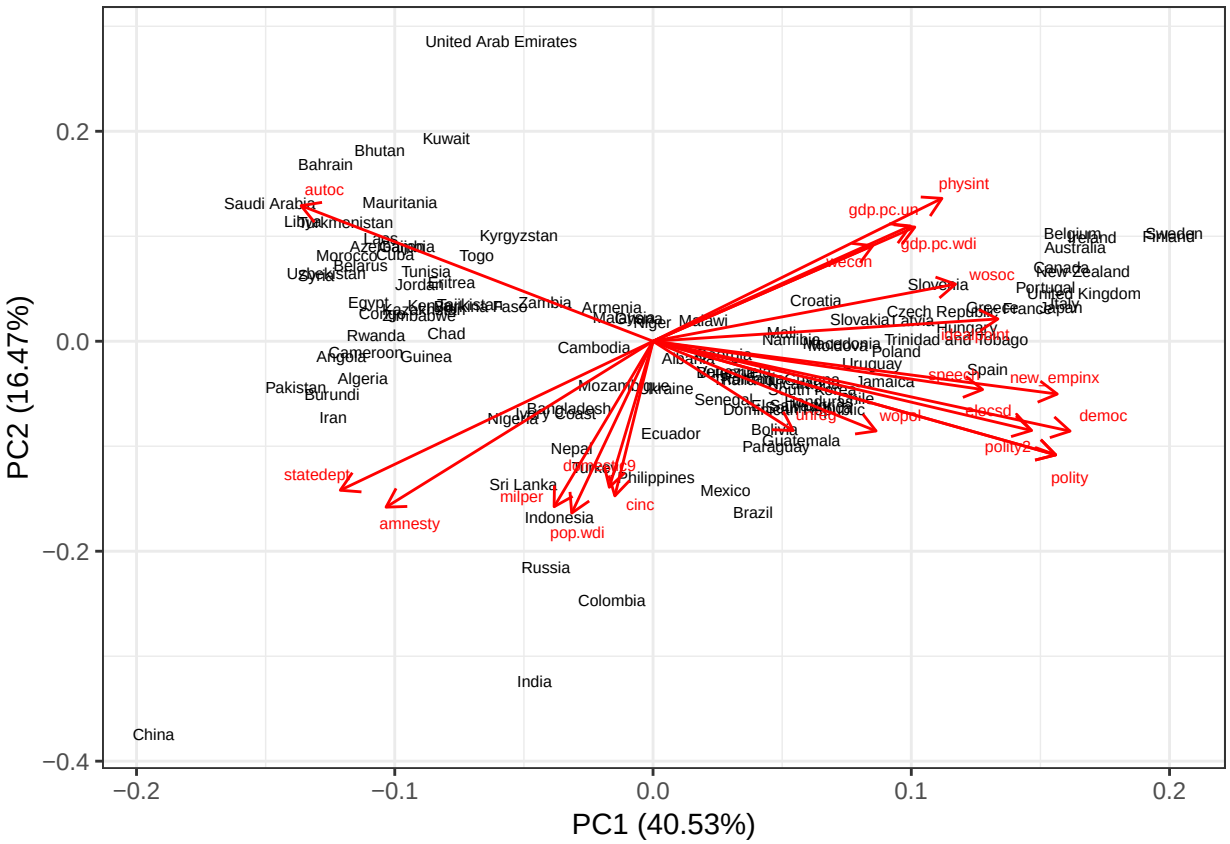
The most distinguishable cluster is the one seen on the upper left side of the plot, where many middle east countries are together (Saudi Araibia, Pakistan, Iran, etc). Autoc is the input feature that is doing the bulk of the clustering here.

On the lower right side of the plot we observe many input features that overlapp. Some of them are polity, democ, wopol, unreg. In this cluset we see some Latin American and Caribean countries such as Guatemala, Paraguay, Bolivia, Dominican Republic, Chile, Uruguay and Jamaica.

A last cluster is made of more developed countries such as Canada, United Kingdom, Portugal, Belgium, Australia, etc. These are clustered around input features such as wosoc and idealpbint.

We know these because in the plot we can observe by which input feature vectors can the position vectors of the countries be represented.

```
# visualize
autoplot(pca.out,
         shape = F, # names instead of points
         label.size=2,
         loadings.label = T,  # show the loading directions
         loadings.label.repel = T,
         loadings.label.size=2) +
theme_bw()
```



Bonus

Fit a sparse PCA model and a probabilistic PCA model. Compare these results substantively. What does each tell you and why do these distinctions matter in terms of inference (or not)?

```
#library(pcaMethods)
#probabilistic_model <- pca(countries_pca, scale = "uv", center = T,
#                       nPcs = 2, method = "ppca")
#probabilistic_model$loadings

#Having compatibility issues with R


sparse_model <- robspca(countries_pca, k = NULL, alpha = 1e-04, beta = 1e-04, gamma = 100, center = TRU
verbose = TRUE)
```

```
## [1] "Iteration:    2, Objective: 6.79470e+00, Relative improvement 6.01962e-04"
## [1] "Iteration:    3, Objective: 6.79096e+00, Relative improvement 5.50831e-04"
## [1] "Iteration:    4, Objective: 6.78747e+00, Relative improvement 5.14668e-04"
## [1] "Iteration:    5, Objective: 6.78416e+00, Relative improvement 4.87157e-04"
## [1] "Iteration:    6, Objective: 6.78103e+00, Relative improvement 4.62488e-04"
## [1] "Iteration:    7, Objective: 6.77802e+00, Relative improvement 4.42710e-04"
## [1] "Iteration:    8, Objective: 6.77514e+00, Relative improvement 4.25512e-04"
## [1] "Iteration:    9, Objective: 6.77237e+00, Relative improvement 4.09920e-04"
```

```
## [1] "Iteration:   10, Objective: 6.76969e+00, Relative improvement 3.95697e-04"
## [1] "Iteration:   11, Objective: 6.76709e+00, Relative improvement 3.84129e-04"
## [1] "Iteration:   12, Objective: 6.76456e+00, Relative improvement 3.73606e-04"
## [1] "Iteration:   13, Objective: 6.76210e+00, Relative improvement 3.63417e-04"
## [1] "Iteration:   14, Objective: 6.75971e+00, Relative improvement 3.54239e-04"
## [1] "Iteration:   15, Objective: 6.75737e+00, Relative improvement 3.46247e-04"
## [1] "Iteration:   16, Objective: 6.75508e+00, Relative improvement 3.38396e-04"
## [1] "Iteration:   17, Objective: 6.75285e+00, Relative improvement 3.30580e-04"
## [1] "Iteration:   18, Objective: 6.75067e+00, Relative improvement 3.23246e-04"
## [1] "Iteration:   19, Objective: 6.74853e+00, Relative improvement 3.17353e-04"
## [1] "Iteration:   20, Objective: 6.74642e+00, Relative improvement 3.11924e-04"
## [1] "Iteration:   21, Objective: 6.74437e+00, Relative improvement 3.04899e-04"
## [1] "Iteration:   22, Objective: 6.74235e+00, Relative improvement 2.98399e-04"
## [1] "Iteration:   23, Objective: 6.74038e+00, Relative improvement 2.92453e-04"
## [1] "Iteration:   24, Objective: 6.73845e+00, Relative improvement 2.87054e-04"
## [1] "Iteration:   25, Objective: 6.73654e+00, Relative improvement 2.82979e-04"
## [1] "Iteration:   26, Objective: 6.73466e+00, Relative improvement 2.78684e-04"
## [1] "Iteration:   27, Objective: 6.73282e+00, Relative improvement 2.74367e-04"
## [1] "Iteration:   28, Objective: 6.73099e+00, Relative improvement 2.70969e-04"
## [1] "Iteration:   29, Objective: 6.72919e+00, Relative improvement 2.67801e-04"
## [1] "Iteration:   30, Objective: 6.72741e+00, Relative improvement 2.64798e-04"
## [1] "Iteration:   31, Objective: 6.72565e+00, Relative improvement 2.61948e-04"
## [1] "Iteration:   32, Objective: 6.72391e+00, Relative improvement 2.59239e-04"
## [1] "Iteration:   33, Objective: 6.72218e+00, Relative improvement 2.56663e-04"
## [1] "Iteration:   34, Objective: 6.72047e+00, Relative improvement 2.54209e-04"
## [1] "Iteration:   35, Objective: 6.71878e+00, Relative improvement 2.51869e-04"
## [1] "Iteration:   36, Objective: 6.71710e+00, Relative improvement 2.49636e-04"
## [1] "Iteration:   37, Objective: 6.71544e+00, Relative improvement 2.47503e-04"
## [1] "Iteration:   38, Objective: 6.71380e+00, Relative improvement 2.44878e-04"
## [1] "Iteration:   39, Objective: 6.71217e+00, Relative improvement 2.42802e-04"
## [1] "Iteration:   40, Objective: 6.71055e+00, Relative improvement 2.40286e-04"
## [1] "Iteration:   41, Objective: 6.70896e+00, Relative improvement 2.38216e-04"
## [1] "Iteration:   42, Objective: 6.70738e+00, Relative improvement 2.34806e-04"
## [1] "Iteration:   43, Objective: 6.70582e+00, Relative improvement 2.32124e-04"
## [1] "Iteration:   44, Objective: 6.70428e+00, Relative improvement 2.30661e-04"
## [1] "Iteration:   45, Objective: 6.70274e+00, Relative improvement 2.29135e-04"
## [1] "Iteration:   46, Objective: 6.70122e+00, Relative improvement 2.27669e-04"
## [1] "Iteration:   47, Objective: 6.69970e+00, Relative improvement 2.26262e-04"
## [1] "Iteration:   48, Objective: 6.69819e+00, Relative improvement 2.24908e-04"
## [1] "Iteration:   49, Objective: 6.69670e+00, Relative improvement 2.23607e-04"
## [1] "Iteration:   50, Objective: 6.69521e+00, Relative improvement 2.22355e-04"
## [1] "Iteration:   51, Objective: 6.69373e+00, Relative improvement 2.21149e-04"
## [1] "Iteration:   52, Objective: 6.69226e+00, Relative improvement 2.19886e-04"
## [1] "Iteration:   53, Objective: 6.69080e+00, Relative improvement 2.17228e-04"
## [1] "Iteration:   54, Objective: 6.68936e+00, Relative improvement 2.15057e-04"
## [1] "Iteration:   55, Objective: 6.68793e+00, Relative improvement 2.13922e-04"
## [1] "Iteration:   56, Objective: 6.68651e+00, Relative improvement 2.12893e-04"
## [1] "Iteration:   57, Objective: 6.68510e+00, Relative improvement 2.11451e-04"
## [1] "Iteration:   58, Objective: 6.68369e+00, Relative improvement 2.09717e-04"
## [1] "Iteration:   59, Objective: 6.68230e+00, Relative improvement 2.08108e-04"
## [1] "Iteration:   60, Objective: 6.68092e+00, Relative improvement 2.07226e-04"
## [1] "Iteration:   61, Objective: 6.67954e+00, Relative improvement 2.06385e-04"
## [1] "Iteration:   62, Objective: 6.67817e+00, Relative improvement 2.04825e-04"
## [1] "Iteration:   63, Objective: 6.67682e+00, Relative improvement 2.03289e-04"
```

```
## [1] "Iteration:   64, Objective: 6.67547e+00, Relative improvement 2.01545e-04"
## [1] "Iteration:   65, Objective: 6.67414e+00, Relative improvement 1.99538e-04"
## [1] "Iteration:   66, Objective: 6.67281e+00, Relative improvement 1.98894e-04"
## [1] "Iteration:   67, Objective: 6.67149e+00, Relative improvement 1.98180e-04"
## [1] "Iteration:   68, Objective: 6.67017e+00, Relative improvement 1.97489e-04"
## [1] "Iteration:   69, Objective: 6.66886e+00, Relative improvement 1.96656e-04"
## [1] "Iteration:   70, Objective: 6.66756e+00, Relative improvement 1.95022e-04"
## [1] "Iteration:   71, Objective: 6.66627e+00, Relative improvement 1.94172e-04"
## [1] "Iteration:   72, Objective: 6.66498e+00, Relative improvement 1.93557e-04"
## [1] "Iteration:   73, Objective: 6.66369e+00, Relative improvement 1.92961e-04"
## [1] "Iteration:   74, Objective: 6.66241e+00, Relative improvement 1.92382e-04"
## [1] "Iteration:   75, Objective: 6.66113e+00, Relative improvement 1.91819e-04"
## [1] "Iteration:   76, Objective: 6.65986e+00, Relative improvement 1.91258e-04"
## [1] "Iteration:   77, Objective: 6.65859e+00, Relative improvement 1.90341e-04"
## [1] "Iteration:   78, Objective: 6.65733e+00, Relative improvement 1.89892e-04"
## [1] "Iteration:   79, Objective: 6.65606e+00, Relative improvement 1.89368e-04"
## [1] "Iteration:   80, Objective: 6.65482e+00, Relative improvement 1.87406e-04"
## [1] "Iteration:   81, Objective: 6.65358e+00, Relative improvement 1.85640e-04"
## [1] "Iteration:   82, Objective: 6.65235e+00, Relative improvement 1.85062e-04"
## [1] "Iteration:   83, Objective: 6.65112e+00, Relative improvement 1.84571e-04"
## [1] "Iteration:   84, Objective: 6.64990e+00, Relative improvement 1.83954e-04"
## [1] "Iteration:   85, Objective: 6.64869e+00, Relative improvement 1.82233e-04"
## [1] "Iteration:   86, Objective: 6.64748e+00, Relative improvement 1.81739e-04"
## [1] "Iteration:   87, Objective: 6.64628e+00, Relative improvement 1.81311e-04"
## [1] "Iteration:   88, Objective: 6.64507e+00, Relative improvement 1.80897e-04"
## [1] "Iteration:   89, Objective: 6.64387e+00, Relative improvement 1.80496e-04"
## [1] "Iteration:   90, Objective: 6.64268e+00, Relative improvement 1.80107e-04"
## [1] "Iteration:   91, Objective: 6.64148e+00, Relative improvement 1.79731e-04"
## [1] "Iteration:   92, Objective: 6.64029e+00, Relative improvement 1.79366e-04"
## [1] "Iteration:   93, Objective: 6.63910e+00, Relative improvement 1.79012e-04"
## [1] "Iteration:   94, Objective: 6.63792e+00, Relative improvement 1.78668e-04"
## [1] "Iteration:   95, Objective: 6.63674e+00, Relative improvement 1.78335e-04"
## [1] "Iteration:   96, Objective: 6.63555e+00, Relative improvement 1.78012e-04"
## [1] "Iteration:   97, Objective: 6.63438e+00, Relative improvement 1.77698e-04"
## [1] "Iteration:   98, Objective: 6.63320e+00, Relative improvement 1.77393e-04"
## [1] "Iteration:   99, Objective: 6.63202e+00, Relative improvement 1.77097e-04"
## [1] "Iteration:  100, Objective: 6.63085e+00, Relative improvement 1.76809e-04"
## [1] "Iteration:  101, Objective: 6.62968e+00, Relative improvement 1.76529e-04"
## [1] "Iteration:  102, Objective: 6.62851e+00, Relative improvement 1.76258e-04"
## [1] "Iteration:  103, Objective: 6.62735e+00, Relative improvement 1.75994e-04"
## [1] "Iteration:  104, Objective: 6.62618e+00, Relative improvement 1.75737e-04"
## [1] "Iteration:  105, Objective: 6.62502e+00, Relative improvement 1.75488e-04"
## [1] "Iteration:  106, Objective: 6.62386e+00, Relative improvement 1.75246e-04"
## [1] "Iteration:  107, Objective: 6.62270e+00, Relative improvement 1.75010e-04"
## [1] "Iteration:  108, Objective: 6.62154e+00, Relative improvement 1.74782e-04"
## [1] "Iteration:  109, Objective: 6.62039e+00, Relative improvement 1.74559e-04"
## [1] "Iteration:  110, Objective: 6.61923e+00, Relative improvement 1.74343e-04"
## [1] "Iteration:  111, Objective: 6.61809e+00, Relative improvement 1.72226e-04"
## [1] "Iteration:  112, Objective: 6.61696e+00, Relative improvement 1.71051e-04"
## [1] "Iteration:  113, Objective: 6.61583e+00, Relative improvement 1.70694e-04"
## [1] "Iteration:  114, Objective: 6.61470e+00, Relative improvement 1.70395e-04"
## [1] "Iteration:  115, Objective: 6.61358e+00, Relative improvement 1.70127e-04"
## [1] "Iteration:  116, Objective: 6.61246e+00, Relative improvement 1.69883e-04"
## [1] "Iteration:  117, Objective: 6.61133e+00, Relative improvement 1.69656e-04"
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## [1] "Iteration:  118, Objective: 6.61021e+00, Relative improvement 1.69444e-04"
## [1] "Iteration:  119, Objective: 6.60910e+00, Relative improvement 1.69244e-04"
## [1] "Iteration:  120, Objective: 6.60798e+00, Relative improvement 1.69054e-04"
## [1] "Iteration:  121, Objective: 6.60686e+00, Relative improvement 1.68873e-04"
## [1] "Iteration:  122, Objective: 6.60575e+00, Relative improvement 1.68699e-04"
## [1] "Iteration:  123, Objective: 6.60464e+00, Relative improvement 1.68533e-04"
## [1] "Iteration:  124, Objective: 6.60352e+00, Relative improvement 1.68372e-04"
## [1] "Iteration:  125, Objective: 6.60241e+00, Relative improvement 1.68218e-04"
## [1] "Iteration:  126, Objective: 6.60130e+00, Relative improvement 1.68070e-04"
## [1] "Iteration:  127, Objective: 6.60020e+00, Relative improvement 1.67927e-04"
## [1] "Iteration:  128, Objective: 6.59909e+00, Relative improvement 1.67789e-04"
## [1] "Iteration:  129, Objective: 6.59798e+00, Relative improvement 1.67656e-04"
## [1] "Iteration:  130, Objective: 6.59688e+00, Relative improvement 1.67528e-04"
## [1] "Iteration:  131, Objective: 6.59577e+00, Relative improvement 1.67404e-04"
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## [1] "Iteration:  146, Objective: 6.57940e+00, Relative improvement 1.63767e-04"
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## [1] "Iteration:  335, Objective: 6.39216e+00, Relative improvement 1.44821e-04"
## [1] "Iteration:  336, Objective: 6.39124e+00, Relative improvement 1.44817e-04"
## [1] "Iteration:  337, Objective: 6.39031e+00, Relative improvement 1.44818e-04"
## [1] "Iteration:  338, Objective: 6.38939e+00, Relative improvement 1.44825e-04"
## [1] "Iteration:  339, Objective: 6.38846e+00, Relative improvement 1.44836e-04"
## [1] "Iteration:  340, Objective: 6.38754e+00, Relative improvement 1.44851e-04"
## [1] "Iteration:  341, Objective: 6.38661e+00, Relative improvement 1.44870e-04"
## [1] "Iteration:  342, Objective: 6.38569e+00, Relative improvement 1.44892e-04"
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## [1] "Iteration:  344, Objective: 6.38384e+00, Relative improvement 1.44945e-04"
## [1] "Iteration:  345, Objective: 6.38291e+00, Relative improvement 1.44976e-04"
## [1] "Iteration:  346, Objective: 6.38198e+00, Relative improvement 1.45009e-04"
## [1] "Iteration:  347, Objective: 6.38106e+00, Relative improvement 1.45045e-04"
## [1] "Iteration:  348, Objective: 6.38013e+00, Relative improvement 1.45082e-04"
## [1] "Iteration:  349, Objective: 6.37921e+00, Relative improvement 1.45121e-04"
## [1] "Iteration:  350, Objective: 6.37828e+00, Relative improvement 1.45163e-04"
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## [1] "Iteration:  352, Objective: 6.37644e+00, Relative improvement 1.44621e-04"
## [1] "Iteration:  353, Objective: 6.37551e+00, Relative improvement 1.44661e-04"
## [1] "Iteration:  354, Objective: 6.37459e+00, Relative improvement 1.44704e-04"
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## [1] "Iteration:  361, Objective: 6.36813e+00, Relative improvement 1.45037e-04"
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## [1] "Iteration:  385, Objective: 6.34601e+00, Relative improvement 1.44850e-04"
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## [1] "Iteration:  387, Objective: 6.34418e+00, Relative improvement 1.44946e-04"
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## [1] "Iteration:  394, Objective: 6.33773e+00, Relative improvement 1.45314e-04"
## [1] "Iteration:  395, Objective: 6.33681e+00, Relative improvement 1.45370e-04"
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## [1] "Iteration:  581, Objective: 6.16752e+00, Relative improvement 1.45925e-04"
## [1] "Iteration:  582, Objective: 6.16662e+00, Relative improvement 1.45964e-04"
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## [1] "Iteration:  584, Objective: 6.16481e+00, Relative improvement 1.46049e-04"
## [1] "Iteration:  585, Objective: 6.16391e+00, Relative improvement 1.46093e-04"
## [1] "Iteration:  586, Objective: 6.16301e+00, Relative improvement 1.46138e-04"
## [1] "Iteration:  587, Objective: 6.16211e+00, Relative improvement 1.46185e-04"
## [1] "Iteration:  588, Objective: 6.16121e+00, Relative improvement 1.46233e-04"
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## [1] "Iteration:  590, Objective: 6.15941e+00, Relative improvement 1.46332e-04"
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## [1] "Iteration:  592, Objective: 6.15761e+00, Relative improvement 1.46434e-04"
## [1] "Iteration:  593, Objective: 6.15670e+00, Relative improvement 1.46487e-04"
## [1] "Iteration:  594, Objective: 6.15580e+00, Relative improvement 1.46541e-04"
## [1] "Iteration:  595, Objective: 6.15490e+00, Relative improvement 1.46596e-04"
## [1] "Iteration:  596, Objective: 6.15400e+00, Relative improvement 1.46651e-04"
## [1] "Iteration:  597, Objective: 6.15309e+00, Relative improvement 1.46707e-04"
## [1] "Iteration:  598, Objective: 6.15219e+00, Relative improvement 1.46764e-04"
## [1] "Iteration:  599, Objective: 6.15129e+00, Relative improvement 1.46822e-04"
## [1] "Iteration:  600, Objective: 6.15039e+00, Relative improvement 1.46880e-04"
## [1] "Iteration:  601, Objective: 6.14948e+00, Relative improvement 1.46939e-04"
## [1] "Iteration:  602, Objective: 6.14858e+00, Relative improvement 1.46999e-04"
## [1] "Iteration:  603, Objective: 6.14767e+00, Relative improvement 1.47059e-04"
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## [1] "Iteration:  605, Objective: 6.14586e+00, Relative improvement 1.47182e-04"
## [1] "Iteration:  606, Objective: 6.14496e+00, Relative improvement 1.47060e-04"
## [1] "Iteration:  607, Objective: 6.14406e+00, Relative improvement 1.46611e-04"
## [1] "Iteration:  608, Objective: 6.14316e+00, Relative improvement 1.46659e-04"
## [1] "Iteration:  609, Objective: 6.14226e+00, Relative improvement 1.46705e-04"
## [1] "Iteration:  610, Objective: 6.14136e+00, Relative improvement 1.46090e-04"
## [1] "Iteration:  611, Objective: 6.14047e+00, Relative improvement 1.45330e-04"
## [1] "Iteration:  612, Objective: 6.13958e+00, Relative improvement 1.45342e-04"
## [1] "Iteration:  613, Objective: 6.13869e+00, Relative improvement 1.45092e-04"
## [1] "Iteration:  614, Objective: 6.13780e+00, Relative improvement 1.44760e-04"
## [1] "Iteration:  615, Objective: 6.13691e+00, Relative improvement 1.44712e-04"
## [1] "Iteration:  616, Objective: 6.13602e+00, Relative improvement 1.44661e-04"
## [1] "Iteration:  617, Objective: 6.13514e+00, Relative improvement 1.44190e-04"
## [1] "Iteration:  618, Objective: 6.13425e+00, Relative improvement 1.43830e-04"
## [1] "Iteration:  619, Objective: 6.13337e+00, Relative improvement 1.43839e-04"
## [1] "Iteration:  620, Objective: 6.13249e+00, Relative improvement 1.43849e-04"
## [1] "Iteration:  621, Objective: 6.13161e+00, Relative improvement 1.43862e-04"
## [1] "Iteration:  622, Objective: 6.13073e+00, Relative improvement 1.43879e-04"
## [1] "Iteration:  623, Objective: 6.12984e+00, Relative improvement 1.43899e-04"
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## [1] "Iteration:  625, Objective: 6.12808e+00, Relative improvement 1.43947e-04"
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## [1] "Iteration:  632, Objective: 6.12190e+00, Relative improvement 1.44175e-04"
## [1] "Iteration:  633, Objective: 6.12102e+00, Relative improvement 1.44214e-04"
## [1] "Iteration:  634, Objective: 6.12014e+00, Relative improvement 1.44254e-04"
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## [1] "Iteration:  652, Objective: 6.10422e+00, Relative improvement 1.45002e-04"
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## [1] "Iteration:  656, Objective: 6.10068e+00, Relative improvement 1.45236e-04"
## [1] "Iteration:  657, Objective: 6.09979e+00, Relative improvement 1.45291e-04"
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## [1] "Iteration:  666, Objective: 6.09180e+00, Relative improvement 1.45819e-04"
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## [1] "Iteration:  668, Objective: 6.09003e+00, Relative improvement 1.45944e-04"
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## [1] "Iteration:  817, Objective: 5.95510e+00, Relative improvement 1.53259e-04"
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## [1] "Iteration:  822, Objective: 5.95053e+00, Relative improvement 1.53576e-04"
## [1] "Iteration:  823, Objective: 5.94962e+00, Relative improvement 1.53641e-04"
## [1] "Iteration:  824, Objective: 5.94870e+00, Relative improvement 1.53707e-04"
## [1] "Iteration:  825, Objective: 5.94779e+00, Relative improvement 1.53774e-04"
## [1] "Iteration:  826, Objective: 5.94688e+00, Relative improvement 1.53823e-04"
## [1] "Iteration:  827, Objective: 5.94596e+00, Relative improvement 1.53884e-04"
## [1] "Iteration:  828, Objective: 5.94505e+00, Relative improvement 1.53962e-04"
## [1] "Iteration:  829, Objective: 5.94413e+00, Relative improvement 1.54030e-04"
## [1] "Iteration:  830, Objective: 5.94321e+00, Relative improvement 1.54098e-04"
## [1] "Iteration:  831, Objective: 5.94230e+00, Relative improvement 1.54167e-04"
## [1] "Iteration:  832, Objective: 5.94138e+00, Relative improvement 1.54235e-04"
## [1] "Iteration:  833, Objective: 5.94046e+00, Relative improvement 1.54305e-04"
## [1] "Iteration:  834, Objective: 5.93955e+00, Relative improvement 1.54375e-04"
## [1] "Iteration:  835, Objective: 5.93863e+00, Relative improvement 1.54445e-04"
## [1] "Iteration:  836, Objective: 5.93771e+00, Relative improvement 1.54516e-04"
## [1] "Iteration:  837, Objective: 5.93680e+00, Relative improvement 1.54587e-04"
## [1] "Iteration:  838, Objective: 5.93588e+00, Relative improvement 1.54659e-04"
## [1] "Iteration:  839, Objective: 5.93496e+00, Relative improvement 1.54731e-04"
## [1] "Iteration:  840, Objective: 5.93404e+00, Relative improvement 1.54803e-04"
## [1] "Iteration:  841, Objective: 5.93312e+00, Relative improvement 1.54594e-04"
## [1] "Iteration:  842, Objective: 5.93221e+00, Relative improvement 1.54644e-04"
## [1] "Iteration:  843, Objective: 5.93129e+00, Relative improvement 1.54721e-04"
## [1] "Iteration:  844, Objective: 5.93037e+00, Relative improvement 1.54792e-04"
## [1] "Iteration:  845, Objective: 5.92945e+00, Relative improvement 1.54863e-04"
## [1] "Iteration:  846, Objective: 5.92853e+00, Relative improvement 1.54935e-04"
## [1] "Iteration:  847, Objective: 5.92761e+00, Relative improvement 1.55007e-04"
## [1] "Iteration:  848, Objective: 5.92670e+00, Relative improvement 1.55079e-04"
## [1] "Iteration:  849, Objective: 5.92578e+00, Relative improvement 1.55008e-04"
## [1] "Iteration:  850, Objective: 5.92486e+00, Relative improvement 1.54801e-04"
## [1] "Iteration:  851, Objective: 5.92394e+00, Relative improvement 1.54874e-04"
## [1] "Iteration:  852, Objective: 5.92302e+00, Relative improvement 1.54936e-04"
## [1] "Iteration:  853, Objective: 5.92211e+00, Relative improvement 1.54999e-04"
## [1] "Iteration:  854, Objective: 5.92119e+00, Relative improvement 1.55064e-04"
## [1] "Iteration:  855, Objective: 5.92027e+00, Relative improvement 1.55130e-04"
## [1] "Iteration:  856, Objective: 5.91936e+00, Relative improvement 1.54354e-04"
## [1] "Iteration:  857, Objective: 5.91845e+00, Relative improvement 1.53527e-04"
## [1] "Iteration:  858, Objective: 5.91754e+00, Relative improvement 1.53723e-04"
## [1] "Iteration:  859, Objective: 5.91663e+00, Relative improvement 1.53788e-04"
## [1] "Iteration:  860, Objective: 5.91572e+00, Relative improvement 1.53854e-04"
## [1] "Iteration:  861, Objective: 5.91481e+00, Relative improvement 1.53921e-04"
## [1] "Iteration:  862, Objective: 5.91390e+00, Relative improvement 1.53989e-04"
## [1] "Iteration:  863, Objective: 5.91299e+00, Relative improvement 1.54057e-04"
## [1] "Iteration:  864, Objective: 5.91207e+00, Relative improvement 1.54127e-04"
## [1] "Iteration:  865, Objective: 5.91116e+00, Relative improvement 1.54197e-04"
## [1] "Iteration:  866, Objective: 5.91025e+00, Relative improvement 1.54267e-04"
## [1] "Iteration:  867, Objective: 5.90934e+00, Relative improvement 1.54338e-04"
## [1] "Iteration:  868, Objective: 5.90843e+00, Relative improvement 1.54374e-04"
## [1] "Iteration:  869, Objective: 5.90752e+00, Relative improvement 1.54400e-04"
## [1] "Iteration:  870, Objective: 5.90660e+00, Relative improvement 1.54473e-04"
## [1] "Iteration:  871, Objective: 5.90569e+00, Relative improvement 1.54542e-04"
## [1] "Iteration:  872, Objective: 5.90478e+00, Relative improvement 1.54613e-04"
## [1] "Iteration:  873, Objective: 5.90386e+00, Relative improvement 1.54684e-04"
```

```
## [1] "Iteration:  874, Objective: 5.90295e+00, Relative improvement 1.54756e-04"
## [1] "Iteration:  875, Objective: 5.90204e+00, Relative improvement 1.54828e-04"
## [1] "Iteration:  876, Objective: 5.90112e+00, Relative improvement 1.54900e-04"
## [1] "Iteration:  877, Objective: 5.90021e+00, Relative improvement 1.54973e-04"
## [1] "Iteration:  878, Objective: 5.89929e+00, Relative improvement 1.55046e-04"
## [1] "Iteration:  879, Objective: 5.89838e+00, Relative improvement 1.55120e-04"
## [1] "Iteration:  880, Objective: 5.89746e+00, Relative improvement 1.55194e-04"
## [1] "Iteration:  881, Objective: 5.89655e+00, Relative improvement 1.55268e-04"
## [1] "Iteration:  882, Objective: 5.89563e+00, Relative improvement 1.55194e-04"
## [1] "Iteration:  883, Objective: 5.89473e+00, Relative improvement 1.53289e-04"
## [1] "Iteration:  884, Objective: 5.89383e+00, Relative improvement 1.52525e-04"
## [1] "Iteration:  885, Objective: 5.89293e+00, Relative improvement 1.52345e-04"
## [1] "Iteration:  886, Objective: 5.89203e+00, Relative improvement 1.52385e-04"
## [1] "Iteration:  887, Objective: 5.89114e+00, Relative improvement 1.52454e-04"
## [1] "Iteration:  888, Objective: 5.89024e+00, Relative improvement 1.52524e-04"
## [1] "Iteration:  889, Objective: 5.88934e+00, Relative improvement 1.52595e-04"
## [1] "Iteration:  890, Objective: 5.88844e+00, Relative improvement 1.52666e-04"
## [1] "Iteration:  891, Objective: 5.88754e+00, Relative improvement 1.52737e-04"
## [1] "Iteration:  892, Objective: 5.88664e+00, Relative improvement 1.52809e-04"
## [1] "Iteration:  893, Objective: 5.88574e+00, Relative improvement 1.52881e-04"
## [1] "Iteration:  894, Objective: 5.88484e+00, Relative improvement 1.52954e-04"
## [1] "Iteration:  895, Objective: 5.88394e+00, Relative improvement 1.53027e-04"
## [1] "Iteration:  896, Objective: 5.88304e+00, Relative improvement 1.53100e-04"
## [1] "Iteration:  897, Objective: 5.88214e+00, Relative improvement 1.53174e-04"
## [1] "Iteration:  898, Objective: 5.88124e+00, Relative improvement 1.53247e-04"
## [1] "Iteration:  899, Objective: 5.88034e+00, Relative improvement 1.53321e-04"
## [1] "Iteration:  900, Objective: 5.87943e+00, Relative improvement 1.53396e-04"
## [1] "Iteration:  901, Objective: 5.87853e+00, Relative improvement 1.53470e-04"
## [1] "Iteration:  902, Objective: 5.87763e+00, Relative improvement 1.53545e-04"
## [1] "Iteration:  903, Objective: 5.87673e+00, Relative improvement 1.53620e-04"
## [1] "Iteration:  904, Objective: 5.87582e+00, Relative improvement 1.53695e-04"
## [1] "Iteration:  905, Objective: 5.87492e+00, Relative improvement 1.53771e-04"
## [1] "Iteration:  906, Objective: 5.87402e+00, Relative improvement 1.53847e-04"
## [1] "Iteration:  907, Objective: 5.87311e+00, Relative improvement 1.53923e-04"
## [1] "Iteration:  908, Objective: 5.87221e+00, Relative improvement 1.53999e-04"
## [1] "Iteration:  909, Objective: 5.87130e+00, Relative improvement 1.54076e-04"
## [1] "Iteration:  910, Objective: 5.87040e+00, Relative improvement 1.54153e-04"
## [1] "Iteration:  911, Objective: 5.86949e+00, Relative improvement 1.54230e-04"
## [1] "Iteration:  912, Objective: 5.86859e+00, Relative improvement 1.54307e-04"
## [1] "Iteration:  913, Objective: 5.86768e+00, Relative improvement 1.54384e-04"
## [1] "Iteration:  914, Objective: 5.86678e+00, Relative improvement 1.54462e-04"
## [1] "Iteration:  915, Objective: 5.86587e+00, Relative improvement 1.54540e-04"
## [1] "Iteration:  916, Objective: 5.86496e+00, Relative improvement 1.54618e-04"
## [1] "Iteration:  917, Objective: 5.86406e+00, Relative improvement 1.54696e-04"
## [1] "Iteration:  918, Objective: 5.86315e+00, Relative improvement 1.54775e-04"
## [1] "Iteration:  919, Objective: 5.86224e+00, Relative improvement 1.54853e-04"
## [1] "Iteration:  920, Objective: 5.86133e+00, Relative improvement 1.54932e-04"
## [1] "Iteration:  921, Objective: 5.86043e+00, Relative improvement 1.54769e-04"
## [1] "Iteration:  922, Objective: 5.85952e+00, Relative improvement 1.54470e-04"
## [1] "Iteration:  923, Objective: 5.85862e+00, Relative improvement 1.54507e-04"
## [1] "Iteration:  924, Objective: 5.85771e+00, Relative improvement 1.54576e-04"
## [1] "Iteration:  925, Objective: 5.85680e+00, Relative improvement 1.54646e-04"
## [1] "Iteration:  926, Objective: 5.85590e+00, Relative improvement 1.54717e-04"
## [1] "Iteration:  927, Objective: 5.85499e+00, Relative improvement 1.54764e-04"
```

```
## [1] "Iteration:  928, Objective: 5.85409e+00, Relative improvement 1.54531e-04"
## [1] "Iteration:  929, Objective: 5.85319e+00, Relative improvement 1.54133e-04"
## [1] "Iteration:  930, Objective: 5.85228e+00, Relative improvement 1.54161e-04"
## [1] "Iteration:  931, Objective: 5.85138e+00, Relative improvement 1.54203e-04"
## [1] "Iteration:  932, Objective: 5.85048e+00, Relative improvement 1.54253e-04"
## [1] "Iteration:  933, Objective: 5.84958e+00, Relative improvement 1.54307e-04"
## [1] "Iteration:  934, Objective: 5.84867e+00, Relative improvement 1.54364e-04"
## [1] "Iteration:  935, Objective: 5.84777e+00, Relative improvement 1.54425e-04"
## [1] "Iteration:  936, Objective: 5.84687e+00, Relative improvement 1.54487e-04"
## [1] "Iteration:  937, Objective: 5.84596e+00, Relative improvement 1.54550e-04"
## [1] "Iteration:  938, Objective: 5.84506e+00, Relative improvement 1.54615e-04"
## [1] "Iteration:  939, Objective: 5.84416e+00, Relative improvement 1.54681e-04"
## [1] "Iteration:  940, Objective: 5.84325e+00, Relative improvement 1.54748e-04"
## [1] "Iteration:  941, Objective: 5.84235e+00, Relative improvement 1.54816e-04"
## [1] "Iteration:  942, Objective: 5.84144e+00, Relative improvement 1.54885e-04"
## [1] "Iteration:  943, Objective: 5.84054e+00, Relative improvement 1.54954e-04"
## [1] "Iteration:  944, Objective: 5.83963e+00, Relative improvement 1.55023e-04"
## [1] "Iteration:  945, Objective: 5.83873e+00, Relative improvement 1.55094e-04"
## [1] "Iteration:  946, Objective: 5.83782e+00, Relative improvement 1.55165e-04"
## [1] "Iteration:  947, Objective: 5.83691e+00, Relative improvement 1.55236e-04"
## [1] "Iteration:  948, Objective: 5.83601e+00, Relative improvement 1.55308e-04"
## [1] "Iteration:  949, Objective: 5.83510e+00, Relative improvement 1.55264e-04"
## [1] "Iteration:  950, Objective: 5.83420e+00, Relative improvement 1.54562e-04"
## [1] "Iteration:  951, Objective: 5.83330e+00, Relative improvement 1.54691e-04"
## [1] "Iteration:  952, Objective: 5.83239e+00, Relative improvement 1.54755e-04"
## [1] "Iteration:  953, Objective: 5.83149e+00, Relative improvement 1.54819e-04"
## [1] "Iteration:  954, Objective: 5.83059e+00, Relative improvement 1.54884e-04"
## [1] "Iteration:  955, Objective: 5.82969e+00, Relative improvement 1.54950e-04"
## [1] "Iteration:  956, Objective: 5.82878e+00, Relative improvement 1.55017e-04"
## [1] "Iteration:  957, Objective: 5.82788e+00, Relative improvement 1.55083e-04"
## [1] "Iteration:  958, Objective: 5.82697e+00, Relative improvement 1.55151e-04"
## [1] "Iteration:  959, Objective: 5.82607e+00, Relative improvement 1.55218e-04"
## [1] "Iteration:  960, Objective: 5.82517e+00, Relative improvement 1.55287e-04"
## [1] "Iteration:  961, Objective: 5.82426e+00, Relative improvement 1.55355e-04"
## [1] "Iteration:  962, Objective: 5.82336e+00, Relative improvement 1.55424e-04"
## [1] "Iteration:  963, Objective: 5.82245e+00, Relative improvement 1.55430e-04"
## [1] "Iteration:  964, Objective: 5.82155e+00, Relative improvement 1.55215e-04"
## [1] "Iteration:  965, Objective: 5.82065e+00, Relative improvement 1.54386e-04"
## [1] "Iteration:  966, Objective: 5.81975e+00, Relative improvement 1.54199e-04"
## [1] "Iteration:  967, Objective: 5.81885e+00, Relative improvement 1.54205e-04"
## [1] "Iteration:  968, Objective: 5.81796e+00, Relative improvement 1.54225e-04"
## [1] "Iteration:  969, Objective: 5.81706e+00, Relative improvement 1.54254e-04"
## [1] "Iteration:  970, Objective: 5.81616e+00, Relative improvement 1.54289e-04"
## [1] "Iteration:  971, Objective: 5.81526e+00, Relative improvement 1.54329e-04"
## [1] "Iteration:  972, Objective: 5.81437e+00, Relative improvement 1.54372e-04"
## [1] "Iteration:  973, Objective: 5.81347e+00, Relative improvement 1.54417e-04"
## [1] "Iteration:  974, Objective: 5.81257e+00, Relative improvement 1.54464e-04"
## [1] "Iteration:  975, Objective: 5.81167e+00, Relative improvement 1.54513e-04"
## [1] "Iteration:  976, Objective: 5.81077e+00, Relative improvement 1.54564e-04"
## [1] "Iteration:  977, Objective: 5.80988e+00, Relative improvement 1.54615e-04"
## [1] "Iteration:  978, Objective: 5.80898e+00, Relative improvement 1.54668e-04"
## [1] "Iteration:  979, Objective: 5.80808e+00, Relative improvement 1.54721e-04"
## [1] "Iteration:  980, Objective: 5.80718e+00, Relative improvement 1.54776e-04"
## [1] "Iteration:  981, Objective: 5.80628e+00, Relative improvement 1.54831e-04"
```

```
## [1] "Iteration:  982, Objective: 5.80538e+00, Relative improvement 1.54887e-04"
## [1] "Iteration:  983, Objective: 5.80448e+00, Relative improvement 1.54832e-04"
## [1] "Iteration:  984, Objective: 5.80359e+00, Relative improvement 1.54212e-04"
## [1] "Iteration:  985, Objective: 5.80269e+00, Relative improvement 1.54145e-04"
## [1] "Iteration:  986, Objective: 5.80180e+00, Relative improvement 1.54190e-04"
## [1] "Iteration:  987, Objective: 5.80091e+00, Relative improvement 1.54235e-04"
## [1] "Iteration:  988, Objective: 5.80001e+00, Relative improvement 1.54281e-04"
## [1] "Iteration:  989, Objective: 5.79912e+00, Relative improvement 1.54327e-04"
## [1] "Iteration:  990, Objective: 5.79822e+00, Relative improvement 1.54374e-04"
## [1] "Iteration:  991, Objective: 5.79732e+00, Relative improvement 1.54421e-04"
## [1] "Iteration:  992, Objective: 5.79643e+00, Relative improvement 1.54469e-04"
## [1] "Iteration:  993, Objective: 5.79553e+00, Relative improvement 1.54517e-04"
## [1] "Iteration:  994, Objective: 5.79464e+00, Relative improvement 1.54566e-04"
## [1] "Iteration:  995, Objective: 5.79374e+00, Relative improvement 1.54616e-04"
## [1] "Iteration:  996, Objective: 5.79285e+00, Relative improvement 1.54666e-04"
## [1] "Iteration:  997, Objective: 5.79195e+00, Relative improvement 1.54717e-04"
## [1] "Iteration:  998, Objective: 5.79105e+00, Relative improvement 1.54768e-04"
## [1] "Iteration:  999, Objective: 5.79016e+00, Relative improvement 1.54819e-04"
## [1] "Iteration: 1000, Objective: 5.78926e+00, Relative improvement 1.54871e-04"
```

```
sparse_model$loadings
```

```
##              [,1]        [,2]        [,3]        [,4]          [,5]
##  [1,]  0.29381532  0.02288480 -0.04281433  0.00000000  0.0183421168
##  [2,]  0.35573582 -0.19596343  0.08268949  0.00000000  0.0000000000
##  [3,]  0.35573582 -0.19596343  0.08268949  0.00000000  0.0000000000
##  [4,]  0.35987224 -0.15515946  0.05256899  0.00000000  0.0000000000
##  [5,] -0.31463465  0.22612662 -0.10788930 -0.01401594  0.0000000000
##  [6,]  0.06021595 -0.12960713  0.04390352  0.09294084 -0.3815498820
##  [7,]  0.24561933  0.31716581 -0.15206401  0.17971556  0.1822159236
##  [8,]  0.22919059 -0.04645770  0.00888112  0.15346120 -0.0237555743
##  [9,]  0.22912100 -0.04311076  0.09833092  0.03494560  0.0000000000
## [10,]  0.06826121  0.23949682 -0.13921052 -0.58157817  0.1147455323
## [11,]  0.10538005 -0.09267341  0.03459803 -0.39971571  0.4602363014
## [12,]  0.17446019  0.16853101 -0.12183116 -0.41986384  0.0473881263
## [13,]  0.25622892 -0.13713380  0.01877174  0.03783766  0.0007258234
## [14,]  0.15602030  0.27617981 -0.23840357 -0.06281784 -0.4109372128
## [15,]  0.15095336  0.27739639 -0.23771007 -0.05664808 -0.4192265067
## [16,] -0.01043035 -0.23214786 -0.49127375  0.00000000  0.1018324305
## [17,] -0.10978972 -0.29050876  0.05666113 -0.15206300 -0.0133860249
## [18,] -0.26261844 -0.24886228  0.09434001 -0.12862413 -0.0890366129
## [19,] -0.03933835 -0.29977336 -0.49728666  0.07223905  0.0417780980
## [20,] -0.02641255 -0.25372033 -0.51632567  0.05061153  0.0280566015
## [21,] -0.04331759 -0.30995559  0.10895016 -0.44456778 -0.4715286975
##               [,6]         [,7]         [,8]         [,9]        [,10]
##  [1,] -0.037106136 -0.638516637 -0.378163581 -0.066501771 -0.374243739
##  [2,] -0.071048461 -0.008529955  0.214988707  0.000000000  0.000000000
##  [3,] -0.071048461 -0.008529955  0.214988707  0.000000000  0.000000000
##  [4,] -0.021890036 -0.037450267  0.185685665  0.000000000 -0.006355993
##  [5,]  0.121999681  0.000000000 -0.228645579  0.000000000  0.000000000
##  [6,]  0.842164125 -0.011759327  0.058118748  0.275421773  0.000000000
##  [7,]  0.208746143 -0.004924839 -0.145776160 -0.201652911  0.486352275
##  [8,]  0.000000000  0.553066069 -0.536002587 -0.174002562 -0.082397456
##  [9,]  0.002421908  0.200184329 -0.150405759  0.000000000  0.000000000
```

```
## [10,]  0.137916757  0.199424897  0.361701664 -0.285005084  0.004901130
## [11,]  0.015530911  0.000000000 -0.270604161  0.662077873  0.262955242
## [12,]  0.253805707  0.000000000 -0.146516953 -0.134473086 -0.441916156
## [13,]  0.000000000  0.182709925  0.020405133  0.000000000  0.000000000
## [14,] -0.234785653  0.095492392  0.000000000  0.285364293 -0.019202253
## [15,] -0.237130040  0.103007956  0.000000000  0.289084030 -0.006531289
## [16,]  0.029734309  0.000000000  0.028470195 -0.016257367  0.048198859
## [17,] -0.005284484  0.283672684 -0.135885886 -0.102138010 -0.185757802
## [18,] -0.085140844  0.123441753  0.008350163  0.189581574 -0.254390112
## [19,]  0.015141947 -0.032609328  0.000000000 -0.040117844  0.000000000
## [20,]  0.000000000  0.000000000  0.000000000 -0.002431232  0.004998845
## [21,] -0.085784397 -0.210781971 -0.278637817 -0.282512915  0.481484873
##              [,11]       [,12]        [,13]         [,14]         [,15]
##  [1,]  0.141127095 -0.35375995 -0.146634857  0.1429988046 -0.0583864991
##  [2,]  0.016482814  0.00000000  0.143698190  0.0000000000  0.0000000000
##  [3,]  0.016482814  0.00000000  0.143698190  0.0000000000  0.0000000000
##  [4,]  0.004327098  0.00000000  0.024654721  0.0000000000 -0.0688403387
##  [5,] -0.023495616  0.00000000 -0.280041383  0.0000000000 -0.1568253811
##  [6,]  0.023972007 -0.14832679  0.000000000 -0.0166652112  0.0000000000
##  [7,]  0.343456053  0.17415315  0.189674062  0.4491395918 -0.0133325134
##  [8,] -0.284898536 -0.34696679  0.182479195 -0.0175172092  0.1103317514
##  [9,]  0.010739033  0.11259418 -0.165877919 -0.0457693346 -0.4421399059
## [10,]  0.000000000 -0.48853898 -0.140486184  0.1100199646 -0.0011880866
## [11,]  0.000000000 -0.05975610  0.000000000 -0.0574336053  0.0780545704
## [12,] -0.148632089  0.59062997  0.215654625 -0.0602385669  0.0780894847
## [13,] -0.111025159  0.25583158 -0.782882891  0.2446999079  0.0904598296
## [14,]  0.106374054  0.00000000  0.005868844  0.0000000000  0.0000000000
## [15,]  0.106047766  0.00000000  0.006409134  0.0000000000  0.0000000000
## [16,] -0.113196200  0.00000000  0.069983992 -0.1149777044 -0.6716831693
## [17,]  0.819458493  0.02188939 -0.045833724 -0.1598454451 -0.0007409286
## [18,] -0.052553201  0.00000000  0.196244007  0.7867188907 -0.1484677124
## [19,] -0.004205042  0.00000000 -0.012981873  0.0456661297  0.4413244125
## [20,]  0.000000000  0.00000000 -0.025266850  0.0180418793  0.1271022607
## [21,] -0.113636984  0.07565260  0.000000000 -0.0002130629  0.0000000000
##              [,16]        [,17]        [,18]       [,19]       [,20]
##  [1,]  0.000000000 -0.064990578  0.010493276  0.0000000  0.0000000
##  [2,]  0.000000000  0.026684497  0.000000000  0.0000000  0.0000000
##  [3,]  0.000000000  0.026684497  0.000000000  0.0000000  0.6774843
##  [4,] -0.205399081  0.625008652 -0.244205069  0.0000000 -0.2748413
##  [5,] -0.088851653  0.572991441 -0.160902710  0.0000000  0.1868845
##  [6,]  0.000000000 -0.039785063  0.000000000  0.0000000  0.0000000
##  [7,] -0.034007211 -0.001321243  0.000000000  0.0000000  0.0000000
##  [8,] -0.149067779  0.000000000 -0.016002915  0.0000000  0.0000000
##  [9,]  0.745496646  0.098845881  0.110584304  0.0000000  0.0000000
## [10,]  0.090194210 -0.004710228  0.003098939  0.0000000  0.0000000
## [11,] -0.008643091  0.000000000  0.000000000  0.0000000  0.0000000
## [12,] -0.018896241  0.000000000  0.000000000  0.0000000  0.0000000
## [13,] -0.241914965 -0.171503951  0.014787944  0.0000000  0.0000000
## [14,] -0.012768619  0.000000000  0.036796902  0.5494879  0.0000000
## [15,] -0.025513034  0.000000000  0.000000000 -0.5467614  0.0000000
## [16,] -0.337467153 -0.132057488  0.173441322  0.0000000  0.0000000
## [17,] -0.121657261  0.000000000  0.000000000  0.0000000  0.0000000
## [18,]  0.016524548  0.040627082  0.000000000  0.0000000  0.0000000
## [19,]  0.174453157  0.310985730  0.505487574  0.0000000  0.0000000
```

```
## [20,]  0.276084425 -0.166086917 -0.678968729  0.0000000  0.0000000
## [21,]  0.000000000  0.000000000  0.000000000  0.0000000  0.0000000
##             [,21]
##  [1,]  0.00000000
##  [2,]  0.69336372
##  [3,] -0.07076568
##  [4,] -0.23330649
##  [5,]  0.15505939
##  [6,]  0.00000000
##  [7,]  0.00000000
##  [8,]  0.00000000
##  [9,]  0.00000000
## [10,]  0.00000000
## [11,]  0.00000000
## [12,]  0.00000000
## [13,]  0.00000000
## [14,]  0.00000000
## [15,]  0.00000000
## [16,]  0.00000000
## [17,]  0.00000000
## [18,]  0.00000000
## [19,]  0.00000000
## [20,]  0.00000000
## [21,]  0.00000000
```

```
#Please excuse huge output
```