1. **Give a clear statement of the problem.**

   Given a file containing 42 PrP (prion protein gene) sequences, I was tasked with find a strategy to predict the 2D secondary structure that best represents these sequences.

2. **Give a brief description of the method of your procedure. This should be a few sentences describing the problem, solution, and results. It should be similar to an abstract in a scientific paper.**

   In order to effectively predict the 2D secondary structure of these 42 PrP sequences, I needed to first align the sequences with each other, find the consensus sequence and compute the covariation or mutual information of the sequences. I then calculate the structure based off of the alignment information I found. This calculation was performed using a dynamic programming strategy followed by a backtracking algorithm to translate the data into a dot-bracket form representation. This dot-bracket along with the consensus sequence that was found enabled me to utilize the Vienna package RNA plotting function to plot the 2D structure.

3. **Present the procedure in detail, including any relevant mathematics. If the solution involves programming, give an overview in words of how the program operates. The presentation should contain sufficient detail so that a reader can follow each step without difficulty. \***

   #NOTE: before starting I used the MUSCLE multi-sequence aligner to obtain my input file based on the provided PRP.fasta file

   procedure main:
           parse alignment file -> obtain sequences
           calculateConsensus(sequences) -> consensussequence, count_matrix (# nucleotide at i)
           convert count_matrix -> frequencey_matrix
           calculateMutualInfo( frequency_matrix, sequences) -> obtain matrix M
           dynamic_program(M) -> obtain g matrix
           Backtrace(g) -> obtain pairs
           StructuredFromPairs(pairs) -> obtain dot-bracket
           #external program: plot dot-bracket to get 2D structure

   procedure calculateConsensus:
           init count_matrix (5 nucleotide options x 42 columns)
           for each sequence , for each position, i:
                           count_matrix[nucleotide at i in seq][i] += 1
           consensus_sequence = ""
           for each position in count_matrix:
                   find nucleotide with max count and append to consensus_sequence
           return consensus_sequence, count_matrix

```
procedure convert(count_matrix):
        init frequencey_matrix = count_matrix
        L = # of rows
        for each nucleotide, column (i)  in count_matrix:
                frequency_matrix[nucleotide][i] /= L
        return frequency matrix

procedure calculateMutualInfo( frequency_matrix, sequences)
        L = # of columns
        def combined_freq(i, j, n1, n2):
                count = 0
                for each sequence:
                        if seq[i] = n1 and seq[j] == n2
                                ++count
                return count

        def find_val1(i,j):
                answer = 0.0
                for each nucleotide, n1,n2:
                        if n1n2 is a valid pair:
                                answer += combined_freq(i,j,n1,n2)
                return answer

        def find_val2(i,j):
                answer = 0.0
                for each nucleotide n1,n2:
                        f_i = frequency_matrix[n1][i]
                        f_2 = frequency_matrix[n2][j]
                        if n1n2 is valid f_ij = combined_freq(i,j,n1,n2)
                        else f_ij = 0
                        if none of the frequencies = 0:
                                answer += log(f_ij / f_i*f_j)
                return answer

        for i in L:
                for j in L:
                        if i != j:
                                val1 = find_val1(i,j)
                                val2 = find_val2(i,j)
                                answer = val1 * val2
                                if answer < 0 --> M[i][j] = 0.0
                                else M[i][j] = answer
        return M
```

```
procedure dynamic_program(M):
        L = # of columns
        init D [L,L]

        def find_val4(i,j):
                answer = 0.0
                k = i+4
                while k <= (j-5)):
                        answer = max(answer, D[i][k] + D[k+1][j])
                        ++k
                return answer

        for i in M from L-1 ->0:
                for j from i+3 -> L-1:
                        vall1 = D[i+1][j]
                        value2 = D[i][j-1]
                        value3 = D[i+1][j-1]+M[i][j]
                        value4 = find_val4(i,j)
                        D[i][j] = max of values1-4
        return D

##provided using the nussinov.py script
procedure Backtrace(g):
    """
    traceback - recursive back trace through g matrix
            fills pairs matrix defined in outer scope
    """
    nonlocal pairs

    if i < j:
       if g[i,j] == g[i+1, j]:
          traceback(i+1, j)
       elif g[i,j] == g[i, j-1]:
          traceback(i, j-1)
       elif g[i,j] == g[i+1, j-1] + M[i][j]:
          if abs(i-j) > 2:
                pairs += [i,j]
          traceback(i+1, j-1)
       else:
          for k in range(i+1, j):
             if g[i,j] == g[i, k] + g[k+1, j]:
                traceback(i, k)
```

```
                traceback(k+1, j)
                break

    L = g.shape[0]
    pairs = []
    traceback(0, L-1)

    dot_bracket = np.zeros([L, L], dtype =int)
    for i in range(0, len(pairs), 2):
        dot_bracket[pairs[i], pairs[i+1]] = 1

    return pairs, dot_bracket

#provided  by nussinov.py script
procedure StructuredFromPairs(pairs):
        struct = list('.' * L)
        for i in range(0, len(pairs), 2):
                struct[pairs[i]] = '('
                struct[pairs[i+1]] = ')'

        return ''.join(struct)
```

4. **If the solution involves programming code, output must be clearly labeled with each item having a descriptive title. Programming code must be documented with comments describing each major step in the program and all relevant variables. Source code should be submitted in a separate file. ***

Note: additional output appended to end of write up (pairs, Mutual information matrix and dynamic program matrix return)

The consensus sequence is:
CCAUGGUGGUGGCUGGGGACAGCCUCAUGGUGGUGGCUG---

The dot-bracket format description of the consensuse sequence is:
(..(...))(((((((((((..)).)).(...).))))))...

Output from plot of 2d secondary structure:
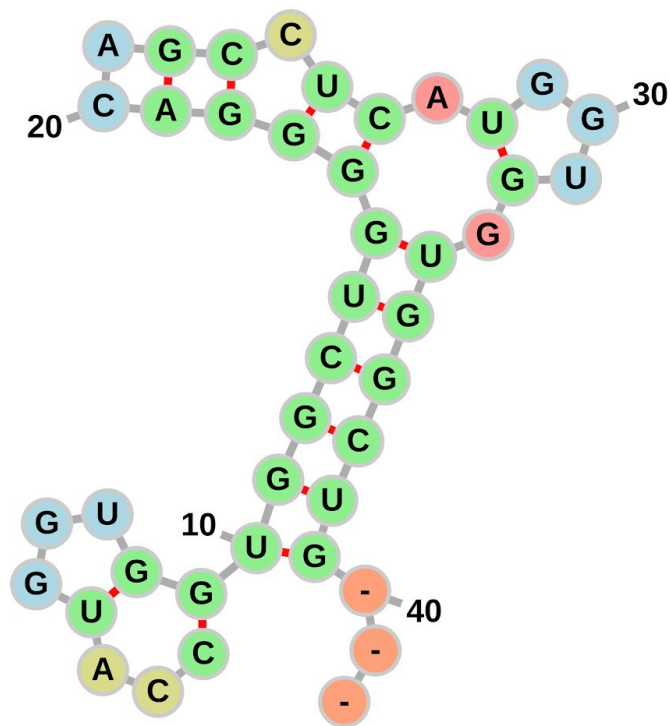
5. **Graphs must be titled and have each axis labeled clearly**

No graphs for this assignment.

**Appended Output**

Pairs:
[0, 8, 3, 7, 9, 38, 10, 37, 11, 36, 12, 35, 13, 34, 14, 33, 15, 25, 16, 24, 17, 22, 18, 21, 27, 31]

Mutual Information Matrix
[[  0.         3.8918203   54.10189853    0.         237.94069076
   236.33021061   25.38087662  241.29285848  239.59412208   17.43253549
   231.69047923  459.36357187    3.81177759    0.         236.33021061
   233.22956453  481.54428165  459.36357187   99.16967556    0.
   168.5565961   462.64634271    7.47533924    3.78645978   26.63636003
     0.          52.66474038    5.39589769  481.54428165  236.33021061
    29.48014348  236.33021061  234.76050651   36.49876588  234.76050651
   234.76050651    0.            0.         234.76050651   96.65934073
     0.            0.        ]

[   3.8918203    0.          0.          0.        138.15911077
  137.22399326   6.97271038 130.37850407 129.44693894   3.8918203
  120.7691924  126.79624653   0.          0.        127.657052
  135.42361812 126.79624653 126.79624653  23.35092179   3.8918203
    0.        123.7744761    3.19867312   0.         11.67546089
    0.          0.          0.        131.54011169 127.657052     0.
  127.657052  131.54011169   7.7836406  126.79624653 131.54011169
    0.          0.        131.54011169  55.64248112   2.79320801
    0.        ]
[  54.10189853   0.          0.        135.25474634   0.          0.
   80.17592747   0.          0.        101.49464182   0.
    7.72884265   3.86442132 126.72548688   0.          0.
    3.86442132   7.72884265  44.52324773   3.86442132   3.86442132
    7.72884265   3.86442132   3.86442132  85.01726913   7.72884265
    0.        131.39032501   3.86442132   7.72884265 107.22124012
    0.          0.        101.49464182   0.          0.
   23.18652794 134.43725504   3.86442132   3.86442132   0.
    3.86442132]
[   0.          0.        135.25474634   0.        276.31822153
  274.44798651 178.30714213 420.28719244 378.76442391  14.6019717
  407.74815145 490.78716853  21.40436646   0.        265.80986754
  270.84723623 264.03762098 490.78716853 243.98795322   0.
  379.58253213 609.57196285  20.0180721    0.         30.44456311
    6.08904488 131.66185095   3.25583153 531.13912997 492.6100507
  100.38156106 265.80986754 264.03762098  31.97653212 412.70123531
  272.62510434   4.99043259   3.06861999 531.13912997  56.06504427
    2.82137889   0.        ]
[ 237.94069076 138.15911077   0.        276.31822153   0.          0.
  175.46668118   3.83775308   0.        273.83447816   0.
    7.67550615 272.42253249 272.42253249   0.          0.
   15.35101231   7.67550615 120.34168758 280.09538861   3.83775308
    7.67550615 272.42253249 280.09538861 259.25347585 279.98982505
    3.83775308 265.32964098  15.35101231   7.67550615 236.85285985
    0.          3.83775308 261.55436613   0.          3.83775308
  279.50337598 138.19866014   3.83775308   3.83775308   0.
    3.83775308]
[ 236.33021061 137.22399326   0.        274.44798651   0.          0.
  182.96532434   3.81177759   0.        280.81718428   0.
    7.62355518 279.10996151 279.10996151   0.          0.
   15.24711036   7.62355518 119.51047202 286.7325583    3.81177759
    7.62355518 279.10996151 286.7325583  267.45836999 286.65347398
    3.81177759 278.98851051  15.24711036   7.62355518 243.95376579
    0.          3.81177759 268.42040052   0.          3.81177759

```
    286.28983484 141.96008397   3.81177759   3.81177759   0.
    3.81177759]
 [ 25.38087662   6.97271038  80.17592747 178.30714213 175.46668118
   182.96532434   0.         186.80737431 185.49222355 228.60726856
   257.64295206 331.41248331  51.47221292  85.47335872 182.96532434
   180.56482415 348.74116282 331.41248331 435.3108857   29.27316487
    82.75887774 333.97714803   6.81262496  29.27316487 129.63482277
    53.89675613  82.75887774 165.05688811 316.25908822 330.22597776
    45.57937105 182.96532434 181.75006956 181.90673077 181.75006956
   181.75006956  74.90274197 105.32948076 316.25908822  56.88053931
     0.           6.37672695]
 [241.29285848 130.37850407   0.         420.28719244   3.83775308
     3.81177759 186.80737431   0.           0.         423.08718968
     3.8918203   21.13730368 132.42623497 137.22399326   0.           0.
    22.52359804  21.13730368 113.13717809 416.6865637    0.
     6.78219206 391.97687692 712.01125371 253.9411242  391.97687692
     0.         406.21735771   0.           3.19867312 220.29252505
     0.           0.         256.52145539   3.78645978   0.
   269.27849457 278.37077057   0.          24.12061343   0.
     7.47533924]
 [239.59412208 129.44693894   0.         378.76442391   0.           0.
   185.49222355   0.           0.         430.48400788   0.
    12.7534539  375.96090587 141.03577085   0.           0.
     6.37672695  12.7534539  179.60560335 386.20109575   6.37672695
    12.7534539  387.16317246 386.20109575 387.85864004 397.351677     0.
   418.92739202   6.37672695  17.70970782 319.22923747   0.           0.
   414.21481983   0.           0.         457.59130362 277.60470003
     6.37672695   6.37672695   0.           6.37672695]
 [ 17.43253549   3.8918203  101.49464182  14.6019717  273.83447816
   280.81718428 228.60726856 423.08718968 430.48400788   0.
   389.08657176 270.14136096  46.08377605  15.77183889 404.6156084
   285.89430491 270.14136096 270.14136096 286.45030441  15.72120327
   108.10810293 261.55436613  14.38554453   3.78645978  64.21367711
    44.0043345  112.8530151   15.79591485 570.54557549 699.61405637
   165.10834793 404.6156084  278.94366649  14.91027306 266.59751834
   278.94366649  19.20714188  15.04706868 570.54557549  94.92530045
     2.97552957   0.        ]
 [231.69047923 120.7691924    0.         407.74815145   0.           0.
   257.64295206   3.8918203    0.         389.08657176   0.
    12.17808975 267.62538161 410.17418202   0.           0.
     6.08904488  12.17808975 122.07183866 365.39367234   6.08904488
    12.17808975 355.4154572  354.50401611 402.67166417 457.99256846
     3.8918203  424.41985117   3.8918203    7.7836406  332.36999525
```

```
    0.          3.8918203   419.2547134    0.          3.8918203
  435.75801278 282.19823842   3.8918203    6.08904488   0.
    6.08904488]
 [ 459.36357187 126.79624653   7.72884265 490.78716853   7.67550615
     7.62355518 331.41248331  21.13730368  12.7534539  270.14136096
    12.17808975   0.          294.33081906 588.55957646   6.08904488
     7.52353434   0.           0.          329.103449   433.31472538
     3.06861999   0.          395.02018632 146.684537   514.63911371
   560.14054205  22.64468086 296.38140837  13.75954477  54.74912899
   222.19108816   6.08904488  13.75954477 278.94366649   3.0933126
    13.75954477 301.75728112 150.47068679  13.75954477   0.
     5.68357977   0.        ]
 [   3.81177759   0.           3.86442132  21.40436646 272.42253249
   279.10996151  51.47221292 132.42623497 375.96090587  46.08377605
   267.62538161 294.33081906   0.           3.81177759 412.15177224
   449.48425626 294.33081906 294.33081906  22.87066554   3.81177759
     3.76176717 401.55745318   6.78219206   7.47533924   6.81262496
     0.           0.           3.94897871 142.89840325 139.08795271
    15.83964199 412.15177224 147.67193152  23.65775834 285.77048159
   142.89840325   0.           3.76176717 142.89840325 150.11255979
     6.81262496   7.62355518]
 [   0.           0.         126.72548688   0.         272.42253249
   279.10996151  85.47335872 137.22399326 141.03577085  15.77183889
   410.17418202 588.55957646   3.81177759   0.         148.65932603
   146.70891962 302.9167826  588.55957646 162.44965463   0.
   449.48425626 548.50400225  28.51506259   7.47533924   6.81262496
     0.         146.70891962   0.         147.67193152 143.86047995
    68.61199663 148.65932603 147.67193152  46.79078814 454.34886676
   147.67193152   0.           0.         147.67193152 150.11255979
     6.81262496   7.62355518]
 [ 236.33021061 127.657052     0.         265.80986754   0.           0.
   182.96532434   0.           0.         404.6156084    0.
     6.08904488 412.15177224 148.65932603   0.           0.           0.
     6.08904488 210.46647483 147.67193152   6.78219206   6.08904488
   423.75878586 147.67193152 425.88728555 396.03289864   0.
   427.40922791   6.78219206  18.41535057 328.53474435   0.           0.
   441.89075824   0.           0.         496.10714696 273.21548637
     6.78219206   0.           0.           0.        ]
 [ 233.22956453 135.42361812   0.         270.84723623   0.           0.
   180.56482415   0.           0.         285.89430491   0.
     7.52353434 449.48425626 146.70891962   0.           0.
    15.04706868   7.52353434 221.14274894 299.92866127   3.76176717
     7.52353434 300.94137359 308.46490793 462.59113318 558.11574782
```

```
   0.         480.59172372  22.47421281  19.70162409 371.08756565
   0.           0.         439.42343643   0.           0.
 534.01649456 307.45251081   7.47533924   3.76176717   0.
   3.76176717]
[481.54428165 126.79624653   3.86442132 264.03762098  15.35101231
  15.24711036 348.74116282  22.52359804   6.37672695 270.14136096
   6.08904488   0.         294.33081906 302.9167826    0.
  15.04706868   0.           0.         356.82933622 461.73375978
   3.76176717   0.         422.74607354 146.684537   541.67185375
 275.19089537  15.0964539  296.38140837  15.14583913  22.79471212
 222.19108816   0.          15.14583913 278.94366649   3.78645978
  15.14583913 301.75728112 150.47068679  15.14583913   0.
   6.37672695   0.        ]
[459.36357187 126.79624653   7.72884265 490.78716853   7.67550615
   7.62355518 331.41248331  21.13730368  12.7534539  270.14136096
  12.17808975   0.         294.33081906 588.55957646   6.08904488
   7.52353434   0.           0.         329.103449   433.31472538
   3.06861999   0.         395.02018632 146.684537   514.63911371
 560.14054205  22.64468086 296.38140837  13.75954477  54.74912899
 222.19108816   6.08904488  13.75954477 278.94366649   3.0933126
  13.75954477 301.75728112 150.47068679  13.75954477   0.
   5.68357977   0.        ]
[ 99.16967556  23.35092179  44.52324773 243.98795322 120.34168758
 119.51047202 435.3108857  113.13717809 179.60560335 286.45030441
 122.07183866 329.103449    22.87066554 162.44965463 210.46647483
 221.14274894 356.82933622 329.103449     0.          49.13463423
 141.68020406 412.53571586  94.19319369 105.66167334 318.63987506
  45.12765799  47.93956957 243.75657947 237.28304448 116.18824218
 373.1260321  210.46647483 127.47979708 434.57606306 136.31255217
 127.47979708  39.18526577 168.84789401 127.47979708 261.34314628
   8.8616336   28.26374816]
[  0.           3.8918203    3.86442132   0.         280.09538861
 286.7325583   29.27316487 416.6865637  386.20109575  15.72120327
 365.39367234 433.31472538   3.81177759   0.         147.67193152
 299.92866127 461.73375978 433.31472538  49.13463423   0.
  22.47421281 412.1774217   52.05253168  15.14583913  57.59939006
   0.           3.76176717   5.39589769 615.94058073 295.31821357
  20.32637346 147.67193152 146.684537    23.58180491 301.90407028
 301.90407028   0.           0.         301.90407028  68.15627608
  29.27316487   7.57291956]
[168.5565961    0.           3.86442132 379.58253213   3.83775308
   3.81177759  82.75887774   0.           6.37672695 108.10810293
   6.08904488   3.06861999   3.76176717 449.48425626   6.78219206
```

```
    3.76176717    3.76176717    3.06861999  141.68020406   22.47421281
    0.            3.06861999   0.            3.76176717   82.75887774
   33.71131922    3.76176717  127.90008378    3.76176717   33.71131922
  109.09124793    6.78219206    3.78645978  108.10810293    0.            0.
   22.57060302  154.23245396    3.76176717    3.76176717    0.
    3.76176717]
[ 462.64634271  123.7744761     7.72884265  609.57196285    7.67550615
    7.62355518  333.97714803    6.78219206   12.7534539   261.55436613
   12.17808975    0.          401.55745318  548.50400225    6.08904488
    7.52353434    0.            0.          412.53571586  412.1774217
    3.06861999    0.          386.13207617  143.88547173  685.9104682
  667.32058088    7.52353434  455.94320612   19.75100932   76.53789295
  350.50539013    6.08904488    3.0933126   430.83863724    3.0933126
    3.0933126   516.98533104  300.94137359   19.75100932    0.
    5.68357977    0.        ]
[   7.47533924    3.19867312    3.86442132   20.0180721   272.42253249
  279.10996151    6.81262496  391.97687692  387.16317246   14.38554453
  355.4154572   395.02018632    6.78219206   28.51506259  423.75878586
  300.94137359  422.74607354  395.02018632   94.19319369   52.05253168
    0.          386.13207617    0.            6.78219206   21.29238625
   42.77259388   21.08791845    7.89795742  422.74607354  694.00744864
   14.45334763  423.75878586  588.55957646   21.57831679  142.89840325
  422.74607354   16.43455316    7.52353434  422.74607354  189.66260219
    6.81262496   31.78190894]
[   3.78645978    0.            3.86442132    0.          280.09538861
  286.7325583    29.27316487  712.01125371  386.20109575    3.78645978
  354.50401611  146.684537      7.47533924    7.47533924  147.67193152
  308.46490793  146.684537    146.684537    105.66167334   15.14583913
    3.76176717  143.88547173    6.78219206    0.           56.56807362
    6.78219206   22.47421281    3.94897871  615.94058073  574.1781577
   15.78900638  147.67193152  461.73375978   23.58180491  293.34342455
  615.94058073    5.68357977    3.76176717  615.94058073   63.39812327
   29.27316487    7.57291956]
[  26.63636003   11.67546089   85.01726913   30.44456311  259.25347585
  267.45836999  129.63482277  253.9411242   387.85864004   64.21367711
  402.67166417  514.63911371    6.81262496    6.81262496  425.88728555
  462.59113318  541.67185375  514.63911371  318.63987506   57.59939006
   82.75887774  685.9104682    21.29238625   56.56807362    0.
   27.26967675   78.02019024   23.52239703  276.23367232  268.83433365
   84.25097656  425.88728555  286.00318287   45.23522025  450.30272501
  276.23367232   24.29848064   11.28530151  276.23367232  233.18476139
    8.47332157   33.05655852]
[   0.            0.            7.72884265    6.08904488  279.98982505
```

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  286.65347398  53.89675613 391.97687692 397.351677    44.0043345
  457.99256846 560.14054205  0.          0.          396.03289864
  558.11574782 275.19089537 560.14054205  45.12765799  0.
   33.71131922 667.32058088  42.77259388   6.78219206  27.26967675
    0.           3.06861999  0.          275.19089537 269.27286804
    3.81177759 396.03289864 147.67193152  23.65775834 301.87776314
  275.19089537  0.          0.          275.19089537 137.63591054
   27.26967675   7.62355518]
[  52.66474038  0.          0.          131.66185095   3.83775308
    3.81177759  82.75887774  0.          0.          112.8530151
    3.8918203   22.64468086  0.          146.70891962  0.          0.
   15.0964539   22.64468086  47.93956957   3.76176717   3.76176717
    7.52353434  21.08791845  22.47421281  78.02019024   3.06861999
    0.          123.15316882  0.           3.06861999 104.3469238
    0.           0.          108.10810293   3.78645978  0.
   17.89722807 149.48298229  0.           16.6934693   0.
    3.76176717]
[   5.39589769  0.          131.39032501   3.25583153 265.32964098
  278.98851051 165.05688811 406.21735771 418.92739202  15.79591485
  424.41985117 296.38140837   3.94897871  0.          427.40922791
  480.59172372 296.38140837 296.38140837 243.75657947   5.39589769
  127.90008378 455.94320612   7.89795742   3.94897871  23.52239703
    0.          123.15316882  0.          296.38140837 289.74656749
   53.24923667 427.40922791 300.49179772   7.89795742 465.69907076
  296.38140837  0.          0.          296.38140837 132.67431685
   23.52239703  10.79179539]
[ 481.54428165 131.54011169   3.86442132 531.13912997  15.35101231
   15.24711036 316.25908822  0.           6.37672695 570.54557549
    3.8918203   13.75954477 142.89840325 147.67193152   6.78219206
   22.47421281  15.14583913  13.75954477 237.28304448 615.94058073
    3.76176717  19.75100932 422.74607354 615.94058073 276.23367232
  275.19089537  0.          296.38140837  0.           3.0933126
  213.97089411   6.78219206   3.78645978 270.14136096   3.78645978
    0.          295.62392032 150.47068679  0.           16.74285452
    0.           3.78645978]
[ 236.33021061 127.657052     7.72884265 492.6100507    7.67550615
    7.62355518 330.22597776   3.19867312  17.70970782 699.61405637
    7.7836406   54.74912899 139.08795271 143.86047995  18.41535057
   19.70162409  22.79471212  54.74912899 116.18824218 295.31821357
   33.71131922  76.53789295 694.00744864 574.1781577  268.83433365
  269.27286804   3.06861999 289.74656749   3.0933126   0.
  368.45822729  18.41535057   3.0933126  417.32411472   7.57291956
    3.0933126  289.0775974  146.70891962   3.0933126   25.19023521
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   0.          3.81177759]
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  243.95376579  45.57937105 220.29252505 319.22923747 165.10834793
  332.36999525 222.19108816  15.83964199  68.61199663 328.53474435
  371.08756565 222.19108816 222.19108816 373.1260321   20.32637346
  109.09124793 350.50539013  14.45334763  15.78900638  84.25097656
    3.81177759 104.3469238   53.24923667 213.97089411 368.45822729
    0.          328.53474435 233.6726756  128.13595727 348.45260285
  213.97089411   3.91999118  67.71180906 213.97089411  77.07273125
    0.           0.        ]
 [ 236.33021061 127.657052     0.          265.80986754   0.           0.
  182.96532434   0.           0.          404.6156084    0.
    6.08904488 412.15177224 148.65932603   0.           0.           0.
    6.08904488 210.46647483 147.67193152   6.78219206   6.08904488
  423.75878586 147.67193152 425.88728555 396.03289864   0.
  427.40922791   6.78219206  18.41535057 328.53474435   0.           0.
  441.89075824   0.           0.          496.10714696 273.21548637
    6.78219206   0.           0.           0.        ]
 [ 234.76050651 131.54011169   0.          264.03762098   3.83775308
    3.81177759 181.75006956   0.           0.          278.94366649
    3.8918203   13.75954477 147.67193152 147.67193152   0.           0.
   15.14583913  13.75954477 127.47979708 146.684537     3.78645978
    3.0933126  588.55957646 461.73375978 286.00318287 147.67193152
    0.          300.49179772   3.78645978   3.0933126  233.6726756
    0.           0.          278.94366649   3.78645978   0.
  287.10280838 145.72152511   0.           4.58496748   0.           0.        ]
 [ 36.49876588   7.7836406  101.49464182  31.97653212 261.55436613
  268.42040052 181.90673077 256.52145539 414.21481983  14.91027306
  419.2547134  278.94366649  23.65775834  46.79078814 441.89075824
  439.42343643 278.94366649 278.94366649 434.57606306  23.58180491
  108.10810293 430.83863724  21.57831679  23.58180491  45.23522025
   23.65775834 108.10810293   7.89795742 270.14136096 417.32411472
  128.13595727 441.89075824 278.94366649   0.          428.38853629
  270.14136096   7.83998235  22.57060302 270.14136096 117.64572288
    4.29728541   4.70275051]
 [ 234.76050651 126.79624653   0.          412.70123531   0.           0.
  181.75006956   3.78645978   0.          266.59751834   0.
    3.0933126  285.77048159 454.34886676   0.           0.
    3.78645978   3.0933126  136.31255217 301.90407028   0.
    3.0933126  142.89840325 293.34342455 450.30272501 301.87776314
    3.78645978 465.69907076   3.78645978   7.57291956 348.45260285
    0.           3.78645978 428.38853629   0.           3.78645978
  536.04128879 308.46490793   3.78645978   3.78645978   0.
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3.78645978]
 [ 234.76050651 131.54011169   0.          272.62510434   3.83775308
   3.81177759 181.75006956   0.          0.          278.94366649
   3.8918203   13.75954477 142.89840325 147.67193152   0.          0.
  15.14583913  13.75954477 127.47979708 301.90407028   0.
   3.0933126  422.74607354 615.94058073 276.23367232 275.19089537
   0.         296.38140837   0.          3.0933126  213.97089411
   0.          0.         270.14136096   3.78645978   0.
 295.62392032 150.47068679   0.         16.74285452   0.
   3.78645978]
 [  0.          0.         23.18652794   4.99043259 279.50337598
 286.28983484  74.90274197 269.27849457 457.59130362  19.20714188
 435.75801278 301.75728112   0.          0.         496.10714696
 534.01649456 301.75728112 301.75728112  39.18526577   0.
  22.57060302 516.98533104  16.43455316   5.68357977  24.29848064
   0.         17.89722807   0.         295.62392032 289.0775974
   3.91999118 496.10714696 287.10280838   7.83998235 536.04128879
 295.62392032   0.          0.         295.62392032 143.94986454
  11.75997353   7.83998235]
 [  0.          0.         134.43725504   3.06861999 138.19866014
 141.96008397 105.32948076 278.37077057 277.60470003  15.04706868
 282.19823842 150.47068679   3.76176717   0.         273.21548637
 307.45251081 150.47068679 150.47068679 168.84789401   0.
 154.23245396 300.94137359   7.52353434   3.76176717  11.28530151
   0.         149.48298229   0.         150.47068679 146.70891962
  67.71180906 273.21548637 145.72152511  22.57060302 308.46490793
 150.47068679   0.          0.         150.47068679  67.71180906
  11.28530151   7.52353434]
 [ 234.76050651 131.54011169   3.86442132 531.13912997   3.83775308
   3.81177759 316.25908822   0.          6.37672695 570.54557549
   3.8918203   13.75954477 142.89840325 147.67193152   6.78219206
   7.47533924  15.14583913  13.75954477 127.47979708 301.90407028
   3.76176717  19.75100932 422.74607354 615.94058073 276.23367232
 275.19089537   0.         296.38140837   0.          3.0933126
 213.97089411   6.78219206   0.         270.14136096   3.78645978
   0.         295.62392032 150.47068679   0.         16.74285452
   0.          3.78645978]
 [  96.65934073  55.64248112   3.86442132  56.06504427   3.83775308
   3.81177759  56.88053931  24.12061343   6.37672695  94.92530045
   6.08904488   0.         150.11255979 150.11255979   0.
   3.76176717   0.          0.         261.34314628  68.15627608
   3.76176717   0.         189.66260219  63.39812327 233.18476139
 137.63591054  16.6934693  132.67431685  16.74285452  25.19023521

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   77.07273125   0.            4.58496748  117.64572288   3.78645978
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    6.37672695   0.          ]
 [  0.            2.79320801   0.            2.82137889   0.            0.
    0.            0.            0.            2.97552957   0.
    5.68357977   6.81262496   6.81262496   0.            0.
    6.37672695   5.68357977   8.8616336    29.27316487   0.
    5.68357977   6.81262496   29.27316487   8.47332157   27.26967675
    0.           23.52239703   0.            0.            0.            0.
    0.            4.29728541   0.            0.           11.75997353
   11.28530151   0.            6.37672695   0.            6.37672695]
 [  0.            0.            3.86442132   0.            3.83775308
    3.81177759   6.37672695   7.47533924   6.37672695   0.
    6.08904488   0.            7.62355518   7.62355518   0.
    3.76176717   0.            0.           28.26374816   7.57291956
    3.76176717   0.           31.78190894   7.57291956   33.05655852
    7.62355518   3.76176717   10.79179539   3.78645978   3.81177759
    0.            0.            0.            4.70275051   3.78645978
    3.78645978   7.83998235   7.52353434   3.78645978   0.
    6.37672695   0.          ]]

Dynamic Programming Matrix Return
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   1.14792891e+03   1.14792891e+03   1.47467110e+03   1.59775349e+03
   1.85204488e+03   1.85204488e+03   1.85204488e+03   1.95162604e+03
   2.06614646e+03   2.52879280e+03   2.65960078e+03   3.02696284e+03
   3.15787258e+03   3.38201461e+03   3.38201461e+03   3.56134788e+03
   4.04289216e+03   4.10156079e+03   4.10156079e+03   4.29348128e+03
   4.41956862e+03   4.46021627e+03   4.51731520e+03   4.67188514e+03
   4.68042236e+03   4.82975493e+03   5.18827317e+03   5.18827317e+03
   5.18827317e+03   5.18827317e+03]
 [ 0.00000000e+00   0.00000000e+00   0.00000000e+00   0.00000000e+00
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   5.49734131e+02   5.49734131e+02   6.88565336e+02   8.15361582e+02
   8.15361582e+02   9.59908313e+02   1.36452392e+03   1.37050060e+03
   1.37050060e+03   1.65431812e+03   1.69884137e+03   1.84147885e+03
   2.06614646e+03   2.29997364e+03   2.39636099e+03   2.83078066e+03
   2.92026745e+03   3.27186743e+03   3.33158356e+03   3.56134788e+03
   3.86523058e+03   3.99288764e+03   4.05715107e+03   4.18480812e+03
   4.18869118e+03   4.28255470e+03   4.43712463e+03   4.56866474e+03
   4.59718203e+03   4.73161928e+03   5.07812599e+03   5.07812599e+03
```

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  7.96248098e+02 9.22973585e+02 1.23507698e+03 1.23507698e+03
  1.25939224e+03 1.65431812e+03 1.69884137e+03 1.81352656e+03
  2.06614646e+03 2.29997364e+03 2.39636099e+03 2.83078066e+03
  2.91993189e+03 3.19992171e+03 3.33158356e+03 3.56134788e+03
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  4.05715107e+03 4.28255470e+03 4.43712463e+03 4.43712463e+03
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  1.25939224e+03 1.65431812e+03 1.65431812e+03 1.73331030e+03
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  4.02004062e+03 4.28255470e+03 4.43712463e+03 4.43712463e+03
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  1.16353095e+03 1.20297384e+03 1.39983137e+03 1.68656393e+03
  1.69040168e+03 1.74505911e+03 2.02416907e+03 2.65247352e+03
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  3.75984075e+03 4.02442339e+03 4.08294490e+03 4.08294490e+03
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  4.77536244e+03 4.77917422e+03]
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  1.68656393e+03 1.74505911e+03 2.02416907e+03 2.65247352e+03
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  3.75981477e+03 4.02442339e+03 4.02442339e+03 4.07814597e+03
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    8.37313388e+02  9.64520482e+02  1.07765766e+03  1.41108196e+03
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    2.65247352e+03  2.84213519e+03  2.84213519e+03  3.14106069e+03
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    3.57303767e+03  3.82955913e+03  3.82955913e+03  3.82955913e+03
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    4.55251247e+03  4.55251247e+03]
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    2.45015831e+03  2.72213329e+03  2.72213329e+03  3.14106069e+03
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    8.14789790e+02  8.14789790e+02  9.26351051e+02  1.29174472e+03
    1.39985283e+03  1.55329909e+03  1.70779566e+03  2.06229967e+03
    2.23162136e+03  2.72213329e+03  2.72213329e+03  2.74492691e+03
    3.12473995e+03  3.25380843e+03  3.25380843e+03  3.38323150e+03

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  3.38323150e+03  3.54206407e+03  3.70695738e+03  3.71930353e+03
  3.85624812e+03  3.95784628e+03  4.52839185e+03  4.52839185e+03
  4.52839185e+03  4.52839185e+03]
[ 0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
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  0.00000000e+00  4.10174182e+02  4.10174182e+02  4.49484256e+02
  4.55573301e+02  5.97247602e+02  9.26351051e+02  1.29174472e+03
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  2.11046732e+03  2.31751769e+03  2.31751769e+03  2.55419438e+03
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  3.80964877e+03  3.95784628e+03  3.95784628e+03  3.95784628e+03
  3.95784628e+03  3.95784628e+03]
[ 0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
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  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
  0.00000000e+00  0.00000000e+00  6.08904488e+00  4.49484256e+02
  4.49484256e+02  5.97247602e+02  9.26351051e+02  1.04474497e+03
  1.04474497e+03  1.31277547e+03  1.70779566e+03  1.70779566e+03
  1.82741458e+03  2.12977452e+03  2.12977452e+03  2.35043383e+03
  2.48242466e+03  2.64624590e+03  2.86843698e+03  3.00734560e+03
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  3.67564804e+03  3.68693334e+03]
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  4.49484256e+02  5.97247602e+02  6.11430242e+02  6.11430242e+02
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  3.37389076e+03  3.37389076e+03  3.58595187e+03  3.61245831e+03
  3.61245831e+03  3.61245831e+03]
[ 0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
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  9.11218016e+02  1.01701995e+03  1.01701995e+03  1.14374670e+03
  1.56963398e+03  1.90734350e+03  2.05405242e+03  2.33475273e+03
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  2.59519383e+03  2.89974878e+03  3.23099236e+03  3.23099236e+03
  3.28647384e+03  3.31467382e+03  3.46234575e+03  3.50494761e+03
  3.50494761e+03  3.50494761e+03]
[ 0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
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  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
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  4.68515952e+02  4.71584572e+02  8.93016080e+02  1.14374670e+03
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  3.31467382e+03  3.31467382e+03]
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  1.41683157e+03  1.90734350e+03  1.90734350e+03  1.90734350e+03
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  2.33475273e+03  2.58513301e+03  2.79036669e+03  2.79036669e+03
  3.04145833e+03  3.05809016e+03  3.05809016e+03  3.05809016e+03
  3.05809016e+03  3.05809016e+03]
[ 0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
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  2.14570958e+03  2.33154380e+03  2.33154380e+03  2.50744184e+03
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  2.92276476e+03  2.92276476e+03]
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  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
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   1.97036784e+03  2.27201861e+03  2.27511192e+03  2.44888037e+03
   2.60095119e+03  2.60095119e+03  2.65504488e+03  2.91638803e+03
   2.92207161e+03  2.92207161e+03]
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   1.95912755e+03  2.27201861e+03  2.27201861e+03  2.29919391e+03
   2.29919391e+03  2.36775625e+03  2.65504488e+03  2.91638803e+03
   2.91638803e+03  2.91638803e+03]
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   1.42975113e+03  1.42975113e+03  1.68397582e+03  1.83164775e+03
   1.83744255e+03  1.86981004e+03  2.17171411e+03  2.17171411e+03
   2.19890836e+03  2.35314081e+03  2.65504488e+03  2.65504488e+03
   2.65504488e+03  2.65504488e+03]
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   8.13810552e+02  1.33347043e+03  1.68397582e+03  1.69075801e+03
   1.69075801e+03  1.86981004e+03  1.86981004e+03  1.86981004e+03
   2.19890836e+03  2.35314081e+03  2.35314081e+03  2.35314081e+03
   2.35314081e+03  2.35314081e+03]
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      2.19890836e+03  2.24429411e+03  2.26258209e+03  2.26716705e+03
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      7.86383005e+02  7.86383005e+02  1.02538388e+03  1.15925686e+03
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      1.54088182e+03  1.54088182e+03]
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      0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00

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    5.75081159e+02   5.75081159e+02   8.83023185e+02   1.15821408e+03
    1.15821408e+03   1.15821408e+03   1.30769706e+03   1.30769706e+03
    1.30769706e+03   1.30769706e+03]
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    4.27409228e+02   5.35517331e+02   8.83023185e+02   8.83023185e+02
    9.00920414e+02   1.03250617e+03   1.08438230e+03   1.10107576e+03
    1.10107576e+03   1.10107576e+03]
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    4.27409228e+02   4.27409228e+02   8.83023185e+02   8.83023185e+02
    8.83023185e+02   8.83023185e+02   1.08438230e+03   1.08438230e+03
    1.08438230e+03   1.08438230e+03]
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    7.99479424e+02   8.03265884e+02]
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   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
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   6.37530200e+02  6.42816067e+02  7.74289189e+02  7.99479424e+02
   7.99479424e+02  7.99479424e+02]
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   0.00000000e+00  1.28135957e+02  3.48452603e+02  3.48452603e+02
   4.96107147e+02  5.63818956e+02  7.74289189e+02  7.74289189e+02
   7.74289189e+02  7.74289189e+02]
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   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   4.96107147e+02  5.60318295e+02  5.78606269e+02  5.83191236e+02
   5.83191236e+02  5.83191236e+02]
 [ 0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   2.87102808e+02  3.08464908e+02  5.78606269e+02  5.83191236e+02
   5.83191236e+02  5.83191236e+02]
 [ 0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
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   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   7.83998235e+00  3.08464908e+02  5.78606269e+02  5.78606269e+02
   5.78606269e+02  5.78606269e+02]
[  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  3.08464908e+02  3.08464908e+02  3.08464908e+02
   3.08464908e+02  3.08464908e+02]
[  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  1.43949865e+02
   1.43949865e+02  1.47736324e+02]
[  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
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   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
   0.00000000e+00  0.00000000e+00  0.00000000e+00  1.43949865e+02
   1.43949865e+02  1.43949865e+02]
[  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
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    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
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    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    1.12853015e+01  1.12853015e+01]
 [  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  3.78645978e+00]
 [  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
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    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00]
 [  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
    0.00000000e+00  0.00000000e+00]
```

```
[ 0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
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  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
  0.00000000e+00  0.00000000e+00  0.00000000e+00  0.00000000e+00
  0.00000000e+00  0.00000000e+00]]
```