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▾ Python Tutorial and Homework 2

This Colab Notebook contains 2 sections. The first section is a Python Tutorial intended to make you familiar with Numpy and Colab functionalities. **This section will not be graded**.

The second section is a coding assignment (Homework 2). **This section will be graded**

▾ 1.0 **Python Tutorial**

This assignment section won't be graded but is intended as a tutorial to refresh the basics of python and its dependencies. It also allows one to get familiarized with Google Colab.

▾ 1.0.0 Array manipulation using numpy

▸ Q1 - Matrix multiplication

[ ] ↳ *1 cell hidden*

▸ Q2 - Diagonals

[ ] ↳ *1 cell hidden*

▸ Q3 - Sin wave

[ ] ↳ *3 cells hidden*

▸ Q4 Car Brands

[ ] ↳ *1 cell hidden*

▾ 1.0.1 Basics tensorflow

Helper functions

```python
import tensorflow as tf
from keras.utils import to_categorical


def plot_image(i, predictions_array, true_label, img):
  true_label, img = true_label[i], img[i]
  plt.grid(False)
  plt.xticks([])
  plt.yticks([])

  plt.imshow(img, cmap=plt.cm.binary)

  predicted_label = np.argmax(predictions_array)
  if predicted_label == true_label:
    color = 'blue'
  else:
    color = 'red'

def plot_value_array(i, predictions_array, true_label):
  true_label = true_label[i]
  # print(true_label)
  plt.grid(False)
  plt.xticks(range(10))
  plt.yticks([])
  thisplot = plt.bar(range(10), predictions_array, color="#777777")
  plt.ylim([0, 1])
  predicted_label = np.argmax(predictions_array)

  thisplot[predicted_label].set_color('red')
  thisplot[true_label].set_color('blue')
```

Q1 MNIST Classifier

```python
## Import the MNIST dataset from keras
mnist = tf.keras.datasets.mnist
### Load the data
(x_train, y_train), (x_test, y_test) = mnist.load_data()

# ### Normalize the 8bit images with values in the range [0,255]
def normalize_img(image):
  return tf.cast(image,tf.float32) / 255.

normalize_img(x_train)
# normalize_img(x_test)
normalize_img(y_train)
```

```
# normalize_img(y_test)
```

```
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datasets/mnist
11490434/11490434 [==============================] - 3s 0us/step
<tf.Tensor: shape=(60000,), dtype=float32, numpy=
array([0.01960784, 0.        , 0.01568628, ..., 0.01960784, 0.02352941,
       0.03137255], dtype=float32)>
```

```
## Create a model with the following architecture Flatten -> Dense(128, relu) -> Dense(64,rel
model = tf.keras.models.Sequential([
  tf.keras.layers.Flatten(input_shape=(28, 28)),
  tf.keras.layers.Dense(128, activation='relu'),
  tf.keras.layers.Dense(64, activation='relu'),
  tf.keras.layers.Dense(10)
])
### Complie the model with the adam optimizer and crossentropy loss
### HINT - No One hot encoding
loss_fn = tf.keras.losses.SparseCategoricalCrossentropy()

model.compile(loss=loss_fn, optimizer='adam')


### Train the model on the train data for 5 epochs

model.fit(x_train, y_train, epochs=5)
```

```
Epoch 1/5
1875/1875 [==============================] - 14s 7ms/step - loss: 8.0575
Epoch 2/5
1875/1875 [==============================] - 12s 7ms/step - loss: 2.3035
Epoch 3/5
1875/1875 [==============================] - 13s 7ms/step - loss: 2.3035
Epoch 4/5
1875/1875 [==============================] - 10s 5ms/step - loss: 2.3035
Epoch 5/5
1875/1875 [==============================] - 9s 5ms/step - loss: 2.3035
<keras.callbacks.History at 0x7f9c8c07de80>
```

```
### Check the accuracy of the trained model
test_acc = model.evaluate(x_test, y_test)
print('\nTest accuracy:', test_acc)
```

```
313/313 [==============================] - 1s 2ms/step - loss: 2.3041

Test accuracy: 2.304086446762085
```

```
import numpy as np
import tensorflow as tf
```

```python
from keras.utils import to_categorical
import tensorflow_probability as tfp

import matplotlib.pyplot as plt

from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense, Flatten, Conv2D, MaxPooling2D, Dropout
from tensorflow.keras.losses import SparseCategoricalCrossentropy
from tensorflow.keras.optimizers import RMSprop

tfd = tfp.distributions
tfpl = tfp.layers


### Convert the above model to a probabilistic model with a softmax as the output layer

def get_probabilistic_model(input_shape, loss, optimizer, metrics):
    """
    This function should return the probabilistic model according to the
    above specification.
    The function takes input_shape, loss, optimizer and metrics as arguments,
    which should be used to define and compile the model.
    will return the compiled model.
    """
    model = Sequential([
        Conv2D(28, kernel_size=(3, 3), input_shape=input_shape),
        MaxPooling2D(pool_size=(2, 2)),
        Flatten(),
        Dense(128, activation=tf.nn.relu),
        Dense(tfpl.OneHotCategorical.params_size(28)),
        Dropout(0.2),
        Dense(10, activation=tf.keras.activations.softmax)
    ])

    model.compile(loss=loss, optimizer=optimizer, metrics=metrics)
    return model

loss_fn = tf.keras.losses.SparseCategoricalCrossentropy()

tf.random.set_seed(0)
probabilistic_model = get_probabilistic_model(
    input_shape=(28, 28, 1),
    loss=loss_fn,
    optimizer=RMSprop(),
    metrics=['accuracy']
)


# ### Run the test data through the new model and get predictions

probabilistic_model.fit(x=x_train,y=y_train, epochs=10)
```

```
predictions = probabilistic_model.predict(x_train, verbose=0)

### Plot a test output
i = 25  ### <---- Change this to some random number to see different predictions

print("compare predicted ",predictions[i].argmax(), ", to expected ",y_test[i])

plt.figure(figsize=(6,3))
plt.subplot(1,2,1)
plot_image(i, predictions[i], y_test, x_test)
plt.subplot(1,2,2)
plot_value_array(i, predictions[i], y_test)
plt.show()
print(predictions[i].argmax())
### Blue bars mean correct guess red bar means wrong guess!!
```
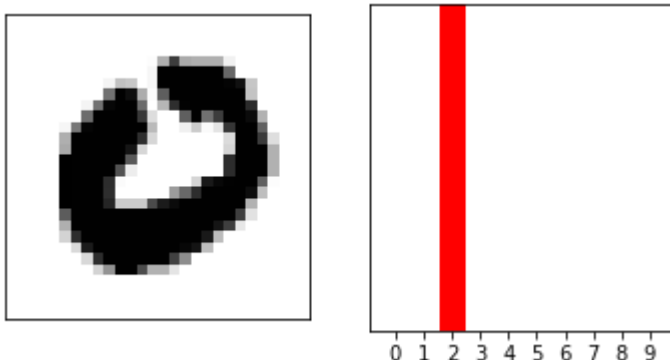
```
    Epoch 1/10
    1875/1875 [==============================] - 74s 39ms/step - loss: 1.1228 - accuracy: 0
    Epoch 2/10
    1875/1875 [==============================] - 80s 43ms/step - loss: 0.1867 - accuracy: 0
    Epoch 3/10
    1875/1875 [==============================] - 74s 40ms/step - loss: 0.1320 - accuracy: 0
    Epoch 4/10
    1875/1875 [==============================] - 76s 41ms/step - loss: 0.1024 - accuracy: 0
    Epoch 5/10
    1875/1875 [==============================] - 72s 38ms/step - loss: 0.0834 - accuracy: 0
    Epoch 6/10
    1875/1875 [==============================] - 72s 38ms/step - loss: 0.0718 - accuracy: 0
    Epoch 7/10
    1875/1875 [==============================] - 75s 40ms/step - loss: 0.0644 - accuracy: 0
    Epoch 8/10
    1875/1875 [==============================] - 76s 41ms/step - loss: 0.0561 - accuracy: 0
    Epoch 9/10
    1875/1875 [==============================] - 74s 39ms/step - loss: 0.0531 - accuracy: 0
    Epoch 10/10
    1875/1875 [==============================] - 75s 40ms/step - loss: 0.0504 - accuracy: 0
    compare predicted  2 , to expected  0
```



```
    2
```

2.0 Homework 2

Note : This section will be graded

1. Program a Discrete CMAC and train it on a 1-D function (ref: Albus 1975, Fig. 5) Explore effect of overlap area on generalization and time to convergence. Use only 35 weights weights for your CMAC, and sample your function at 100 evenly spaced points. Use 70 for training and 30 for testing. Report the accuracy of your CMAC network using only the 30 test points.

```python
import numpy as np
import matplotlib.pyplot as plt
import math
import time
```

```python
'''CMAC Parent Class'''
class CMAC:
    def __init__(self, gen_factor, num_weights):
        self.gen_factor = gen_factor
        self.num_weights = num_weights
        self.weight_vec = np.ones(self.num_weights)
        self.association_map = {}

    def set_gen_factor(self, gen_factor):
        self.gen_factor = gen_factor
```

```python
# Child Inherited class for Discrete CMAC
class DiscreteCMAC(CMAC):

    def __init__(self, gen_factor, num_weights):
        CMAC.__init__(self, gen_factor, num_weights)

    '''This will return the index (or the ith sample), in the association_input_vec values,
    corresponding the actual input value'''
    def get_assoc_vec_ind(self, input_val, num_of_assoc_vec, input_min, input_max):
        if input_val < input_min:
            return 1
        elif input_val > input_max:
            return num_of_assoc_vec-1
        else:
            proportion_ind = (num_of_assoc_vec-2) * ((input_val - input_min)/(input_max - inp
            return proportion_ind


    '''Association map in CMAC is an assiociation unit matrix of size (m x n),
        where m = number of association input vectors (possible values of the sample input)
        n = number of weights
```

```python
    >> This function will return a map with:
            key = specific sample input value
            value = index of the first cell in the range of consecutive ones in that row
    '''
    def process_association_map(self, data, input_min, input_max):
        num_of_assoc_vec = self.num_weights + 1 - self.gen_factor
        for ind, data_val in enumerate(data):
            assoc_vec_ind = self.get_assoc_vec_ind(data_val[0], num_of_assoc_vec, input_min,
            self.association_map[data_val[0]] = int(math.floor(assoc_vec_ind))


    def train(self, data, input_min, input_max, total_epoch = 5000, learning_rate = 0.01):
        self.weight_vec = np.ones(self.num_weights)
        input_X = np.linspace(input_min, input_max, self.num_weights + 1 - self.gen_factor)
        alpha = learning_rate
        epoch = 0

        self.association_map = {}
        self.process_association_map(data, input_min, input_max)

        is_converged = False
        prev_error = 0
        new_error = 0
        start_time = time.time()
        while epoch <= total_epoch and not is_converged:
            prev_error = new_error
            for ind, data_val in enumerate(data):
                asc_wt_ind = self.association_map[data_val[0]]
                y_output = np.sum(self.weight_vec[asc_wt_ind: asc_wt_ind + self.gen_factor])
                error = data_val[1] - y_output
                correction = alpha*error/self.gen_factor
                self.weight_vec[asc_wt_ind: (asc_wt_ind + self.gen_factor)] = [(self.weight_v


            intermediate_output, accuracy = self.predict(data, input_min, input_max, False)
            new_error = 1 - accuracy
            if np.abs(prev_error - new_error) < 0.0000001:
                is_converged = True

            epoch = epoch + 1
            print("Discrete CMAC: ", " => g -", self.gen_factor ,"epoch - ", epoch, "  => err

        end_time = time.time()
        process_time = end_time - start_time
        return process_time, np.copy(self.weight_vec)

    def calculate_error(self, y_predict, y_expected):
        error = np.subtract(y_expected, y_predict)
        error_sq = np.power(error, 2)
        sum_error_sq = np.sum(error_sq)
        total_error = np.sqrt(sum_error_sq)/len(y_expected)
```

```python
            return total_error

        def predict(self, data, input_min, input_max, re_process_asso_map = True):
            output = []
            if re_process_asso_map:
                self.process_association_map(data, input_min, input_max)

            for ind, data_val in enumerate(data):
                asc_wt_ind = self.association_map[data_val[0]]
                y_output = np.sum(self.weight_vec[asc_wt_ind: asc_wt_ind + self.gen_factor])
                output.append(y_output)

            error = self.calculate_error(output, data[:, 1])
            accuracy = 1 - error
            return output, accuracy

    #main

    # 1D function: sin(x)
    TWO_PI = 2*np.pi #create data
    sample_input = np.linspace(0, TWO_PI, 100) #100 evenly spaced sample points
    sample_output = np.sin(sample_input)

    total_data = np.column_stack((sample_input, sample_output))
    np.random.shuffle(total_data)

    train_data = total_data[:70]
    test_data = total_data[70:] #30 data points

    x_train = train_data[:, 0]
    x_test = test_data[:, 0]

    y_train = train_data[:, 1]
    y_test = test_data[:, 1]

    num_weights = 35

    gen_factor_list = range(1, num_weights)

    convergence_time_discrete = []
    accuracies_discrete = []

    #create class Object
    discrete_cmac = DiscreteCMAC(1, num_weights)

    for gen_factor in gen_factor_list:
        discrete_cmac.set_gen_factor(gen_factor)
        process_time_discrete, weight_vec_discrete = discrete_cmac.train(train_data, 0, TWO_PI, 1
        y_output_discrete, accuracy_discrete = discrete_cmac.predict(test_data, 0, TWO_PI)

        convergence_time_discrete.append(process_time_discrete)
        accuracies_discrete.append(accuracy_discrete)
```

```
fig, (ax1, ax2) = plt.subplots(1, 2)
plt.style.use('seaborn-whitegrid')

ax1.set_title('Convergence time v/s Generalization Factor')
ax1.plot(gen_factor_list, convergence_time_discrete, label="Discrete CMAC")
ax1.set(xlabel='generalization factor', ylabel='Convergence time')
ax1.legend()


ax2.set_title('Accuracy v/s Generalization Factor')
ax2.plot(gen_factor_list, accuracies_discrete, label="Discrete CMAC")
ax2.set(xlabel='generalization factor', ylabel='Accuracy')
ax2.legend()

plt.show()
```

```
Streaming output truncated to the last 5000 lines.
Discrete CMAC:    => g - 27 epoch -   464    => error -   0.021765856516337223   accuracy -
Discrete CMAC:    => g - 27 epoch -   465    => error -   0.021758439914125627   accuracy -
Discrete CMAC:    => g - 27 epoch -   466    => error -   0.02175108042114693    accuracy -
Discrete CMAC:    => g - 27 epoch -   467    => error -   0.021743777555385813   accuracy -
Discrete CMAC:    => g - 27 epoch -   468    => error -   0.021736530839295276   accuracy -
Discrete CMAC:    => g - 27 epoch -   469    => error -   0.02172933979975067    accuracy -
Discrete CMAC:    => g - 27 epoch -   470    => error -   0.021722203968003062   accuracy -
Discrete CMAC:    => g - 27 epoch -   471    => error -   0.021715122879634285   accuracy -
Discrete CMAC:    => g - 27 epoch -   472    => error -   0.02170809607451174    accuracy -
Discrete CMAC:    => g - 27 epoch -   473    => error -   0.021701123096744324   accuracy -
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Discrete CMAC:    => g - 27 epoch -   475    => error -   0.021687336820654934   accuracy -
Discrete CMAC:    => g - 27 epoch -   476    => error -   0.021680522631365662   accuracy -
Discrete CMAC:    => g - 27 epoch -   477    => error -   0.021673760487412097   accuracy -
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Discrete CMAC:    => g - 27 epoch -   481    => error -   0.02164722371787453    accuracy -
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Discrete CMAC:    => g - 27 epoch -   483    => error -   0.021634256473939795   accuracy -
Discrete CMAC:    => g - 27 epoch -   484    => error -   0.021627846678450524   accuracy -
Discrete CMAC:    => g - 27 epoch -   485    => error -   0.021621485555005315   accuracy -
Discrete CMAC:    => g - 27 epoch -   486    => error -   0.02161517269904545    accuracy -
Discrete CMAC:    => g - 27 epoch -   487    => error -   0.021608907709685266   accuracy -
Discrete CMAC:    => g - 27 epoch -   488    => error -   0.021602690189674312   accuracy -
Discrete CMAC:    => g - 27 epoch -   489    => error -   0.021596519745361253   accuracy -
Discrete CMAC:    => g - 27 epoch -   490    => error -   0.02159039598665735    accuracy -
Discrete CMAC:    => g - 27 epoch -   491    => error -   0.02158431852700049    accuracy -
Discrete CMAC:    => g - 27 epoch -   492    => error -   0.021578286983319872   accuracy -
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Discrete CMAC:    => g - 27 epoch -   503    => error -   0.0215148642905304     accuracy -  9
Discrete CMAC:    => g - 27 epoch -   504    => error -   0.021509355083214055   accuracy -
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Discrete CMAC:    => g - 27 epoch -   509    => error -   0.02148242091286201    accuracy -
Discrete CMAC:    => g - 27 epoch -   510    => error -   0.021477154129868725   accuracy -
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Discrete CMAC:    => g - 27 epoch -   512    => error -   0.0214667380137874     accuracy -  9
Discrete CMAC:    => g - 27 epoch -   513    => error -   0.02146158804333287    accuracy -
Discrete CMAC:    => g - 27 epoch -   514    => error -   0.021456476377719635   accuracy -
Discrete CMAC:    => g - 27 epoch -   515    => error -   0.0214514027052648     accuracy -  9
Discrete CMAC:    => g - 27 epoch -   516    => error -   0.021446366717037257   accuracy -
Discrete CMAC:    => g - 27 epoch -   517    => error -   0.021441368106830172   accuracy -
Discrete CMAC:    => g - 27 epoch -   518    => error -   0.021436406571135103   accuracy -
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Discrete CMAC:   => g - 27 epoch -   519   => error -   0.021431481809115693   accuracy -
Discrete CMAC:   => g - 27 epoch -   520   => error -   0.021426593522581694   accuracy -
Discrete CMAC:   => g - 27 epoch -   521   => error -   0.021421741415963647   accuracy -
Discrete CMAC:   => g - 27 epoch -   522   => error -   0.02141692519628724    accuracy -
Discrete CMAC:   => g - 27 epoch -   523   => error -   0.021412144573148995   accuracy -
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Discrete CMAC:   => g - 27 epoch -   525   => error -   0.0214026889675758     accuracy -    9
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Discrete CMAC:   => g - 27 epoch -   554   => error -   0.021280128290151357   accuracy -
Discrete CMAC:   => g - 27 epoch -   555   => error -   0.021276347591982603   accuracy -
Discrete CMAC:   => g - 27 epoch -   556   => error -   0.021272594200267503   accuracy -
Discrete CMAC:   => g - 27 epoch -   557   => error -   0.021268867898883048   accuracy -
Discrete CMAC:   => g - 27 epoch -   558   => error -   0.02126516847355131    accuracy -
Discrete CMAC:   => g - 27 epoch -   559   => error -   0.021261495711822676   accuracy -
Discrete CMAC:   => g - 27 epoch -   560   => error -   0.02125784940305886    accuracy -
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Discrete CMAC:    => g - 27  epoch -  1026    => error -  0.02073791248100426   accuracy -
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Discrete CMAC:    => g - 28 epoch -  4    => error -  0.2627402987057088   accuracy -   73.
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Discrete CMAC:    => g - 28 epoch -  6    => error -  0.12010549879118426   accuracy -   87
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Discrete CMAC:    => g - 28 epoch -  21   => error -  0.08008557409871697   accuracy -   9
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Discrete CMAC:    => g - 28 epoch -  71    => error -  0.05229143964792371   accuracy -   9
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Discrete CMAC:    => g - 28 epoch -  75    => error -  0.05120225020484037   accuracy -   9
Discrete CMAC:    => g - 28 epoch -  76    => error -  0.05094148563891243   accuracy -   9
Discrete CMAC:    => g - 28 epoch -  77    => error -  0.05068503154249071   accuracy -   9
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Discrete CMAC:    => g - 28 epoch -   79    => error -   0.050184503385232504  accuracy -
Discrete CMAC:    => g - 28 epoch -   80    => error -   0.049940169088531494  accuracy -
Discrete CMAC:    => g - 28 epoch -   81    => error -   0.049699624210950755  accuracy -
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Discrete CMAC:    => g - 28 epoch -   90    => error -   0.0476877163914039  accuracy -   95
Discrete CMAC:    => g - 28 epoch -   91    => error -   0.04747946831762917  accuracy -   9
Discrete CMAC:    => g - 28 epoch -   92    => error -   0.047273982367526446  accuracy -
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Discrete CMAC:    => g - 28 epoch -    999   => error -   0.025879374557256307   accuracy -
Discrete CMAC:    => g - 28 epoch -    1000   => error -   0.025879185820381623   accuracy -
Discrete CMAC:    => g - 28 epoch -    1001   => error -   0.025878998308883627   accuracy -
Discrete CMAC:    => g - 28 epoch -    1002   => error -   0.02587881201451603   accuracy -
Discrete CMAC:    => g - 28 epoch -    1003   => error -   0.025878626929090265   accuracy -
Discrete CMAC:    => g - 28 epoch -    1004   => error -   0.025878443044474397   accuracy -
Discrete CMAC:    => g - 28 epoch -    1005   => error -   0.025878260352593108   accuracy -
Discrete CMAC:    => g - 28 epoch -    1006   => error -   0.025878078845427255   accuracy -
Discrete CMAC:    => g - 28 epoch -    1007   => error -   0.02587789851501321   accuracy -
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Discrete CMAC:    => g - 28 epoch -    1009   => error -   0.0258775413528628   accuracy -
Discrete CMAC:    => g - 28 epoch -    1010   => error -   0.0258773645054744   accuracy -
Discrete CMAC:    => g - 28 epoch -    1011   => error -   0.025877188803532847   accuracy -
Discrete CMAC:    => g - 28 epoch -    1012   => error -   0.025877014239347296   accuracy -
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Discrete CMAC:    => g - 28 epoch -    1026   => error -   0.02587468562288353   accuracy -
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Discrete CMAC:    => g - 28 epoch -    1033   => error -   0.025873598143622556   accuracy -
Discrete CMAC:    => g - 28 epoch -    1034   => error -   0.025873446768329478   accuracy -
Discrete CMAC:    => g - 28 epoch -    1035   => error -   0.02587329636788538   accuracy -
Discrete CMAC:    => g - 28 epoch -    1036   => error -   0.025873146935780467   accuracy -
Discrete CMAC:    => g - 28 epoch -    1037   => error -   0.02587299465549357   accuracy -
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Discrete CMAC:    => g - 28 epoch -   1037   => error -   0.025872990109949997   accuracy -
Discrete CMAC:    => g - 28 epoch -   1038   => error -   0.025872285095077163   accuracy -
Discrete CMAC:    => g - 28 epoch -   1039   => error -   0.025872704385071166   accuracy -
Discrete CMAC:    => g - 28 epoch -   1040   => error -   0.025872558762115583   accuracy -
Discrete CMAC:    => g - 28 epoch -   1041   => error -   0.02587241407561658    accuracy -
Discrete CMAC:    => g - 28 epoch -   1042   => error -   0.025872270319328816   accuracy -
Discrete CMAC:    => g - 28 epoch -   1043   => error -   0.025872127487050145   accuracy -
Discrete CMAC:    => g - 28 epoch -   1044   => error -   0.02587198557262138    accuracy -
Discrete CMAC:    => g - 28 epoch -   1045   => error -   0.025871844569925417   accuracy -
Discrete CMAC:    => g - 28 epoch -   1046   => error -   0.02587170447288767    accuracy -
Discrete CMAC:    => g - 28 epoch -   1047   => error -   0.025871565275475294   accuracy -
Discrete CMAC:    => g - 28 epoch -   1048   => error -   0.025871426971696643   accuracy -
Discrete CMAC:    => g - 28 epoch -   1049   => error -   0.025871289555601917   accuracy -
Discrete CMAC:    => g - 28 epoch -   1050   => error -   0.025871153021281956   accuracy -
Discrete CMAC:    => g - 28 epoch -   1051   => error -   0.02587101736286812    accuracy -
Discrete CMAC:    => g - 28 epoch -   1052   => error -   0.025870882574532517   accuracy -
Discrete CMAC:    => g - 28 epoch -   1053   => error -   0.025870748650487108   accuracy -
Discrete CMAC:    => g - 28 epoch -   1054   => error -   0.025870615584983825   accuracy -
Discrete CMAC:    => g - 28 epoch -   1055   => error -   0.025870483372314013   accuracy -
Discrete CMAC:    => g - 28 epoch -   1056   => error -   0.025870352006808206   accuracy -
Discrete CMAC:    => g - 28 epoch -   1057   => error -   0.025870221482836242   accuracy -
Discrete CMAC:    => g - 28 epoch -   1058   => error -   0.02587009179480637    accuracy -
Discrete CMAC:    => g - 28 epoch -   1059   => error -   0.025869962937165147   accuracy -
Discrete CMAC:    => g - 28 epoch -   1060   => error -   0.02586983490439776    accuracy -
Discrete CMAC:    => g - 28 epoch -   1061   => error -   0.025869707691026811   accuracy -
Discrete CMAC:    => g - 28 epoch -   1062   => error -   0.025869581291612653   accuracy -
Discrete CMAC:    => g - 28 epoch -   1063   => error -   0.025869455700753274   accuracy -
Discrete CMAC:    => g - 28 epoch -   1064   => error -   0.0258693309130833     accuracy -
Discrete CMAC:    => g - 28 epoch -   1065   => error -   0.025869206923274546   accuracy -
Discrete CMAC:    => g - 28 epoch -   1066   => error -   0.025869083726035025   accuracy -
Discrete CMAC:    => g - 28 epoch -   1067   => error -   0.025868961316109496   accuracy -
Discrete CMAC:    => g - 28 epoch -   1068   => error -   0.025868839688278356   accuracy -
Discrete CMAC:    => g - 28 epoch -   1069   => error -   0.025868718837358085   accuracy -
Discrete CMAC:    => g - 28 epoch -   1070   => error -   0.02586859875820058    accuracy -
Discrete CMAC:    => g - 28 epoch -   1071   => error -   0.025868479445693038   accuracy -
Discrete CMAC:    => g - 28 epoch -   1072   => error -   0.025868360894757636   accuracy -
Discrete CMAC:    => g - 28 epoch -   1073   => error -   0.025868243100351518   accuracy -
Discrete CMAC:    => g - 28 epoch -   1074   => error -   0.025868126057466245   accuracy -
Discrete CMAC:    => g - 28 epoch -   1075   => error -   0.025868009761127575   accuracy -
Discrete CMAC:    => g - 28 epoch -   1076   => error -   0.025867894206395460   accuracy -
Discrete CMAC:    => g - 28 epoch -   1077   => error -   0.025867779388363932   accuracy -
Discrete CMAC:    => g - 28 epoch -   1078   => error -   0.025867665302160003   accuracy -
Discrete CMAC:    => g - 28 epoch -   1079   => error -   0.025867551942944544   accuracy -
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Discrete CMAC:    => g - 28 epoch -   1081   => error -   0.025867327386287053   accuracy -
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Discrete CMAC:    => g - 28 epoch -   1083   => error -   0.025867105680335012   accuracy -
Discrete CMAC:    => g - 28 epoch -   1084   => error -   0.025866995884622823   accuracy -
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Discrete CMAC:    => g - 28 epoch -   1088   => error -   0.025866563642205853   accuracy -
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Discrete CMAC:    => g - 28 epoch -   1090   => error -   0.02586635162145079    accuracy -
Discrete CMAC:    => g - 28 epoch -   1091   => error -   0.025866246662045245   accuracy -
Discrete CMAC:    => g - 28 epoch -   1092   => error -   0.025866142286461224   accuracy -
Discrete CMAC:    => g - 28 epoch -   1093   => error -   0.025866038615080855   accuracy -
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Discrete CMAC:    => g - 28  epoch -   1095    => error -   0.025865833242716407   accuracy -
Discrete CMAC:    => g - 28  epoch -   1096    => error -   0.025865731533088687   accuracy -
Discrete CMAC:    => g - 28  epoch -   1097    => error -   0.025865630468783873   accuracy -
Discrete CMAC:    => g - 28  epoch -   1098    => error -   0.025865530045553586   accuracy -
Discrete CMAC:    => g - 28  epoch -   1099    => error -   0.02586543025917809   accuracy -
Discrete CMAC:    => g - 29  epoch -   1      => error -   1.777787186730735   accuracy -   -77.
Discrete CMAC:    => g - 29  epoch -   2      => error -   0.9173293481186868   accuracy -   8.2
Discrete CMAC:    => g - 29  epoch -   3      => error -   0.47880696764221575   accuracy -   52
Discrete CMAC:    => g - 29  epoch -   4      => error -   0.25978568190028384   accuracy -   74
Discrete CMAC:    => g - 29  epoch -   5      => error -   0.15685342071237507   accuracy -   84
Discrete CMAC:    => g - 29  epoch -   6      => error -   0.11441176789387941   accuracy -   88
Discrete CMAC:    => g - 29  epoch -   7      => error -   0.09929232242547648   accuracy -   90
Discrete CMAC:    => g - 29  epoch -   8      => error -   0.09390690605533103   accuracy -   90
Discrete CMAC:    => g - 29  epoch -   9      => error -   0.09144681092995544   accuracy -   90
Discrete CMAC:    => g - 29  epoch -   10     => error -   0.0898202389210615   accuracy -   91
Discrete CMAC:    => g - 29  epoch -   11     => error -   0.08844413574462862   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   12     => error -   0.08716089777981173   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   13     => error -   0.08592804311796742   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   14     => error -   0.08473376459036441   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   15     => error -   0.08357434305261091   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   16     => error -   0.08244816604633831   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   17     => error -   0.08135416341476565   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   18     => error -   0.080291406981016   accuracy -   91.
Discrete CMAC:    => g - 29  epoch -   19     => error -   0.07925901235751642   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   20     => error -   0.07825611693075751   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   21     => error -   0.07728187593827673   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   22     => error -   0.07633546227434473   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   23     => error -   0.07541606675781343   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   24     => error -   0.07452289826815728   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   25     => error -   0.07365518372577584   accuracy -   9
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Discrete CMAC:    => g - 29  epoch -   30     => error -   0.06967260702914291   accuracy -   9
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Discrete CMAC:    => g - 29  epoch -   34     => error -   0.06687234535054165   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   35     => error -   0.06622049880284397   accuracy -   9
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Discrete CMAC:    => g - 29  epoch -   38     => error -   0.06437122653854832   accuracy -   9
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Discrete CMAC:    => g - 29  epoch -   44     => error -   0.06110251323087745   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   45     => error -   0.06060764525316409   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   46     => error -   0.06012581637452863   accuracy -   9
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Discrete CMAC:    => g - 29  epoch -   48     => error -   0.05919957517693297   accuracy -   9
Discrete CMAC:    => g - 29  epoch -   49     => error -   0.05875434454182216   accuracy -   9
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Discrete CMAC:    => g - 29  epoch -   51     => error -   0.05789771082341966   accuracy -   9
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Discrete CMAC:    => g - 29 epoch -    54    => error -    0.056691831425427 66    accuracy -    9
Discrete CMAC:    => g - 29 epoch -    55    => error -    0.056309571747426346   accuracy -
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Discrete CMAC:    => g - 29 epoch -    59    => error -    0.05487052478065957    accuracy -    9
Discrete CMAC:    => g - 29 epoch -    60    => error -    0.05453178186299956    accuracy -    9
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Discrete CMAC:    => g - 29 epoch -    63    => error -    0.05356161466531484    accuracy -    9
Discrete CMAC:    => g - 29 epoch -    64    => error -    0.053252735149564745   accuracy -
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Discrete CMAC:    => g - 29 epoch -    79    => error -    0.04932806895270381    accuracy -    9
Discrete CMAC:    => g - 29 epoch -    80    => error -    0.04910559090807476    accuracy -    9
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Discrete CMAC:    => g - 29 epoch -    83    => error -    0.04846192034386865    accuracy -    9
Discrete CMAC:    => g - 29 epoch -    84    => error -    0.04825487988630406    accuracy -    9
Discrete CMAC:    => g - 29 epoch -    85    => error -    0.048051406476725456   accuracy -
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Discrete CMAC:    => g - 29 epoch -    92    => error -    0.04671836743899205    accuracy -    9
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Discrete CMAC:    => g - 29 epoch -    95    => error -    0.04619093384689932    accuracy -    9
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Discrete CMAC:    => g - 29 epoch -    99    => error -    0.04552345547536907    accuracy -    9
Discrete CMAC:    => g - 29 epoch -    100    => error -    0.045362516072652403   accuracy -
Discrete CMAC:    => g - 29 epoch -    101    => error -    0.045203823102225926   accuracy -
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Discrete CMAC:    => g - 29 epoch -    104    => error -    0.044740646178357935   accuracy -
Discrete CMAC:    => g - 29 epoch -    105    => error -    0.04459037291507817    accuracy -
Discrete CMAC:    => g - 29 epoch -    106    => error -    0.04444207336801731    accuracy -
Discrete CMAC:    => g - 29 epoch -    107    => error -    0.04429569889001095    accuracy -
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Discrete CMAC:    => g - 29 epoch -  108    => error -  0.04415120262022176   accuracy -
Discrete CMAC:    => g - 29 epoch -  109    => error -  0.044008539413093684  accuracy -
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Discrete CMAC:    => g - 29 epoch -  111    => error -  0.043728539773406405  accuracy -
Discrete CMAC:    => g - 29 epoch -  112    => error -  0.04359112102374407   accuracy -
Discrete CMAC:    => g - 29 epoch -  113    => error -  0.0434553705784434   accuracy -  9
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Discrete CMAC:    => g - 29 epoch -  115    => error -  0.04318872576731492   accuracy -
Discrete CMAC:    => g - 29 epoch -  116    => error -  0.043057760286518645  accuracy -
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Discrete CMAC:    => g - 29 epoch -   1051    => error -   0.02836833512814918    accuracy -
Discrete CMAC:    => g - 29 epoch -   1052    => error -   0.028368222551670597   accuracy -
Discrete CMAC:    => g - 29 epoch -   1053    => error -   0.02836811069335654    accuracy -
Discrete CMAC:    => g - 29 epoch -   1054    => error -   0.028367999548393197   accuracy -
Discrete CMAC:    => g - 29 epoch -   1055    => error -   0.02836788911200072    accuracy -
Discrete CMAC:    => g - 29 epoch -   1056    => error -   0.028367779379432134   accuracy -
Discrete CMAC:    => g - 29 epoch -   1057    => error -   0.028367670345973983   accuracy -
Discrete CMAC:    => g - 29 epoch -   1058    => error -   0.028367562006945457   accuracy -
Discrete CMAC:    => g - 29 epoch -   1059    => error -   0.028367454357698385   accuracy -
Discrete CMAC:    => g - 29 epoch -   1060    => error -   0.028367347393617237   accuracy -
Discrete CMAC:    => g - 29 epoch -   1061    => error -   0.028367241110118346   accuracy -
Discrete CMAC:    => g - 29 epoch -   1062    => error -   0.028367135502650243   accuracy -
Discrete CMAC:    => g - 29 epoch -   1063    => error -   0.028367030566692986   accuracy -
Discrete CMAC:    => g - 29 epoch -   1064    => error -   0.028366926297758166   accuracy -
Discrete CMAC:    => g - 29 epoch -   1065    => error -   0.028366822691388682   accuracy -
Discrete CMAC:    => g - 29 epoch -   1066    => error -   0.028366719743158297   accuracy -
Discrete CMAC:    => g - 29 epoch -   1067    => error -   0.02836661744867186    accuracy -
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Discrete CMAC:    => g - 29 epoch -   1068    => error -   0.02836651580356464   accuracy -
Discrete CMAC:    => g - 29 epoch -   1069    => error -   0.028366414803502216  accuracy -
Discrete CMAC:    => g - 29 epoch -   1070    => error -   0.0283663144418025    accuracy -
Discrete CMAC:    => g - 29 epoch -   1071    => error -   0.028366214721324723  accuracy -
Discrete CMAC:    => g - 30 epoch -   1     => error -   1.822095474908885   accuracy -   -82.
Discrete CMAC:    => g - 30 epoch -   2     => error -   0.9313680877228183  accuracy -   6.8
Discrete CMAC:    => g - 30 epoch -   3     => error -   0.48135718103873726 accuracy -   51
Discrete CMAC:    => g - 30 epoch -   4     => error -   0.25825056925019685 accuracy -   74
Discrete CMAC:    => g - 30 epoch -   5     => error -   0.15393624445425158 accuracy -   84
Discrete CMAC:    => g - 30 epoch -   6     => error -   0.11115039478689037 accuracy -   88
Discrete CMAC:    => g - 30 epoch -   7     => error -   0.0961328322092927  accuracy -   90.
Discrete CMAC:    => g - 30 epoch -   8     => error -   0.09098433171794462 accuracy -   90
Discrete CMAC:    => g - 30 epoch -   9     => error -   0.0887873743033133  accuracy -   91.
Discrete CMAC:    => g - 30 epoch -   10    => error -   0.08742829026007581 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   11    => error -   0.08631826065486681 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   12    => error -   0.08529580085186583 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   13    => error -   0.08431557180167593 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   14    => error -   0.08336402697798362 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   15    => error -   0.08243659777414836 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   16    => error -   0.08153140316695529 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   17    => error -   0.08064744323898199 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   18    => error -   0.07978404356757196 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   19    => error -   0.07894066667758726 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   20    => error -   0.07811684017916387 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   21    => error -   0.07731212619144134 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   22    => error -   0.07652610717937691 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   23    => error -   0.07575837901278681 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   24    => error -   0.07500854744292695 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   25    => error -   0.07427622627067954 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   26    => error -   0.07356103637372557 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   27    => error -   0.0728626051761414  accuracy -   92
Discrete CMAC:    => g - 30 epoch -   28    => error -   0.07218056634781456 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   29    => error -   0.07151455962402176 accuracy -   9
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Discrete CMAC:    => g - 30 epoch -   32    => error -   0.06960921817334331 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   33    => error -   0.06900385503351736 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   34    => error -   0.06841281045552894 accuracy -   9
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Discrete CMAC:    => g - 30 epoch -   37    => error -   0.0667223604134265  accuracy -   93
Discrete CMAC:    => g - 30 epoch -   38    => error -   0.06618539025304615 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   39    => error -   0.06566116644164655 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   40    => error -   0.065149391011885   accuracy -   93.
Discrete CMAC:    => g - 30 epoch -   41    => error -   0.06464977139171402 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   42    => error -   0.06416202036320884 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   43    => error -   0.06368585602119092 accuracy -   9
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Discrete CMAC:    => g - 30 epoch -   45    => error -   0.06276718608895338 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   46    => error -   0.06232414287442645 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   47    => error -   0.06189161101173335 accuracy -   9
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Discrete CMAC:    => g - 30 epoch -   49    => error -   0.061057062486089775 accuracy -
Discrete CMAC:    => g - 30 epoch -   50    => error -   0.06065454898435574 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   51    => error -   0.06026155306453651 accuracy -   9
Discrete CMAC:    => g - 30 epoch -   52    => error -   0.05987783868690444 accuracy -   9
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Discrete CMAC:  => g - 30 epoch -  54   => error -  0.05913733467673532   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  55   => error -  0.05878009709237153   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  56   => error -  0.05843124504424679   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  57   => error -  0.05809056631336951   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  58   => error -  0.057757853287814465  accuracy -
Discrete CMAC:  => g - 30 epoch -  59   => error -  0.05743290290795988   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  60   => error -  0.05711551661072478   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  61   => error -  0.05680550027283515   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  62   => error -  0.056502664153150195  accuracy -
Discrete CMAC:  => g - 30 epoch -  63   => error -  0.05620682283408773   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  64   => error -  0.05591779516219153   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  65   => error -  0.05563540418788615   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  66   => error -  0.05535947710447264   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  67   => error -  0.05508984518641702   accuracy -  9
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Discrete CMAC:  => g - 30 epoch -  71   => error -  0.054071033989639083  accuracy -
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Discrete CMAC:  => g - 30 epoch -  74   => error -  0.05336534142705407   accuracy -  9
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Discrete CMAC:  => g - 30 epoch -  78   => error -  0.05249501492496944   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  79   => error -  0.052289163363634095  accuracy -
Discrete CMAC:  => g - 30 epoch -  80   => error -  0.05208775593156756   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  81   => error -  0.05189067430963401   accuracy -  9
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Discrete CMAC:  => g - 30 epoch -  83   => error -  0.05150903071852475   accuracy -  9
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Discrete CMAC:  => g - 30 epoch -  86   => error -  0.05096622646516202   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  87   => error -  0.05079278481405225   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  88   => error -  0.050622924305582795  accuracy -
Discrete CMAC:  => g - 30 epoch -  89   => error -  0.05045654973685576   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  90   => error -  0.05029356851337008   accuracy -  9
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Discrete CMAC:  => g - 30 epoch -  93   => error -  0.049824096828836706  accuracy -
Discrete CMAC:  => g - 30 epoch -  94   => error -  0.04967381310505137   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  95   => error -  0.049526496785828544  accuracy -
Discrete CMAC:  => g - 30 epoch -  96   => error -  0.04938206968088721   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  97   => error -  0.04924045580006864   accuracy -  9
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Discrete CMAC:  => g - 30 epoch -  99   => error -  0.04896537442090321   accuracy -  9
Discrete CMAC:  => g - 30 epoch -  100   => error -  0.04883176545109447   accuracy -
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Discrete CMAC:  => g - 30 epoch -  109   => error -  0.04773562979166324   accuracy -
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Discrete CMAC:    => g - 30  epoch -  109   => error -   0.017739025791005.. accuracy
Discrete CMAC:    => g - 30  epoch -  110   => error -   0.047624577349548725  accuracy -
Discrete CMAC:    => g - 30  epoch -  111   => error -   0.04751547604819628  accuracy -
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Discrete CMAC:    => g - 30  epoch -  115   => error -   0.047097621514785803  accuracy -
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Discrete CMAC:    => g - 30  epoch -  117   => error -   0.04689919056545022  accuracy -
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Discrete CMAC:    => g - 30  epoch -  120   => error -   0.04661371793317837  accuracy -
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Discrete CMAC:    => g - 30  epoch -  164   => error -   0.043608637805263584  accuracy -
Discrete CMAC:    => g - 30  epoch -  165   => error -   0.04355860547739909  accuracy -
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Discrete CMAC:     => g - 30 epoch -   166    => error -   0.043509162662193734   accuracy -
Discrete CMAC:     => g - 30 epoch -   167    => error -   0.043460299145655634   accuracy -
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Discrete CMAC:   => g - 30  epoch -  917   => error -  0.038339586223239966   accuracy -
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Discrete CMAC:   => g - 31  epoch -  2    => error -  0.9446533716810105     accuracy -  5.5
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Discrete CMAC:   => g - 31  epoch -  4    => error -  0.2539095405535632     accuracy -  74.
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Discrete CMAC:   => g - 31  epoch -  6    => error -  0.10321128625022868    accuracy -  89
Discrete CMAC:   => g - 31  epoch -  7    => error -  0.08822400404325226    accuracy -  91
Discrete CMAC:   => g - 31  epoch -  8    => error -  0.08350767437935647    accuracy -  91
Discrete CMAC:   => g - 31  epoch -  9    => error -  0.08177086635952446    accuracy -  91
```

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Discrete CMAC:     => g - 31 epoch -   11  => error -   0.08009066898767225   accuracy -   9
Discrete CMAC:     => g - 31 epoch -   12  => error -   0.07941524636434538   accuracy -   9
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Discrete CMAC:     => g - 31 epoch -   15  => error -   0.07749995128078313   accuracy -   9
Discrete CMAC:     => g - 31 epoch -   16  => error -   0.0768865346743719    accuracy -   92
Discrete CMAC:     => g - 31 epoch -   17  => error -   0.07628490922746178   accuracy -   9
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Discrete CMAC:     => g - 31 epoch -   19  => error -   0.07511649868769543   accuracy -   9
Discrete CMAC:     => g - 31 epoch -   20  => error -   0.07454940234809071   accuracy -   9
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Discrete CMAC:     => g - 31 epoch -   22  => error -   0.07344856350990936   accuracy -   9
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Discrete CMAC:     => g - 31 epoch -   56  => error -   0.06027521706251315   accuracy -   9
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Discrete CMAC:     => g - 31 epoch -   63  => error -   0.05855997356659248   accuracy -   9
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Discrete CMAC:     => g - 31 epoch -   65  => error -   0.05811621038825332   accuracy -   9
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Discrete CMAC:    => g - 31 epoch -    71    => error -   0.056896004630409     accuracy -   94.
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Discrete CMAC:    => g - 31 epoch -    73    => error -   0.056523737738709445  accuracy -
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Discrete CMAC:    => g - 31 epoch -    75    => error -   0.05616749235015672   accuracy -   9
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Discrete CMAC:    => g - 31 epoch -   136   => error -   0.05026333779511183   accuracy -
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Discrete CMAC:    => g - 31 epoch -   655    => error -   0.04712919198766905245 accuracy -
Discrete CMAC:    => g - 31 epoch -   656    => error -   0.047129070287246    accuracy -   95
Discrete CMAC:    => g - 31 epoch -   657    => error -   0.04712894301499981   accuracy -
Discrete CMAC:    => g - 31 epoch -   658    => error -   0.047128816938322604  accuracy -
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Discrete CMAC:    => g - 32 epoch -   1     => error -   1.910041539148246    accuracy -   -91.
Discrete CMAC:    => g - 32 epoch -   2     => error -   0.9587384612979546   accuracy -   4.1
Discrete CMAC:    => g - 32 epoch -   3     => error -   0.48579302136505353  accuracy -   51
```

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Discrete CMAC:   => g - 32 epoch -  5   => error -  0.14790308753047332  accuracy -  85
Discrete CMAC:   => g - 32 epoch -  6   => error -  0.10488726192753206  accuracy -  89
Discrete CMAC:   => g - 32 epoch -  7   => error -  0.09040640476144535  accuracy -  90
Discrete CMAC:   => g - 32 epoch -  8   => error -  0.085830147796362   accuracy -  91.4
Discrete CMAC:   => g - 32 epoch -  9   => error -  0.08409110567735922  accuracy -  91
Discrete CMAC:   => g - 32 epoch -  10  => error -  0.08310994616744638  accuracy -  9
Discrete CMAC:   => g - 32 epoch -  11  => error -  0.08233376883285759  accuracy -  9
Discrete CMAC:   => g - 32 epoch -  12  => error -  0.08161891028123858  accuracy -  9
Discrete CMAC:   => g - 32 epoch -  13  => error -  0.080927683677389    accuracy -  91.
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Discrete CMAC:   => g - 32 epoch -  15  => error -  0.07958243066106796  accuracy -  9
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Discrete CMAC:   => g - 32 epoch -  29  => error -  0.07114150652895967  accuracy -  9
Discrete CMAC:   => g - 32 epoch -  30  => error -  0.07059878182903323  accuracy -  9
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Discrete CMAC:   => g - 32 epoch -  58  => error -  0.05820106216223242  accuracy -  9
Discrete CMAC:   => g - 32 epoch -  59  => error -  0.05784773202400073  accuracy -  9
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Discrete CMAC:    => g - 32 epoch -  427    => error -  0.038450644714726145  accuracy -
Discrete CMAC:    => g - 32 epoch -  428    => error -  0.038450475170103804  accuracy -
Discrete CMAC:    => g - 32 epoch -  429    => error -  0.03845030935831306   accuracy -
Discrete CMAC:    => g - 32 epoch -  430    => error -  0.03845014719826456   accuracy -
Discrete CMAC:    => g - 32 epoch -  431    => error -  0.03844998861061877   accuracy -
Discrete CMAC:    => g - 32 epoch -  432    => error -  0.03844983351774811   accuracy -
Discrete CMAC:    => g - 32 epoch -  433    => error -  0.03844968184369979   accuracy -
Discrete CMAC:    => g - 32 epoch -  434    => error -  0.03844953351416036   accuracy -
Discrete CMAC:    => g - 32 epoch -  435    => error -  0.0384493884564201    accuracy -  9
Discrete CMAC:    => g - 32 epoch -  436    => error -  0.03844924659933879   accuracy -
Discrete CMAC:    => g - 32 epoch -  437    => error -  0.038449107873312016  accuracy -
Discrete CMAC:    => g - 32 epoch -  438    => error -  0.038448972210237464  accuracy -
Discrete CMAC:    => g - 32 epoch -  439    => error -  0.03844883954348388   accuracy -
Discrete CMAC:    => g - 32 epoch -  440    => error -  0.038448709807858084  accuracy -
Discrete CMAC:    => g - 32 epoch -  441    => error -  0.038448582939575204  accuracy -
Discrete CMAC:    => g - 32 epoch -  442    => error -  0.0384484588762275    accuracy -  9
Discrete CMAC:    => g - 32 epoch -  443    => error -  0.03844833755675536   accuracy -
Discrete CMAC:    => g - 32 epoch -  444    => error -  0.03844821892141803   accuracy -
Discrete CMAC:    => g - 32 epoch -  445    => error -  0.0384481029117652    accuracy -
Discrete CMAC:    => g - 32 epoch -  446    => error -  0.03844798947060957   accuracy -
Discrete CMAC:    => g - 32 epoch -  447    => error -  0.03844787854199905   accuracy -
Discrete CMAC:    => g - 32 epoch -  448    => error -  0.03844777007191045   accuracy -
Discrete CMAC:    => g - 32 epoch -  449    => error -  0.038447664004625626  accuracy -
Discrete CMAC:    => g - 32 epoch -  450    => error -  0.038447560289900706  accuracy -
Discrete CMAC:    => g - 32 epoch -  451    => error -  0.03844745887574674   accuracy -
Discrete CMAC:    => g - 32 epoch -  452    => error -  0.038447359712002305  accuracy -
Discrete CMAC:    => g - 33 epoch -  1     => error -  1.9484369392152547   accuracy -   -94
Discrete CMAC:    => g - 33 epoch -  2     => error -  0.9671361269589073   accuracy -  3.2
Discrete CMAC:    => g - 33 epoch -  3     => error -  0.4842902457062216   accuracy -  51
```

```
Discrete CMAC:    => g - 33 epoch -  3    => error -  0.4842302437002210   accuracy -  31.
Discrete CMAC:    => g - 33 epoch -  4    => error -  0.2506227912476535   accuracy -   74.
Discrete CMAC:    => g - 33 epoch -  5    => error -  0.14388496708928133  accuracy -   85
Discrete CMAC:    => g - 33 epoch -  6    => error -  0.10179641568509445  accuracy -   89
Discrete CMAC:    => g - 33 epoch -  7    => error -  0.08840803452257429  accuracy -   91
Discrete CMAC:    => g - 33 epoch -  8    => error -  0.08476575548566467  accuracy -   91
Discrete CMAC:    => g - 33 epoch -  9    => error -  0.08382855743178952  accuracy -   91
Discrete CMAC:    => g - 33 epoch -  10   => error -  0.08358693727589672  accuracy -    9
Discrete CMAC:    => g - 33 epoch -  11   => error -  0.08352245076140885  accuracy -    9
Discrete CMAC:    => g - 33 epoch -  12   => error -  0.08350407117414216  accuracy -    9
Discrete CMAC:    => g - 33 epoch -  13   => error -  0.08349829251610774  accuracy -    9
Discrete CMAC:    => g - 33 epoch -  14   => error -  0.08349624527894117  accuracy -    9
```

2. Program a Continuous CMAC by allowing partial cell overlap, and modifying the weight update rule accordingly. Use only 35 weights weights for your CMAC, and sample your function at 100 evenly spaced points. Use 70 for training and 30 for testing. Report the accuracy of your CMAC network using only the 30 test points. Compare the output of the Discrete CMAC with that of the Continuous CMAC.

```
Discrete CMAC:    => g - 34 epoch -  6    => error -  0.1028103860910845   accuracy -   89.
```

```python
# Child class of CMAC for continuous case
class ContinuousCMAC(CMAC):

    def __init__(self, gen_factor, num_weights):
        CMAC.__init__(self, gen_factor, num_weights)

    def get_assoc_vec_ind(self, input_val, num_of_assoc_vec, input_min, input_max):
        if input_val < input_min:
            return 1
        elif input_val > input_max:
            return num_of_assoc_vec-1
        else:
            proportion_ind = (num_of_assoc_vec-2) * ((input_val - input_min)/(input_max - inp
            return proportion_ind

    '''  For continuous CMAC we need to consider some portion of adjacent
            windows too for consecutive input values.
        To consider the window of adjacent weights, this function return a set of two indices
            where the sample input value lies
            e.g. if the value = 2.5564 and it lies between the samples 2.4 (at ind=3)
                and 2.9(at ind=4) (values in the assoc_input_vector),
                then this function will return 2.5566 -> (3,4)
    '''
    def process_association_map(self, data, input_min, input_max):
        num_of_assoc_vec = self.num_weights + 1 - self.gen_factor
        for ind, data_val in enumerate(data):
            assoc_vec_ind = self.get_assoc_vec_ind(data_val[0], num_of_assoc_vec, input_min,
            assoc_vec_ind_flr = int(math.floor(assoc_vec_ind))
            assoc_vec_ind_ceil = int(math.ceil(assoc_vec_ind))

            if (assoc_vec_ind_flr != assoc_vec_ind_ceil):
```

```python
                self.association_map[data_val[0]] = (assoc_vec_ind_flr, assoc_vec_ind_ceil)
            else:
                self.association_map[data_val[0]] = (assoc_vec_ind_flr, 0)


    def train(self, train_data, input_min, input_max, total_epoch = 5000, learning_rate = 0.6
        self.weight_vec = np.ones(self.num_weights)
        input_X_vec = np.linspace(input_min, input_max, self.num_weights + 1 - self.gen_facto
        alpha = learning_rate
        epoch = 0

        self.association_map = {}
        self.process_association_map(train_data, input_min, input_max)

        is_converged = False
        prev_error = 0
        new_error = 0
        start_time = time.time()

        while epoch <= total_epoch and not is_converged:
            prev_error = new_error
            for ind, train_val in enumerate(train_data):
                asc_wt_ind_flr = self.association_map[train_val[0]][0]
                asc_wt_ind_ceil = self.association_map[train_val[0]][1]

                left_common = np.abs(input_X_vec[asc_wt_ind_flr] - train_val[0])
                right_common = np.abs(input_X_vec[asc_wt_ind_ceil] - train_val[0])

                left_contri_ratio = right_common/(left_common + right_common)
                right_contri_ratio = left_common/(left_common + right_common)

                y_output = (left_contri_ratio * np.sum(self.weight_vec[asc_wt_ind_flr: asc_wt

                error = train_val[1] - y_output
                correction = alpha*error/self.gen_factor

                self.weight_vec[asc_wt_ind_flr: (asc_wt_ind_flr + self.gen_factor)] = \
                                            [(self.weight_vec[ind] + correction) for ind in r

                self.weight_vec[asc_wt_ind_ceil: (asc_wt_ind_ceil + self.gen_factor)] = \
                                            [(self.weight_vec[ind] + correction) for ind in r


            intermediate_output, accuracy = self.predict(train_data, input_min, input_max, Fa
            new_error = 1 - accuracy
            if np.abs(prev_error - new_error) < 0.0000001:
                is_converged = True


            epoch = epoch + 1
            print("Continuous CMAC: ", " => g -", self.gen_factor, "epoch - ", epoch, "  => e
```

```python
        end_time = time.time()
        process_time = end_time - start_time
        return process_time, np.copy(self.weight_vec)


    def calculate_error(self, y_predict, y_expected):
        error = np.subtract(y_expected, y_predict)
        error_sq = np.power(error, 2)
        sum_error_sq = np.sum(error_sq)
        total_error = np.sqrt(sum_error_sq)/len(y_expected)
        return total_error



    def predict(self, test_data, input_min, input_max, re_process_asso_map = True):
        output = []

        input_X_vec = np.linspace(input_min, input_max, self.num_weights + 1 - self.gen_facto

        if re_process_asso_map:
            self.process_association_map(test_data, input_min, input_max)

        for ind, test_val in enumerate(test_data):
            asc_wt_ind_flr = self.association_map[test_val[0]][0]
            asc_wt_ind_ceil = self.association_map[test_val[0]][1]

            left_common = np.abs(input_X_vec[asc_wt_ind_flr] - test_val[0])
            right_common = np.abs(input_X_vec[asc_wt_ind_ceil] - test_val[0])

            left_contri_ratio = right_common/(left_common + right_common)
            right_contri_ratio = left_common/(left_common + right_common)

            y_output = (left_contri_ratio * np.sum(self.weight_vec[asc_wt_ind_flr: asc_wt_ind

            output.append(y_output)

        error = self.calculate_error(output, test_data[:, 1])
        accuracy = 1 - error
        return output, accuracy
# The process to the train the continuous CMAC was similar
#      to that of the discrete CMAC.
# The only difference here was to consider the proportion of weights
#      (overlapping window size) to find out which weights are contributing
#      in which proportion.
'''This Code runs discrete and Continuous CMAC models'''

### These lines are repeated from Discrete in case this block run separately###
TWO_PI = 2*np.pi
sample_input = np.linspace(0, TWO_PI, 100)
sample_output = np.sin(sample_input)

total_data = np.column_stack((sample_input, sample_output))
```

```
np.random.shuffle(total_data)

train_data = total_data[:70]
test_data = total_data[70:] #30 data points

x_train = train_data[:, 0]
x_test = test_data[:, 0]

y_train = train_data[:, 1]
y_test = test_data[:, 1]

num_weights = 35

gen_factor_list = range(1, num_weights)

convergence_time_discrete = []
accuracies_discrete = []
#######################

# Continuous variables
convergence_time_continuous = []
accuracies_continuous = []

#continuus class Object
continuous_cmac = ContinuousCMAC(1, num_weights)
discrete_cmac = DiscreteCMAC(1, num_weights)

for gen_factor in gen_factor_list:
    # Discrete CMAC
    discrete_cmac.set_gen_factor(gen_factor)
    process_time_discrete, weight_vec_discrete = discrete_cmac.train(train_data, 0, TWO_PI,
    y_output_discrete, accuracy_discrete = discrete_cmac.predict(test_data, 0, TWO_PI)

    # Continuous CMAC
    continuous_cmac.set_gen_factor(gen_factor)
    process_time_continuous, weight_vec_continuous = continuous_cmac.train(train_data, 0, 1
    y_output_continuous, accuracy_continuous = continuous_cmac.predict(test_data, 0, TWO_PI

    #Accuracy and Convergence time
    convergence_time_discrete.append(process_time_discrete)
    accuracies_discrete.append(accuracy_discrete)
    convergence_time_continuous.append(process_time_continuous)
    accuracies_continuous.append(accuracy_continuous)

fig, (ax1, ax2) = plt.subplots(1, 2)
plt.style.use('seaborn-whitegrid')

ax1.set_title('Convergence time v/s Generalization Factor')
ax1.plot(gen_factor_list, convergence_time_discrete, label="Discrete CMAC")
ax1.plot(gen_factor_list, convergence_time_continuous, color = (1,0,0), label="Continuous CMA
ax1.set(xlabel='generalization factor', ylabel='Convergence time')
```

```
  ax1.legend()


  ax2.set_title('Accuracy v/s Generalization Factor')
  ax2.plot(gen_factor_list, accuracies_discrete, label="Discrete CMAC")
  ax2.plot(gen_factor_list, accuracies_continuous, color = (1,0,0), label="Continuous CMAC")
  ax2.set(xlabel='generalization factor', ylabel='Accuracy')
  ax2.legend()

  plt.show()
```

```
Streaming output truncated to the last 5000 lines.
Continuous CMAC:    => g - 31 epoch -    2229    => error -   0.04020003765139257   accuracy
Continuous CMAC:    => g - 31 epoch -    2230    => error -   0.040196759282436045  accuracy
Continuous CMAC:    => g - 31 epoch -    2231    => error -   0.040193483433979105  accuracy
Continuous CMAC:    => g - 31 epoch -    2232    => error -   0.040190210105198076  accuracy
Continuous CMAC:    => g - 31 epoch -    2233    => error -   0.04018693929526873   accuracy
Continuous CMAC:    => g - 31 epoch -    2234    => error -   0.04018367100336584   accuracy
Continuous CMAC:    => g - 31 epoch -    2235    => error -   0.04018040522866384   accuracy
Continuous CMAC:    => g - 31 epoch -    2236    => error -   0.04017714197033606   accuracy
Continuous CMAC:    => g - 31 epoch -    2237    => error -   0.040173881227555386  accuracy
Continuous CMAC:    => g - 31 epoch -    2238    => error -   0.04017062299949414   accuracy
Continuous CMAC:    => g - 31 epoch -    2239    => error -   0.0401673367285323774  accuracy
Continuous CMAC:    => g - 31 epoch -    2240    => error -   0.04016411408421505   accuracy
Continuous CMAC:    => g - 31 epoch -    2241    => error -   0.0401608633953382    accuracy -
Continuous CMAC:    => g - 31 epoch -    2242    => error -   0.04015761521786265   accuracy
Continuous CMAC:    => g - 31 epoch -    2243    => error -   0.040015436955095719  accuracy
Continuous CMAC:    => g - 31 epoch -    2244    => error -   0.04015112639379004   accuracy
Continuous CMAC:    => g - 31 epoch -    2245    => error -   0.04014788574552852   accuracy
Continuous CMAC:    => g - 31 epoch -    2246    => error -   0.040144647605339534  accuracy
Continuous CMAC:    => g - 31 epoch -    2247    => error -   0.040141411972389296  accuracy
Continuous CMAC:    => g - 31 epoch -    2248    => error -   0.04013817884584325   accuracy
Continuous CMAC:    => g - 31 epoch -    2249    => error -   0.040134948224866185  accuracy
Continuous CMAC:    => g - 31 epoch -    2250    => error -   0.040131720108622204  accuracy
Continuous CMAC:    => g - 31 epoch -    2251    => error -   0.04012849449627509   accuracy
Continuous CMAC:    => g - 31 epoch -    2252    => error -   0.040125271386987515  accuracy
Continuous CMAC:    => g - 31 epoch -    2253    => error -   0.0401220507799217    accuracy -
Continuous CMAC:    => g - 31 epoch -    2254    => error -   0.040118832674239435  accuracy
Continuous CMAC:    => g - 31 epoch -    2255    => error -   0.040115617069101495  accuracy
Continuous CMAC:    => g - 31 epoch -    2256    => error -   0.04011240396366822   accuracy
Continuous CMAC:    => g - 31 epoch -    2257    => error -   0.04010919335709939   accuracy
Continuous CMAC:    => g - 31 epoch -    2258    => error -   0.04010598524855413   accuracy
Continuous CMAC:    => g - 31 epoch -    2259    => error -   0.040102779637190555  accuracy
Continuous CMAC:    => g - 31 epoch -    2260    => error -   0.04009957652216667   accuracy
Continuous CMAC:    => g - 31 epoch -    2261    => error -   0.04009637590263959   accuracy
Continuous CMAC:    => g - 31 epoch -    2262    => error -   0.040093177777766     accuracy -
Continuous CMAC:    => g - 31 epoch -    2263    => error -   0.040089982146701564  accuracy
Continuous CMAC:    => g - 31 epoch -    2264    => error -   0.04008678900860174   accuracy
Continuous CMAC:    => g - 31 epoch -    2265    => error -   0.04008359836262121   accuracy
Continuous CMAC:    => g - 31 epoch -    2266    => error -   0.040080410207913975  accuracy
Continuous CMAC:    => g - 31 epoch -    2267    => error -   0.040077224543633605  accuracy
Continuous CMAC:    => g - 31 epoch -    2268    => error -   0.04007404136893289   accuracy
Continuous CMAC:    => g - 31 epoch -    2269    => error -   0.04007086068296406   accuracy
Continuous CMAC:    => g - 31 epoch -    2270    => error -   0.0400676824848788    accuracy -
Continuous CMAC:    => g - 31 epoch -    2271    => error -   0.040064506773822822  accuracy
Continuous CMAC:    => g - 31 epoch -    2272    => error -   0.0400613335489625574 accuracy
Continuous CMAC:    => g - 31 epoch -    2273    => error -   0.04005816280943186   accuracy
Continuous CMAC:    => g - 31 epoch -    2274    => error -   0.040054994554385326  accuracy
Continuous CMAC:    => g - 31 epoch -    2275    => error -   0.04005182878297153   accuracy
Continuous CMAC:    => g - 31 epoch -    2276    => error -   0.04004866549433861   accuracy
Continuous CMAC:    => g - 31 epoch -    2277    => error -   0.040045504687634015  accuracy
Continuous CMAC:    => g - 31 epoch -    2278    => error -   0.040042346362004655  accuracy
Continuous CMAC:    => g - 31 epoch -    2279    => error -   0.04003919051659688   accuracy
Continuous CMAC:    => g - 31 epoch -    2280    => error -   0.04003603715055648   accuracy
Streaming CMAC:     => g - 31 epoch -    2281    => error -   0.040032886263002848  accuracy
Continuous CMAC:    => g - 31 epoch -    2282    => error -   0.04002973785315744   accuracy
Continuous CMAC:    => g - 31 epoch -    2283    => error -   0.0400026591920087395 accuracy
```

```
Continuous CMAC:    => g - 31 epoch -    2284    => error -    0.04002344846296191    accuracy
Continuous CMAC:    => g - 31 epoch -    2285    => error -    0.04002030748092367    accuracy
Continuous CMAC:    => g - 31 epoch -    2286    => error -    0.040017168973115136   accuracy
Continuous CMAC:    => g - 31 epoch -    2287    => error -    0.04001403293867778    accuracy
Continuous CMAC:    => g - 31 epoch -    2288    => error -    0.04001089937675306    accuracy
Continuous CMAC:    => g - 31 epoch -    2289    => error -    0.04000776828648145    accuracy
Continuous CMAC:    => g - 31 epoch -    2290    => error -    0.04000463966700296    accuracy
Continuous CMAC:    => g - 31 epoch -    2291    => error -    0.04000151351745718    accuracy
Continuous CMAC:    => g - 31 epoch -    2292    => error -    0.039998389836983006   accuracy
Continuous CMAC:    => g - 31 epoch -    2293    => error -    0.039995268624718694   accuracy
Continuous CMAC:    => g - 31 epoch -    2294    => error -    0.039992149879802374   accuracy
Continuous CMAC:    => g - 31 epoch -    2295    => error -    0.03998903360137107    accuracy
Continuous CMAC:    => g - 31 epoch -    2296    => error -    0.039985919788561586   accuracy
Continuous CMAC:    => g - 31 epoch -    2297    => error -    0.039982808440510276   accuracy
Continuous CMAC:    => g - 31 epoch -    2298    => error -    0.03997969955635261    accuracy
Continuous CMAC:    => g - 31 epoch -    2299    => error -    0.03997659313522384    accuracy
Continuous CMAC:    => g - 31 epoch -    2300    => error -    0.0399734891762584825  accuracy
Continuous CMAC:    => g - 31 epoch -    2301    => error -    0.039970387678590624   accuracy
Continuous CMAC:    => g - 31 epoch -    2302    => error -    0.03996728864135368    accuracy
Continuous CMAC:    => g - 31 epoch -    2303    => error -    0.03996419206368085    accuracy
Continuous CMAC:    => g - 31 epoch -    2304    => error -    0.03996109794470437    accuracy
Continuous CMAC:    => g - 31 epoch -    2305    => error -    0.03995800628355639    accuracy
Continuous CMAC:    => g - 31 epoch -    2306    => error -    0.03995491707936816    accuracy
Continuous CMAC:    => g - 31 epoch -    2307    => error -    0.03995183033127059    accuracy
Continuous CMAC:    => g - 31 epoch -    2308    => error -    0.039948746038394156   accuracy
Continuous CMAC:    => g - 31 epoch -    2309    => error -    0.03994566419986867    accuracy
Continuous CMAC:    => g - 31 epoch -    2310    => error -    0.03994258481482338    accuracy
Continuous CMAC:    => g - 31 epoch -    2311    => error -    0.039939507882387204   accuracy
Continuous CMAC:    => g - 31 epoch -    2312    => error -    0.03993643340168851    accuracy
Continuous CMAC:    => g - 31 epoch -    2313    => error -    0.03993336137185499    accuracy
Continuous CMAC:    => g - 31 epoch -    2314    => error -    0.039930291792013906   accuracy
Continuous CMAC:    => g - 31 epoch -    2315    => error -    0.03992722466129217    accuracy
Continuous CMAC:    => g - 31 epoch -    2316    => error -    0.039924159978816154   accuracy
Continuous CMAC:    => g - 31 epoch -    2317    => error -    0.03992109774371133    accuracy
Continuous CMAC:    => g - 31 epoch -    2318    => error -    0.03991803795510329    accuracy
Continuous CMAC:    => g - 31 epoch -    2319    => error -    0.039914980612116735   accuracy
Continuous CMAC:    => g - 31 epoch -    2320    => error -    0.03991192571387592    accuracy
Continuous CMAC:    => g - 31 epoch -    2321    => error -    0.03990887325950476    accuracy
Continuous CMAC:    => g - 31 epoch -    2322    => error -    0.039905823248126415   accuracy
Continuous CMAC:    => g - 31 epoch -    2323    => error -    0.0399027756788638    accuracy -
Continuous CMAC:    => g - 31 epoch -    2324    => error -    0.039899730550839285   accuracy
Continuous CMAC:    => g - 31 epoch -    2325    => error -    0.039896687863174685   accuracy
Continuous CMAC:    => g - 31 epoch -    2326    => error -    0.03989364761499137    accuracy
Continuous CMAC:    => g - 31 epoch -    2327    => error -    0.03989060980541037    accuracy
Continuous CMAC:    => g - 31 epoch -    2328    => error -    0.03988757443355184    accuracy
Continuous CMAC:    => g - 31 epoch -    2329    => error -    0.03988454149853593    accuracy
Continuous CMAC:    => g - 31 epoch -    2330    => error -    0.039881510999481895   accuracy
Continuous CMAC:    => g - 31 epoch -    2331    => error -    0.039878482935508996   accuracy
Continuous CMAC:    => g - 31 epoch -    2332    => error -    0.03987545730573561    accuracy
Continuous CMAC:    => g - 31 epoch -    2333    => error -    0.039872434109279764   accuracy
Continuous CMAC:    => g - 31 epoch -    2334    => error -    0.039869413345259064   accuracy
Continuous CMAC:    => g - 31 epoch -    2335    => error -    0.039866395012790656   accuracy
Continuous CMAC:    => g - 31 epoch -    2336    => error -    0.03986337911099114    accuracy
Continuous CMAC:    => g - 31 epoch -    2337    => error -    0.039860365638977666   accuracy
Continuous CMAC:    => g - 31 epoch -    2338    => error -    0.039857354459586315   accuracy
Continuous CMAC:    => g - 31 epoch -    2339    => error -    0.039854345980765776   accuracy
Continuous CMAC:    => g - 31 epoch -    2340    => error -    0.039851339792799931   accuracy
```

```
Continuous CMAC:   => g - 31 epoch -   2340   => error -   0.039851339792799.51   accuracy
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Continuous CMAC:   => g - 31 epoch -   3988   => error -   0.037500263159392255   accuracy
Continuous CMAC:   => g - 31 epoch -   3989   => error -   0.03750001117607238   accuracy
Continuous CMAC:   => g - 31 epoch -   3990   => error -   0.03749976017234535   accuracy
Continuous CMAC:   => g - 31 epoch -   3991   => error -   0.03749951014751185   accuracy
Continuous CMAC:   => g - 31 epoch -   3992   => error -   0.037499261100873094   accuracy
Continuous CMAC:   => g - 31 epoch -   3993   => error -   0.03749901303173042   accuracy
Continuous CMAC:   => g - 31 epoch -   3994   => error -   0.037498765939385614   accuracy
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Continuous CMAC:   => g - 31 epoch -   3998   => error -   0.03749778732402809   accuracy
Continuous CMAC:   => g - 31 epoch -   3999   => error -   0.037497545105207974   accuracy
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Continuous CMAC:   => g - 31 epoch -   4001   => error -   0.03749706358471405   accuracy
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Continuous CMAC:   => g - 31 epoch -   4031   => error -   0.03749030385682839   accuracy
Continuous CMAC:   => g - 31 epoch -   4032   => error -   0.03749009336829345   accuracy
Continuous CMAC:   => g - 31 epoch -   4033   => error -   0.03748988382955443   accuracy
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Continuous CMAC:     => g - 31 epoch -    4034    => error -    0.03748967523992486    accuracy
Continuous CMAC:     => g - 31 epoch -    4035    => error -    0.03748946759871874    accuracy
Continuous CMAC:     => g - 31 epoch -    4036    => error -    0.03748926090525029    accuracy
Continuous CMAC:     => g - 31 epoch -    4037    => error -    0.03748905515883394    accuracy
Continuous CMAC:     => g - 31 epoch -    4038    => error -    0.037488850358784465   accuracy
Continuous CMAC:     => g - 31 epoch -    4039    => error -    0.03748864650441708    accuracy
Continuous CMAC:     => g - 31 epoch -    4040    => error -    0.037488443595046994   accuracy
Continuous CMAC:     => g - 31 epoch -    4041    => error -    0.03748824162998998    accuracy
Continuous CMAC:     => g - 31 epoch -    4042    => error -    0.03748804060856192    accuracy
Continuous CMAC:     => g - 31 epoch -    4043    => error -    0.037487840530079364   accuracy
Continuous CMAC:     => g - 31 epoch -    4044    => error -    0.03748764139385863    accuracy
Continuous CMAC:     => g - 31 epoch -    4045    => error -    0.03748744319921671    accuracy
Continuous CMAC:     => g - 31 epoch -    4046    => error -    0.037487245945470704   accuracy
Continuous CMAC:     => g - 31 epoch -    4047    => error -    0.03748704963193816    accuracy
Continuous CMAC:     => g - 31 epoch -    4048    => error -    0.03748685425793696    accuracy
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Continuous CMAC:     => g - 31 epoch -    4051    => error -    0.037486273766302425   accuracy
Continuous CMAC:     => g - 31 epoch -    4052    => error -    0.03748608214360971    accuracy
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Continuous CMAC:     => g - 31 epoch -    4058    => error -    0.037484952042263764   accuracy
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Continuous CMAC:     => g - 31 epoch -    4060    => error -    0.03748458280543221    accuracy
Continuous CMAC:     => g - 31 epoch -    4061    => error -    0.03748439958338956    accuracy
Continuous CMAC:     => g - 31 epoch -    4062    => error -    0.03748421729135831    accuracy
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Continuous CMAC:     => g - 31 epoch -    4090    => error -    0.037479487955572766   accuracy
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Continuous CMAC:    => g - 31 epoch -    4090    => error -    0.03747948793372788    accuracy
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Continuous CMAC:    => g - 31 epoch -    4092    => error -    0.037479177763475095    accuracy
Continuous CMAC:    => g - 31 epoch -    4093    => error -    0.03747902383838386    accuracy
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Continuous CMAC:    => g - 31 epoch -    4096    => error -    0.03747856789743664    accuracy
Continuous CMAC:    => g - 31 epoch -    4097    => error -    0.037478417730945845    accuracy
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Continuous CMAC:    => g - 31 epoch -    4099    => error -    0.03747812011469753    accuracy
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Continuous CMAC:    => g - 31 epoch -    4101    => error -    0.03747782611631478    accuracy
Continuous CMAC:    => g - 31 epoch -    4102    => error -    0.03747768047215716    accuracy
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Continuous CMAC:    => g - 31 epoch -    4146    => error -    0.037472156173137594    accuracy
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Continuous CMAC:    => g - 31 epoch -  4153   => error -  0.03747143466527214   accuracy
Continuous CMAC:    => g - 31 epoch -  4154   => error -  0.0374713350735536   accuracy -
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Discrete CMAC:   => g - 32 epoch -  2    => error -  0.9597341739903504   accuracy -   4.0
Discrete CMAC:   => g - 32 epoch -  3    => error -  0.4857884628955125   accuracy -   51.
Discrete CMAC:   => g - 32 epoch -  4    => error -  0.2540145064457683   accuracy -   74.
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Discrete CMAC:   => g - 32 epoch -  6    => error -  0.10406851086233726   accuracy -   89
Discrete CMAC:   => g - 32 epoch -  7    => error -  0.08983445863553574   accuracy -   91
Discrete CMAC:   => g - 32 epoch -  8    => error -  0.08545553148805818   accuracy -   91
Discrete CMAC:   => g - 32 epoch -  9    => error -  0.08382788229134486   accuracy -   91
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Discrete CMAC:   => g - 32 epoch -  11   => error -  0.08214229575112264   accuracy -   9
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Discrete CMAC:   => g - 32 epoch -  14   => error -  0.08004099063742132   accuracy -   9
Discrete CMAC:   => g - 32 epoch -  15   => error -  0.07935951433070598   accuracy -   9
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Discrete CMAC:   => g - 32 epoch -  19   => error -  0.076671857185074726  accuracy -   9
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Discrete CMAC:   => g - 32 epoch -  33   => error -  0.0685241655823593   accuracy -   93
Discrete CMAC:   => g - 32 epoch -  34   => error -  0.06799757334141598   accuracy -   9
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Discrete CMAC:   => g - 32 epoch -  42   => error -  0.06404465514414892   accuracy -   9
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Discrete CMAC:   => g - 32 epoch -  44   => error -  0.063125802924627   accuracy -   93.
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Discrete CMAC:   => g - 32 epoch -  46   => error -  0.06223351107085129   accuracy -   9
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Discrete CMAC:   => g - 32 epoch -  48   => error -  0.06136719923492895   accuracy -   9
Discrete CMAC:   => g - 32 epoch -  49   => error -  0.060943606701963304  accuracy -
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Discrete CMAC:   => g - 32 epoch -  49   => error -  0.060943606701963504   accuracy -
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Discrete CMAC:   => g - 32 epoch -  53   => error -  0.05931134675714378    accuracy -   9
Discrete CMAC:   => g - 32 epoch -  54   => error -  0.05891846151427227    accuracy -   9
Discrete CMAC:   => g - 32 epoch -  55   => error -  0.05853151070985141    accuracy -   9
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Discrete CMAC:   => g - 32 epoch -  57   => error -  0.05777514122602123    accuracy -   9
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Discrete CMAC:   => g - 32 epoch -  60   => error -  0.056683412318854765   accuracy -
Discrete CMAC:   => g - 32 epoch -  61   => error -  0.05633065791685765    accuracy -   9
Discrete CMAC:   => g - 32 epoch -  62   => error -  0.05598337207147086    accuracy -   9
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Discrete CMAC:   => g - 32 epoch -  92   => error -  0.047801682000435     accuracy -   95.
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Discrete CMAC:  => g - 33 epoch -  2    => error -  0.9680335504499742    accuracy -   3.1
Discrete CMAC:  => g - 33 epoch -  3    => error -  0.48437657131806355   accuracy -   51
Discrete CMAC:  => g - 33 epoch -  4    => error -  0.25041869112980186   accuracy -   74
Discrete CMAC:  => g - 33 epoch -  5    => error -  0.14392488761261557   accuracy -   85
Discrete CMAC:  => g - 33 epoch -  6    => error -  0.10243591916258377   accuracy -   89
Discrete CMAC:  => g - 33 epoch -  7    => error -  0.08957630210759993   accuracy -   91
Discrete CMAC:  => g - 33 epoch -  8    => error -  0.08623574501726328   accuracy -   91
Discrete CMAC:  => g - 33 epoch -  9    => error -  0.08544856252331157   accuracy -   91
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Discrete CMAC:  => g - 33 epoch - 11    => error -  0.08525000601051835   accuracy -    9
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Discrete CMAC:  => g - 33 epoch - 13    => error -  0.08524974202092495   accuracy -    9
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Continuous CMAC:    => g - 33 epoch -    1845    => error -    0.092960172963673049   accuracy
Continuous CMAC:    => g - 33 epoch -    1846    => error -    0.092960716411558721   accuracy
Continuous CMAC:    => g - 33 epoch -    1847    => error -    0.09296125706189728    accuracy
Continuous CMAC:    => g - 33 epoch -    1848    => error -    0.09296179491658803    accuracy -
Continuous CMAC:    => g - 33 epoch -    1849    => error -    0.0929623299775556     accuracy -
Continuous CMAC:    => g - 33 epoch -    1850    => error -    0.092962862246674222   accuracy
Continuous CMAC:    => g - 33 epoch -    1851    => error -    0.092963391726605894   accuracy
Continuous CMAC:    => g - 33 epoch -    1852    => error -    0.092963918417422457   accuracy
Continuous CMAC:    => g - 33 epoch -    1853    => error -    0.092964442322755736   accuracy
Continuous CMAC:    => g - 33 epoch -    1854    => error -    0.092964963443397542   accuracy
Continuous CMAC:    => g - 33 epoch -    1855    => error -    0.09296548178329968    accuracy -
Continuous CMAC:    => g - 33 epoch -    1856    => error -    0.092965997341373916   accuracy
Continuous CMAC:    => g - 33 epoch -    1857    => error -    0.092966510122111987   accuracy
Continuous CMAC:    => g - 33 epoch -    1858    => error -    0.092967020126055607   accuracy
Continuous CMAC:    => g - 33 epoch -    1859    => error -    0.092967527355546476   accuracy
Continuous CMAC:    => g - 33 epoch -    1860    => error -    0.092968031812262265   accuracy
Continuous CMAC:    => g - 33 epoch -    1861    => error -    0.0929685334983662     accuracy -
Continuous CMAC:    => g - 33 epoch -    1862    => error -    0.09296903241569154    accuracy
Continuous CMAC:    => g - 33 epoch -    1863    => error -    0.09296952856615459    accuracy
Continuous CMAC:    => g - 33 epoch -    1864    => error -    0.09297002195167103    accuracy
Continuous CMAC:    => g - 33 epoch -    1865    => error -    0.092970512574415645   accuracy
Continuous CMAC:    => g - 33 epoch -    1866    => error -    0.092971000435552586   accuracy
Continuous CMAC:    => g - 33 epoch -    1867    => error -    0.0929714855376943     accuracy -
Continuous CMAC:    => g - 33 epoch -    1868    => error -    0.092971967888257645   accuracy
Continuous CMAC:    => g - 33 epoch -    1869    => error -    0.092972447447208655   accuracy
Continuous CMAC:    => g - 33 epoch -    1870    => error -    0.092972924430813886   accuracy
Continuous CMAC:    => g - 33 epoch -    1871    => error -    0.09297339839264729    accuracy
Continuous CMAC:    => g - 33 epoch -    1872    => error -    0.09297386972752542    accuracy
Continuous CMAC:    => g - 33 epoch -    1873    => error -    0.0929743383146866     accuracy -
Continuous CMAC:    => g - 33 epoch -    1874    => error -    0.092974804415604398   accuracy
Continuous CMAC:    => g - 33 epoch -    1875    => error -    0.09297526725351035    accuracy
Continuous CMAC:    => g - 33 epoch -    1876    => error -    0.0929757276089982     accuracy -
Continuous CMAC:    => g - 33 epoch -    1877    => error -    0.09297618522441986    accuracy
Continuous CMAC:    => g - 33 epoch -    1878    => error -    0.09297664010168738    accuracy
Continuous CMAC:    => g - 33 epoch -    1879    => error -    0.09297709224271244    accuracy
Continuous CMAC:    => g - 33 epoch -    1880    => error -    0.09297754164940653    accuracy
Continuous CMAC:    => g - 33 epoch -    1881    => error -    0.09297798832368076    accuracy
Continuous CMAC:    => g - 33 epoch -    1882    => error -    0.09297843226744618    accuracy
Continuous CMAC:    => g - 33 epoch -    1883    => error -    0.09297887348261336    accuracy
Continuous CMAC:    => g - 33 epoch -    1884    => error -    0.092979311971009255   accuracy
Continuous CMAC:    => g - 33 epoch -    1885    => error -    0.092979747734794     accuracy -
Continuous CMAC:    => g - 33 epoch -    1886    => error -    0.09298018077562731    accuracy
Continuous CMAC:    => g - 33 epoch -    1887    => error -    0.09298061109550215    accuracy
Continuous CMAC:    => g - 33 epoch -    1888    => error -    0.09298103869632757    accuracy
Continuous CMAC:    => g - 33 epoch -    1889    => error -    0.09298146358001258    accuracy
Continuous CMAC:    => g - 33 epoch -    1890    => error -    0.09298188574846589    accuracy
Continuous CMAC:    => g - 33 epoch -    1891    => error -    0.09298230520359574    accuracy
Continuous CMAC:    => g - 33 epoch -    1892    => error -    0.09298272194731028    accuracy
Continuous CMAC:    => g - 33 epoch -    1893    => error -    0.0929831359815172     accuracy -
Continuous CMAC:    => g - 33 epoch -    1894    => error -    0.09298354730812386    accuracy
Continuous CMAC:    => g - 33 epoch -    1895    => error -    0.09298395592903774    accuracy
Continuous CMAC:    => g - 33 epoch -    1896    => error -    0.09298436184616554    accuracy
Continuous CMAC:    => g - 33 epoch -    1897    => error -    0.09298476506141384    accuracy
Continuous CMAC:    => g - 33 epoch -    1898    => error -    0.09298516557668901    accuracy
Continuous CMAC:    => g - 33 epoch -    1899    => error -    0.09298556339389685    accuracy
Continuous CMAC:    => g - 33 epoch -    1900    => error -    0.09298595851494329    accuracy
Continuous CMAC:    => g - 33 epoch -    1901    => error -    0.09298635094173358    accuracy
```

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Continuous CMAC:   => g - 33 epoch -  1901   => error -  0.092998674067617285   accuracy
Continuous CMAC:   => g - 33 epoch -  1902   => error -  0.092998674067617285   accuracy
Continuous CMAC:   => g - 33 epoch -  1903   => error -  0.09298712772016571    accuracy
Continuous CMAC:   => g - 33 epoch -  1904   => error -  0.09298751207561684    accuracy
Continuous CMAC:   => g - 33 epoch -  1905   => error -  0.092998789374443028   accuracy
Continuous CMAC:   => g - 33 epoch -  1906   => error -  0.092998827272850996   accuracy
Continuous CMAC:   => g - 33 epoch -  1907   => error -  0.092998864902975934   accuracy
Continuous CMAC:   => g - 33 epoch -  1908   => error -  0.092998902265008158   accuracy
Continuous CMAC:   => g - 33 epoch -  1909   => error -  0.092998939359137981   accuracy
Continuous CMAC:   => g - 33 epoch -  1910   => error -  0.092998976185555641   accuracy
Continuous CMAC:   => g - 33 epoch -  1911   => error -  0.09299012744451374    accuracy
Continuous CMAC:   => g - 33 epoch -  1912   => error -  0.092999049036015383   accuracy
Continuous CMAC:   => g - 33 epoch -  1913   => error -  0.092999085060437828   accuracy
Continuous CMAC:   => g - 33 epoch -  1914   => error -  0.092999120817908835   accuracy
Continuous CMAC:   => g - 33 epoch -  1915   => error -  0.092999156308618517   accuracy
Continuous CMAC:   => g - 33 epoch -  1916   => error -  0.092999191532756934   accuracy
Continuous CMAC:   => g - 33 epoch -  1917   => error -  0.092999226490514123   accuracy
Continuous CMAC:   => g - 33 epoch -  1918   => error -  0.092999261182080087   accuracy
Continuous CMAC:   => g - 33 epoch -  1919   => error -  0.092999295607644797   accuracy
Continuous CMAC:   => g - 33 epoch -  1920   => error -  0.092999329767398201   accuracy
Continuous CMAC:   => g - 33 epoch -  1921   => error -  0.092999363661530191   accuracy
Continuous CMAC:   => g - 33 epoch -  1922   => error -  0.092999397290230638   accuracy
Continuous CMAC:   => g - 33 epoch -  1923   => error -  0.092994306536894     accuracy -
Continuous CMAC:   => g - 33 epoch -  1924   => error -  0.092999463752096271   accuracy
Continuous CMAC:   => g - 33 epoch -  1925   => error -  0.0929949658564102     accuracy -
Continuous CMAC:   => g - 33 epoch -  1926   => error -  0.092999529154513386   accuracy
Continuous CMAC:   => g - 33 epoch -  1927   => error -  0.092999561458903083   accuracy
Continuous CMAC:   => g - 33 epoch -  1928   => error -  0.092999593498999781   accuracy
Continuous CMAC:   => g - 33 epoch -  1929   => error -  0.092999625274993106   accuracy
Continuous CMAC:   => g - 33 epoch -  1930   => error -  0.092999656787072685   accuracy
Continuous CMAC:   => g - 33 epoch -  1931   => error -  0.092999688035428066   accuracy
Continuous CMAC:   => g - 33 epoch -  1932   => error -  0.092999719020248809   accuracy
Continuous CMAC:   => g - 33 epoch -  1933   => error -  0.09299749741724384    accuracy
Continuous CMAC:   => g - 33 epoch -  1934   => error -  0.092999780200044294   accuracy
Continuous CMAC:   => g - 33 epoch -  1935   => error -  0.092999810395397945   accuracy
Continuous CMAC:   => g - 33 epoch -  1936   => error -  0.0929984032797474     accuracy -
Continuous CMAC:   => g - 33 epoch -  1937   => error -  0.0929986999796405     accuracy -
Continuous CMAC:   => g - 33 epoch -  1938   => error -  0.0929989940555519     accuracy -
Continuous CMAC:   => g - 33 epoch -  1939   => error -  0.09299928550937475    accuracy
Continuous CMAC:   => g - 33 epoch -  1940   => error -  0.09299957434300143    accuracy
Continuous CMAC:   => g - 33 epoch -  1941   => error -  0.09299986055832421    accuracy
Continuous CMAC:   => g - 33 epoch -  1942   => error -  0.09300014415723501    accuracy
Continuous CMAC:   => g - 33 epoch -  1943   => error -  0.09300042514162532    accuracy
Continuous CMAC:   => g - 33 epoch -  1944   => error -  0.0930007035133863     accuracy -
Continuous CMAC:   => g - 33 epoch -  1945   => error -  0.09300097927440876    accuracy
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Continuous CMAC:   => g - 33 epoch -  1947   => error -  0.09300152297179964    accuracy
Continuous CMAC:   => g - 33 epoch -  1948   => error -  0.09300179091194771    accuracy
Continuous CMAC:   => g - 33 epoch -  1949   => error -  0.093002056248917      accuracy -
Continuous CMAC:   => g - 33 epoch -  1950   => error -  0.09300231898459632    accuracy
Continuous CMAC:   => g - 33 epoch -  1951   => error -  0.09300257912087428    accuracy
Continuous CMAC:   => g - 33 epoch -  1952   => error -  0.09300283665963938    accuracy
Continuous CMAC:   => g - 33 epoch -  1953   => error -  0.0930030916027792     accuracy -
Continuous CMAC:   => g - 33 epoch -  1954   => error -  0.09300334395218157    accuracy
Continuous CMAC:   => g - 33 epoch -  1955   => error -  0.093003593709733355   accuracy
Continuous CMAC:   => g - 33 epoch -  1956   => error -  0.09300384087732172    accuracy
Continuous CMAC:   => g - 33 epoch -  1957   => error -  0.09300408545683281    accuracy
```

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Continuous CMAC:    => g - 33 epoch -  1958    => error -  0.09300432745015275   accuracy
Continuous CMAC:    => g - 33 epoch -  1959    => error -  0.09300456685916725   accuracy
Continuous CMAC:    => g - 33 epoch -  1960    => error -  0.09300480368576147   accuracy
Continuous CMAC:    => g - 33 epoch -  1961    => error -  0.09300503793182036   accuracy
Continuous CMAC:    => g - 33 epoch -  1962    => error -  0.09300526959922861   accuracy
Continuous CMAC:    => g - 33 epoch -  1963    => error -  0.09300549868987029   accuracy
Continuous CMAC:    => g - 33 epoch -  1964    => error -  0.09300572520562922   accuracy
Continuous CMAC:    => g - 33 epoch -  1965    => error -  0.09300594914838867   accuracy
Continuous CMAC:    => g - 33 epoch -  1966    => error -  0.0930061705200319    accuracy -
Continuous CMAC:    => g - 33 epoch -  1967    => error -  0.09300638932244132   accuracy
Continuous CMAC:    => g - 33 epoch -  1968    => error -  0.0930066055574994    accuracy -
Continuous CMAC:    => g - 33 epoch -  1969    => error -  0.09300681922708776   accuracy
Continuous CMAC:    => g - 33 epoch -  1970    => error -  0.0930070303330881    accuracy -
Continuous CMAC:    => g - 33 epoch -  1971    => error -  0.09300723887738138   accuracy
Continuous CMAC:    => g - 33 epoch -  1972    => error -  0.09300744486184831   accuracy
Continuous CMAC:    => g - 33 epoch -  1973    => error -  0.09300764828836938   accuracy
Continuous CMAC:    => g - 33 epoch -  1974    => error -  0.09300784915882432   accuracy
Continuous CMAC:    => g - 33 epoch -  1975    => error -  0.09300804747509273   accuracy
Continuous CMAC:    => g - 33 epoch -  1976    => error -  0.09300824323905377   accuracy
Continuous CMAC:    => g - 33 epoch -  1977    => error -  0.09300843645258616   accuracy
Continuous CMAC:    => g - 33 epoch -  1978    => error -  0.0930086271175683    accuracy -
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Continuous CMAC:    => g - 33 epoch -  1980    => error -  0.09300900080939312   accuracy
Continuous CMAC:    => g - 33 epoch -  1981    => error -  0.09300918383999046   accuracy
Continuous CMAC:    => g - 33 epoch -  1982    => error -  0.09300936432954698   accuracy
Continuous CMAC:    => g - 33 epoch -  1983    => error -  0.09300954227993896   accuracy
Continuous CMAC:    => g - 33 epoch -  1984    => error -  0.09300971769304245   accuracy
Continuous CMAC:    => g - 33 epoch -  1985    => error -  0.09300989057073294   accuracy
Continuous CMAC:    => g - 33 epoch -  1986    => error -  0.0930100609148855    accuracy -
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Continuous CMAC:    => g - 33 epoch -  1988    => error -  0.09301039401007583   accuracy
Continuous CMAC:    => g - 33 epoch -  1989    => error -  0.0930105567648617    accuracy -
Continuous CMAC:    => g - 33 epoch -  1990    => error -  0.0930107169936063    accuracy -
Continuous CMAC:    => g - 33 epoch -  1991    => error -  0.09301087469818281   accuracy
Continuous CMAC:    => g - 33 epoch -  1992    => error -  0.09301102988046361   accuracy
Continuous CMAC:    => g - 33 epoch -  1993    => error -  0.09301118254232132   accuracy
Continuous CMAC:    => g - 33 epoch -  1994    => error -  0.09301133268562767   accuracy
Continuous CMAC:    => g - 33 epoch -  1995    => error -  0.09301148031225415   accuracy
Continuous CMAC:    => g - 33 epoch -  1996    => error -  0.09301162542407182   accuracy
Continuous CMAC:    => g - 33 epoch -  1997    => error -  0.09301176802295119   accuracy
Continuous CMAC:    => g - 33 epoch -  1998    => error -  0.09301190811076276   accuracy
Continuous CMAC:    => g - 33 epoch -  1999    => error -  0.09301204568937604   accuracy
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Continuous CMAC:    => g - 33 epoch -  2001    => error -  0.09301231332648519   accuracy
Continuous CMAC:    => g - 33 epoch -  2002    => error -  0.0930124433887185    accuracy -
Continuous CMAC:    => g - 33 epoch -  2003    => error -  0.09301257094922866   accuracy
Continuous CMAC:    => g - 33 epoch -  2004    => error -  0.09301269600988327   accuracy
Continuous CMAC:    => g - 33 epoch -  2005    => error -  0.09301281857254973   accuracy
Continuous CMAC:    => g - 33 epoch -  2006    => error -  0.09301293863909466   accuracy
Continuous CMAC:    => g - 33 epoch -  2007    => error -  0.09301305621138478   accuracy
Continuous CMAC:    => g - 33 epoch -  2008    => error -  0.09301317129128583   accuracy
Continuous CMAC:    => g - 33 epoch -  2009    => error -  0.09301328388066343   accuracy
Continuous CMAC:    => g - 33 epoch -  2010    => error -  0.09301339398138286   accuracy
Continuous CMAC:    => g - 33 epoch -  2011    => error -  0.09301350159530863   accuracy
Continuous CMAC:    => g - 33 epoch -  2012    => error -  0.09301360672430503   accuracy
Continuous CMAC:    => g - 33 epoch -  2013    => error -  0.093013709370236 01   accuracy
Continuous CMAC:    => g - 33 epoch -  2014    => error -  0.09301380953496496   accuracy
```

```
Continuous CMAC:   => g - 33 epoch -   2014    => error -   0.09301380933498490   accuracy
Continuous CMAC:   => g - 33 epoch -   2015    => error -   0.09301390722035474   accuracy
Discrete CMAC:   => g - 34 epoch -   1    => error -   2.0083115801336135   accuracy -   -10
Discrete CMAC:   => g - 34 epoch -   2    => error -   0.9956203190311901   accuracy -   0.4
Discrete CMAC:   => g - 34 epoch -   3    => error -   0.4972133933941083   accuracy -   50.
```

3. Discuss how you might use recurrent connections to train a CMAC to output a desired trajectory without using time as an input (e.g., state only). You may earn up to 5 extra homework points if you implement your idea and show that it works.

```
Discrete CMAC:   => g - 34 epoch -   10    => error -   0.08404767709313377   accuracy -   9
```

Framework for recurrent Neural Network (RNN)

1. Initialize weight matrices U, V, W from random distribution and bias b, c with zeros
2. Forward propagation to compute predictions
3. Compute the loss
4. Back-propagation to compute gradients
5. Update weights based on gradients
6. Repeat steps 2–5

The below is code for predicting words based on a couple sentences.

For applying to a trajectory, one could make the data the various states possible (up, down, left, right) and have it decide on where to go. This can be similar to a path-planning algorithm but can be more cumbersome to write/code than doing a more basic algorithm like A* or Djisktra which can also account for the environment and obstacles (moving and stationary).

```
Continuous CMAC:   => g - 34 epoch -   11    => error -   0.08409269399201358   accuracy -
```

```python
# Class for Recurrent Neural Network
import numpy as np

class RNN:
    def __init__(self, hidden_size, vocab_size, seq_length, learning_rate):
        # hyper parameters
        self.hidden_size = hidden_size
        self.vocab_size = vocab_size
        self.seq_length = seq_length
        self.learning_rate = learning_rate
        # model parameters
        self.U = np.random.uniform(-np.sqrt(1./vocab_size), np.sqrt(1./vocab_size), (hidden_s
        self.V = np.random.uniform(-np.sqrt(1./hidden_size), np.sqrt(1./hidden_size), (vocab_
        self.W = np.random.uniform(-np.sqrt(1./hidden_size), np.sqrt(1./hidden_size), (hidden
        self.b = np.zeros((hidden_size, 1)) # bias for hidden layer
        self.c = np.zeros((vocab_size, 1)) # bias for output

        # memory vars
        self.mU = np.zeros_like(self.U)
        self.mW = np.zeros_like(self.W)
        self.mV = np.zeros_like(self.V)
```

```
        self.mb = np.zeros_like(self.b)
        self.mc = np.zeros_like(self.c)


    #probability of next character (like chatGPT)
    def softmax(self, x):
        p = np.exp(x- np.max(x))
        return p / np.sum(p)


    def forward(self, inputs, hprev):
            xs, hs, os, ycap = {}, {}, {}, {}
            hs[-1] = np.copy(hprev)
            for t in range(len(inputs)):
                xs[t] = np.zeros((self.vocab_size,1))
                xs[t][inputs[t]] = 1 # one hot encoding , 1-of-k
                hs[t] = np.tanh(np.dot(self.U,xs[t]) + np.dot(self.W,hs[t-1]) + self.b) # hic
                os[t] = np.dot(self.V,hs[t]) + self.c # unnormalised log probs for next char
                ycap[t] = self.softmax(os[t]) # probs for next char
            return xs, hs, ycap


    def backward(self, xs, hs, ps, targets):
            # backward pass: compute gradients going backwards
            dU, dW, dV = np.zeros_like(self.U), np.zeros_like(self.W), np.zeros_like(self.V)
            db, dc = np.zeros_like(self.b), np.zeros_like(self.c)
            dhnext = np.zeros_like(hs[0])
            for t in reversed(range(self.seq_length)):
                dy = np.copy(ps[t])
                #through softmax
                dy[targets[t]] -= 1 # backprop into y
                #calculate dV, dc
                dV += np.dot(dy, hs[t].T)
                dc += dc
                #dh includes gradient from two sides, next cell and current output
                dh = np.dot(self.V.T, dy) + dhnext # backprop into h
                # backprop through tanh non-linearity
                dhrec = (1 - hs[t] * hs[t]) * dh  #dhrec is the term used in many equations
                db += dhrec
                #calculate dU and dW
                dU += np.dot(dhrec, xs[t].T)
                dW += np.dot(dhrec, hs[t-1].T)
                #pass the gradient from next cell to the next iteration.
                dhnext = np.dot(self.W.T, dhrec)
            # clip to mitigate exploding gradients
            for dparam in [dU, dW, dV, db, dc]:
                np.clip(dparam, -5, 5, out=dparam)
            return dU, dW, dV, db, dc


    def loss(self, ps, targets):
            """loss for a sequence"""
            # calculate cross-entrpy loss
            return sum(-np.log(ps[t][targets[t],0]) for t in range(self.seq_length))
```

```python
    def update_model(self, dU, dW, dV, db, dc):
        for param, dparam, mem in zip([self.U, self.W, self.V, self.b, self.c],
                                      [dU, dW, dV, db, dc],
                                      [self.mU, self.mW, self.mV, self.mb, self.mc]):
            mem += dparam*dparam
            param += -self.learning_rate*dparam/np.sqrt(mem+1e-8)



    def sample(self, h, seed_ix, n):
        """
        sample a sequence of integers from the model
        h is memory state, seed_ix is seed letter from the first time step
        """
        x = np.zeros((self.vocab_size, 1))
        x[seed_ix] = 1
        ixes = []
        for t in range(n):
            h = np.tanh(np.dot(self.U, x) + np.dot(self.W, h) + self.b)
            y = np.dot(self.V, h) + self.c
            p = np.exp(y)/np.sum(np.exp(y))
            ix = np.random.choice(range(self.vocab_size), p = p.ravel())
            x = np.zeros((self.vocab_size, 1))
            x[ix] = 1
            ixes.append(ix)
        return ixes

    def train(self, data_reader):
        iter_num = 0
        threshold = 0.01
        smooth_loss = -np.log(1.0/data_reader.vocab_size)*self.seq_length
        while (smooth_loss > threshold):
            if data_reader.just_started():
                hprev = np.zeros((self.hidden_size,1))
            inputs, targets = data_reader.next_batch()
            xs, hs, ps = self.forward(inputs, hprev)
            dU, dW, dV, db, dc = self.backward(xs, hs, ps, targets)
            loss = self.loss(ps, targets)
            self.update_model(dU, dW, dV, db, dc)
            smooth_loss = smooth_loss*0.999 + loss*0.001
            hprev = hs[self.seq_length-1]
            #print every 500 epochs/iterations
            if not iter_num%500: #print every 500 epochs/iterations
                sample_ix = self.sample(hprev, inputs[0], 200)
                print( ''.join(data_reader.ix_to_char[ix] for ix in sample_ix))
                print( "\n\niter :%d, loss:%f"%(iter_num, smooth_loss))
            iter_num += 1

    def predict(self, data_reader, start, n):

        #initialize input vector
```

```python
        x =  np.zeros((self.vocab_size,1))
        chars = [ch for ch in start]
        ixes = []
        for i in range(len(chars)):
            ix = data_reader.char_to_ix[chars[i]]
            x[ix] = 1
            ixes.append(ix)

        h = np.zeros((self.hidden_size,1))
        # predict next n chars
        for t in range(n):
            h = np.tanh(np.dot(self.U, x) + np.dot(self.W, h) + self.b)
            y = np.dot(self.V, h) + self.c
            p = np.exp(y)/np.sum(np.exp(y))
            ix = np.random.choice(range(self.vocab_size), p = p.ravel())
            x = np.zeros((self.vocab_size,1))
            x[ix] = 1
            ixes.append(ix)
        txt = ''.join(data_reader.ix_to_char[i] for i in ixes)
        return txt

class DataReader:
    def __init__(self, data, seq_length):
        self.data = data

        #find unique chars
        chars = list(set(self.data))
        #create dictionary mapping for each char
        self.char_to_ix = {ch:i for (i,ch) in enumerate(chars)}
        self.ix_to_char = {i:ch for (i,ch) in enumerate(chars)}
        #total data
        self.data_size = len(self.data)
        #num of unique chars
        self.vocab_size = len(chars)
        self.pointer = 0
        self.seq_length = seq_length

    def next_batch(self):
        input_start = self.pointer
        input_end = self.pointer + self.seq_length
        inputs = [self.char_to_ix[ch] for ch in self.data[input_start:input_end]]
        targets = [self.char_to_ix[ch] for ch in self.data[input_start+1:input_end+1]]
        self.pointer += self.seq_length
        if self.pointer + self.seq_length + 1 >= self.data_size:
            # reset pointer
            self.pointer = 0
        return inputs, targets

    def just_started(self):
        return self.pointer == 0
```

```
    def close(self):
        self.fp.close()

seq_length = 100
test_data = "Discuss how you might use recurrent connections to train a CMAC to output a desi
# seq_length = len(test_data) #347
# print(seq_length)
data_reader = DataReader(test_data, seq_length)
rnn = RNN(hidden_size=200, vocab_size=data_reader.vocab_size,seq_length=seq_length,learning_r
rnn.train(data_reader)

rnn.predict(data_reader, 'earn', 50)
```

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