Prepared by: Abu Naweem Khan & Sayed Muhammad Saifuddin

Decision Tree Construction via ID3

Objective:

The main goal is to implement ID3 algorithm for generating Decision Tree classifier. So, we have to write a program that generates a Decision Tree via the ID3 algorithm.

Background:

In this project, we were given a Tutorial describing the operation of the ID3 algorithm and five sample datasets. Among those datasets, we have used four of them and we have chosen the datafile format as below:

- Header: metadata describing the dataset
  attributeName: *attributeValues* # list of attributes with their possible values
  targetName: *targetValues* # values the target can take

- Data: Training set
  attributeValues, *targetValue* # one example/line

The sample datasets that are involved to this classification project are:

- **Treatment** (HW #7): predict how a patient will respond to a new treatment
- **CAD**: predict if a patient is likely to incur coronary artery disease
- **Fishing**: is it a good day to fish?
- **Contact-lens**: suggest the best (out of three) contact-lens option

We have implemented our program as "non-recursive" first and then extended it to "recursive" for further investigation. We have written re-usable functions to generalize our program that it can work with either dataset. Furthermore, we have used **pyvis.network** package for the visualization. To validate the correctness of our program, we have tested it against the DecisionTreeClassifier() found in **scikit.learn**. For non-recursive part, the program was executed on the **Treatment** dataset. Then we have executed our recursive program to the **Fishing**, **CAD**, and **Contact-lens** datasets for further investigation. In addition, we have added "Classification mode" to our program for the unseen input instance and used our decision tree to output a prediction/classification. And finally, we were able to see the growing tree by using our program.

Methodology:

We have implemented the basic ID3 algorithm by using the below metrics for creating a decision tree classifier -

- A measure of purity:

$$\text{Entropy}(S) \equiv -\sum_{i=1}^{k} p_i \log_2 p_i$$

where S is the collection of examples, k is the number of categories, and p_i is the ratio of the cardinality of category i to the cardinality of S, as in $p_i = N_i / N$

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- The formula for Information Gain:

$$\text{Gain}(S, a) = \text{Entropy}(S) - \sum_{v=\text{values}(a)} \frac{|S_v|}{|S|} \text{Entropy}(S_v)$$

where *values(a)* is the set of all possible values for attribute a, and S_v is the subset of set S for which attribute a has value v.

The ID3 algorithm is –

<u>ID3 (S)</u>
    if all examples in S are of the same class
        return a leaf with that class label
    else if there are no more attributes to test
        return a leaf with the majority class label
    else
        choose the attribute a that maximizes the Information Gain of S
        let attribute a be the decision for the current node
        add a branch from the current node for each possible value v of attribute a
        for each branch
            "sort" examples down the branches based on their value v of attribute a
            recursively call ID3(S_v) on the set of examples now at each branch

```python
def __tree_at(self, node: dict, attrs: list):
    """
    Uses Depth-first-search approach to build the tree
    recursively using ID3 algorithm.
    :param node: the current node to split
    :return:
    """
    if node['S']['entropy'] == 0 or len(attrs) == 0:
        self.__make_leaf(node)
        return

    self.__split(node, attrs)

    # TODO: remove split attr from list and recursive call
    new_attrs = attrs.copy()
    new_attrs.remove(node['split']['attr'])

    if node['branches'] is not None:
        for key in node['branches']:
            self.__tree_at(node['branches'][key], new_attrs)
```

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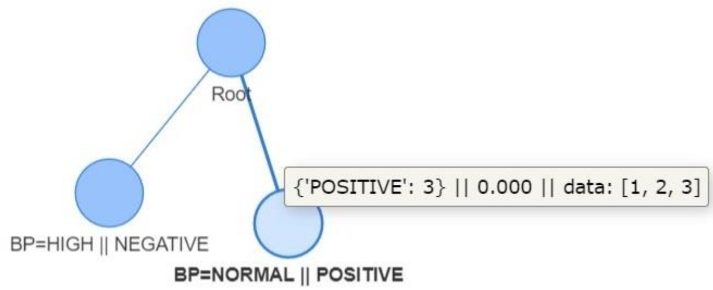
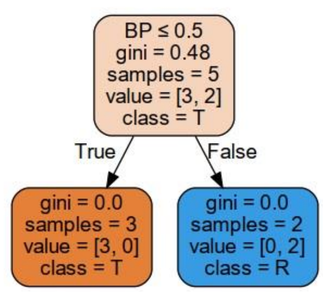
Visualization: [Display the Output]

Treatment Dataset:

```
Enter dataset name: treatment.data
*****************************************************
    Custom implementation of Decision Tree.
*****************************************************

Step 1: Pre-processing and Initialization.
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 5 entries, 0 to 4
Data columns (total 4 columns):
 #   Column  Non-Null Count  Dtype
---  ------  --------------  -----
 0   PULSE   5 non-null      object
 1   BP      5 non-null      object
 2   AGE     5 non-null      object
 3   TREAT   5 non-null      object
dtypes: object(4)
memory usage: 288.0+ bytes
None

Step 2: Training...Done

Step 2: Plotting Tree...Done

Step 3: Prediction.
PULSE: normal
BP: normal
AGE: <25
Root -> BP=NORMAL || POSITIVE
Press "q" to quit, any key to continue:
PULSE: normal
BP: low
AGE: <25
Root -> Not predictable: {'NEGATIVE': 'Prob: 0.400', 'POSITIVE': 'Prob: 0.600'}
Press "q" to quit, any key to continue: q
*****************************************************
    sklearn implementation of Decision Tree.
*****************************************************

Step 1: Pre-processing and Initialization.
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 5 entries, 0 to 4
Data columns (total 4 columns):
 #   Column  Non-Null Count  Dtype
---  ------  --------------  -----
 0   PULSE   5 non-null      object
 1   BP      5 non-null      object
 2   AGE     5 non-null      object
 3   TREAT   5 non-null      object
dtypes: object(4)
memory usage: 288.0+ bytes
None
    PULSE      BP    AGE  ... BP_encoded  AGE_encoded  TREAT_encoded
0  NORMAL  NORMAL    <25  ...          0            0              0
1  NORMAL  NORMAL  25-40  ...          0            1              0
2   RAPID  NORMAL    >40  ...          0            2              0
3  NORMAL    HIGH    >40  ...          1            2              1
4   RAPID    HIGH    >40  ...          1            2              1

[5 rows x 8 columns]

Step 2: Training...Done

Step 2: Plotting Tree...Done

Step 3: Prediction.
PULSE: Normal
BP: Normal
AGE: <25
Prediction: POSITIVE
Press "q" to quit, any key to continue: q

Process finished with exit code 0
```





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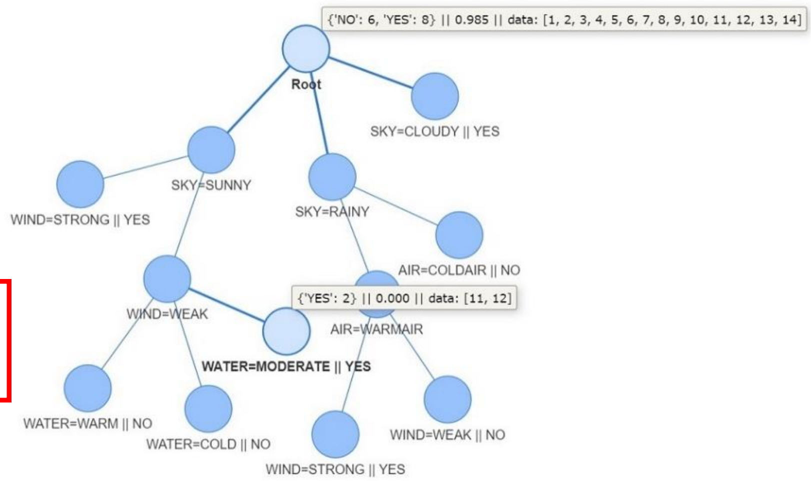
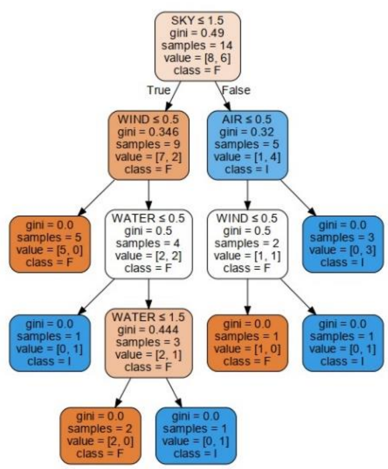
Fishing Dataset:

```
Enter dataset name: fishing.data
*****************************************************
    Custom implementation of Decision Tree.
*****************************************************

Step 1: Pre-processing and Initialization.
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 14 entries, 0 to 13
Data columns (total 5 columns):
 #   Column  Non-Null Count  Dtype
---  ------  --------------  -----
 0   WIND    14 non-null     object
 1   AIR     14 non-null     object
 2   WATER   14 non-null     object
 3   SKY     14 non-null     object
 4   FISH    14 non-null     object
dtypes: object(5)
memory usage: 688.0+ bytes
None

Step 2: Training...Done

Step 2: Plotting Tree...Done

Step 3: Prediction.
WIND: Strong
AIR: WarmAir
WATER: Warm
SKY: Sunny
Root -> SKY=SUNNY -> WIND=STRONG || YES
Press "q" to quit, any key to continue:
WIND: Moderate
AIR: WarmAir
WATER: Warm
SKY: Sunny
Root -> SKY=SUNNY -> Not predictable: {'NO': 'Prob: 0.250', 'YES': 'Prob: 0.750'}
Press "q" to quit, any key to continue: q
*****************************************************
    sklearn implementation of Decision Tree.
*****************************************************

Step 1: Pre-processing and Initialization.
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 14 entries, 0 to 13
Data columns (total 5 columns):
 #   Column  Non-Null Count  Dtype
---  ------  --------------  -----
 0   WIND    14 non-null     object
 1   AIR     14 non-null     object
 2   WATER   14 non-null     object
 3   SKY     14 non-null     object
 4   FISH    14 non-null     object
dtypes: object(5)
memory usage: 688.0+ bytes
None
     WIND      AIR     WATER  ... WATER_encoded SKY_encoded  FISH_encoded
0  STRONG  WARMAIR      WARM  ...             0           0             0
1    WEAK  WARMAIR      WARM  ...             0           0             1
2  STRONG  WARMAIR      WARM  ...             0           1             0
3  STRONG  WARMAIR  MODERATE  ...             1           2             0
4  STRONG  COLDAIR      COLD  ...             2           2             1

[5 rows x 10 columns]

Step 2: Training...Done

Step 2: Plotting Tree...Done

Step 3: Prediction.
WIND: Strong
AIR: WarmAir
WATER: Warm
SKY: Sunny
Prediction: YES
Press "q" to quit, any key to continue: q

Process finished with exit code 0

```





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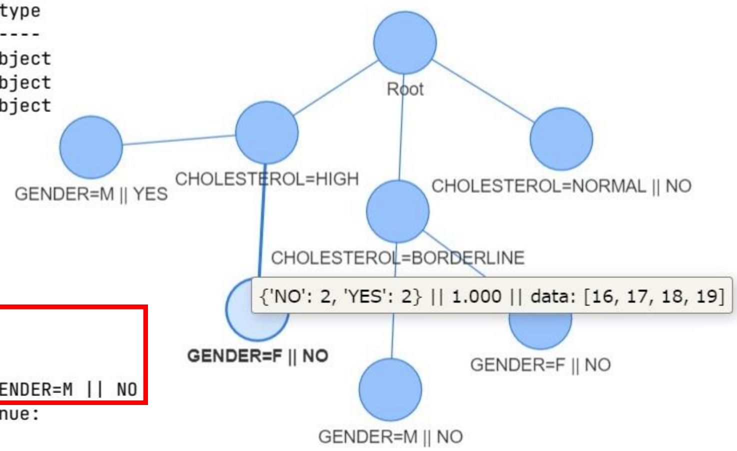
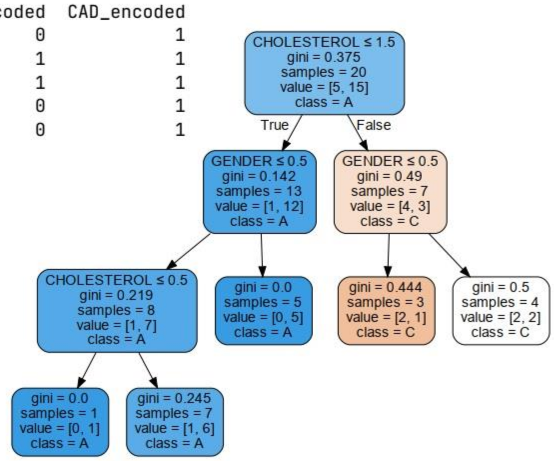
CAD Dataset:

```
Enter dataset name: CAD.data
*****************************************************
    Custom implementation of Decision Tree.
*****************************************************

Step 1: Pre-processing and Initialization.
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 20 entries, 0 to 19
Data columns (total 3 columns):
 #   Column       Non-Null Count  Dtype
---  ------       --------------  -----
 0   CHOLESTEROL  20 non-null     object
 1   GENDER       20 non-null     object
 2   CAD          20 non-null     object
dtypes: object(3)
memory usage: 608.0+ bytes
None

Step 2: Training...Done

Step 2: Plotting Tree...Done

Step 3: Prediction.
CHOLESTEROL: Borderline
GENDER: M
Root -> CHOLESTEROL=BORDERLINE -> GENDER=M || NO
Press "q" to quit, any key to continue:
CHOLESTEROL: Low
GENDER: M
Root -> Not predictable: {'NO': 'Prob: 0.750', 'YES': 'Prob: 0.250'}
Press "q" to quit, any key to continue: q
*****************************************************
    sklearn implementation of Decision Tree.
*****************************************************

Step 1: Pre-processing and Initialization.
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 20 entries, 0 to 19
Data columns (total 3 columns):
 #   Column       Non-Null Count  Dtype
---  ------       --------------  -----
 0   CHOLESTEROL  20 non-null     object
 1   GENDER       20 non-null     object
 2   CAD          20 non-null     object
dtypes: object(3)
memory usage: 608.0+ bytes
None
  CHOLESTEROL GENDER CAD  CHOLESTEROL_encoded  GENDER_encoded  CAD_encoded
0      NORMAL      M  NO                    0               0            1
1      NORMAL      F  NO                    0               1            1
2      NORMAL      F  NO                    0               1            1
3  BORDERLINE      M  NO                    1               0            1
4  BORDERLINE      M  NO                    1               0            1

Step 2: Training...Done

Step 2: Plotting Tree...Done

Step 3: Prediction.
CHOLESTEROL: Borderline
GENDER: M

Prediction: NO
Press "q" to quit, any key to continue: q

Process finished with exit code 0

```





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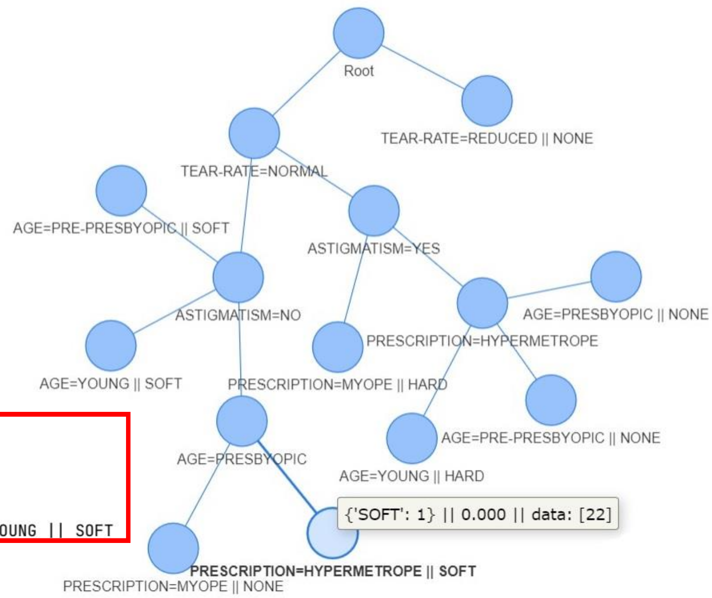
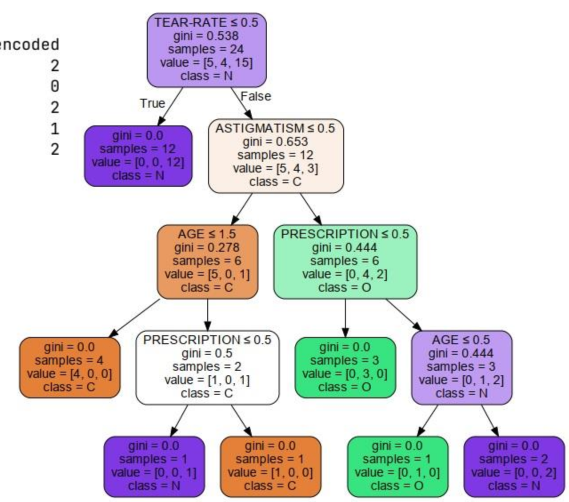
Contact-lens Dataset:

```
Enter dataset name: contact-lenses.data
******************************************************
    Custom implementation of Decision Tree.
******************************************************

Step 1: Pre-processing and Initialization.
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 24 entries, 0 to 23
Data columns (total 5 columns):
 #   Column          Non-Null Count  Dtype
---  ------          --------------  -----
 0   AGE             24 non-null     object
 1   PRESCRIPTION    24 non-null     object
 2   ASTIGMATISM     24 non-null     object
 3   TEAR-RATE       24 non-null     object
 4   CONTACT-LENSES  24 non-null     object
dtypes: object(5)
memory usage: 1.1+ KB
None

Step 2: Training...Done

Step 2: Plotting Tree...Done

Step 3: Prediction.
AGE: young
PRESCRIPTION: myope
ASTIGMATISM: no
TEAR-RATE: normal
Root -> TEAR-RATE=NORMAL -> ASTIGMATISM=NO -> AGE=YOUNG || SOFT
Press "q" to quit, any key to continue:
AGE: old
PRESCRIPTION: myope
ASTIGMATISM: no
TEAR-RATE: noraml
Root -> Not predictable: {'HARD': 'Prob: 0.167', 'NONE': 'Prob: 0.625', 'SOFT': 'Prob: 0.208'}
Press "q" to quit, any key to continue: q
```




```
******************************************************
    sklearn implementation of Decision Tree.
******************************************************

Step 1: Pre-processing and Initialization.
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 24 entries, 0 to 23
Data columns (total 5 columns):
 #   Column          Non-Null Count  Dtype
---  ------          --------------  -----
 0   AGE             24 non-null     object
 1   PRESCRIPTION    24 non-null     object
 2   ASTIGMATISM     24 non-null     object
 3   TEAR-RATE       24 non-null     object
 4   CONTACT-LENSES  24 non-null     object
dtypes: object(5)
memory usage: 1.1+ KB
None
     AGE  PRESCRIPTION  ... TEAR-RATE_encoded CONTACT-LENSES_encoded
0  YOUNG         MYOPE  ...                 0                      2
1  YOUNG         MYOPE  ...                 1                      0
2  YOUNG         MYOPE  ...                 0                      2
3  YOUNG         MYOPE  ...                 1                      1
4  YOUNG  HYPERMETROPE  ...                 0                      2

[5 rows x 10 columns]

Step 2: Training...Done

Step 2: Plotting Tree...Done

Step 3: Prediction.
AGE: Young
PRESCRIPTION: Myope
ASTIGMATISM: No
TEAR-RATE: Normal
Prediction: SOFT
Press "q" to quit, any key to continue: q

Process finished with exit code 0
```



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Analysis and Discussion:

We can see from the above visualization part that the output generated using the implemented algorithm and the output generated using the DecisionTreeClassifier() found in **scikit.learn** are same. So, we can say that our implemented algorithm is validated by a library package.

Future Work:

In future, we can extend our program by implementing the capability to process numeric (continuous-valued) attributes and extract the rule-base (IF-THEN) from our decision tree.

[Note: Please turn next page for the Source Code]

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Source Code:

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```python
import math
from collections import defaultdict
from queue import Queue

import pandas as pd
from pyvis.network import Network


class DecisionTree:
    __data = None
    __attrs = None
    __cls = None
    __tree = defaultdict(dict)

    def __init__(self, df: pd.DataFrame, attrs=None):
        self.__data = df
        self.__gen_attr_set(attrs)

    def __gen_attr_set(self, attrs=None):
        """
        If attrs is None, generates the unique values for each attribute
        from the dataset. If any value of an attribute is not present in
        the dataset, this will fail to discover all possible values of an
        attribute.
        In that case attrs must not be None.

        Considers class to be the last column.
        :return:
        """
        self.__attrs = dict()
        self.__cls = dict()

        if attrs is not None:
            k, l = attrs.popitem()
            self.__cls = {k: l}
            self.__attrs = attrs.copy()
            return

        columns = self.__data.columns.to_list()
        for col in columns[:-1]:
            self.__attrs[col] = self.__data[col].unique().tolist()

        self.__cls[columns[-1]] = self.__data[columns[-1]].unique().tolist()

    def __entropy_of(self, cls_freq: dict) -> float:
        total = 0
        for i in cls_freq.values():
            total += i

        entropy = 0
        for i in cls_freq.values():
            entropy -= (i / total) * math.log2((i / total))

        return entropy

    def __gain_of(self, node_entropy, col, col_cls_name, df):
        S = defaultdict(dict)
        d = df.groupby(by=[col, col_cls_name]).count().iloc[:, 0]

```

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```python
        for key in d.keys():
            attr, cls = key
            S[attr][cls] = d[key]

        gain = node_entropy
        for key in S:
            cls_freq = S[key]
            attr_total = d.loc[key].sum()
            total = d.sum()
            S[key]['entropy'] = self.__entropy_of(cls_freq)
            gain -= (S[key]['entropy'] * attr_total / total)

        return S, gain

    def __split(self, node: dict, attrs: list):
        """
        Splits the node on the attribute with the highest gain value.
        Uses Entropy for gain calculation.
        :param node: node to split
        :param attrs: allowed attributes to split on
        """

        col_cls_name = list(self.__cls.keys())[0]
        df = self.__data.loc[node['data']]

        max_gain = -1
        max_S = None
        split_col = None
        for col in attrs:
            S, gain = self.__gain_of(node['S']['entropy'], col, col_cls_name, df)

            if max_gain < gain:
                max_gain = gain
                max_S = S
                split_col = col

        node['split']['attr'] = split_col
        node['split']['gain'] = max_gain
        node['branches'] = dict()

        for key in max_S:
            cls_freq = max_S[key].copy()
            cls_freq.pop('entropy')
            n = {
                'data': [i for i in df[df[split_col] == key].index],
                'S': {
                    'cls_freq': cls_freq,
                    'entropy': max_S[key]['entropy']
                },
                'split': {'attr': None, 'gain': None},
                'branches': None,
                'label': f'{split_col}={key}'
            }
            node['branches'][key] = n

    def __make_leaf(self, node: dict):
        """
        Marks a node as a leaf, by assigning the majority class as the label.
        :param node:
        :return:
```

```python
        """
        max_freq = -1
        label = ''
        for key in node['S']['cls_freq']:
            freq = node['S']['cls_freq'][key]
            if max_freq < freq:
                max_freq = freq
                label = key

        node['label'] = f"{node['label']} || {label}"

    def __tree_at(self, node: dict, attrs: list):
        """
        Uses Depth-first-search approach to build the tree
        recursively using ID3 algorithm.
        :param node: the current node to split
        :return:
        """
        if node['S']['entropy'] == 0 or len(attrs) == 0:
            self.__make_leaf(node)
            return

        self.__split(node, attrs)

        # TODO: remove split attr from list and recursive call
        new_attrs = attrs.copy()
        new_attrs.remove(node['split']['attr'])

        if node['branches'] is not None:
            for key in node['branches']:
                self.__tree_at(node['branches'][key], new_attrs)

    def train(self):
        cls_col_name = list(self.__cls.keys())[0]
        attr_names = list(self.__attrs.keys())

        self.__tree = {
            'data': [i for i in range(len(self.__data))],
            'S': {
                'cls_freq': self.__data.groupby(cls_col_name).count()[
                    attr_names[0]].to_dict()
            },
            'split': {'attr': None, 'gain': None},
            'branches': None,
            'label': 'Root'
        }

        self.__tree['S']['entropy'] = self.__entropy_of(self.__tree['S']['cls_freq'])

        self.__tree_at(node=self.__tree, attrs=attr_names)

    def predict(self, attr_vals: dict):
        node = self.__tree

        predict_vals = dict()
        for key in attr_vals:
            predict_vals[key.upper()] = attr_vals[key].upper()

        while True:
```

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```python
            if node['branches'] is None:
                print(f'{node["label"]}')
                return

            print(f"{node['label']} -> ", end='')

            split = node['split']['attr']
            if split not in predict_vals:
                print(f'{split} not in given values {attr_vals.keys()}')
                return

            attr_val = predict_vals[split]

            for key in node['branches']:
                n = node['branches'][key]
                if n['label'].startswith(f"{split}={attr_val}"):
                    node = n
                    break
            else:
                total = len(node['data'])
                cls_col = list(self.__cls.keys())[0]
                counts = self.__data.loc[node['data']].groupby(cls_col).count()[
                    self.__data.columns[0]].to_dict()
                for key in counts:
                    counts[key] = f"Prob: {counts[key] / total:.3f}"

                print(f'Not predictable: {counts}')
                return

    def plot_tree(self):
        # print(self.__tree)
        net = Network()
        net.height = '100%'
        net.width = '100%'

        node = self.__tree
        node['id'] = 1
        title = f"{node['S']['cls_freq']} || " \
                f"{node['S']['entropy']:.3f} || " \
                f"data: {[i + 1 for i in node['data']]}"
        net.add_node(1, label=node['label'], title=title)

        q = Queue()
        q.put(node)

        self.__bfs_plot(q, net)

        net.show('tree.html')

    def __bfs_plot(self, q: Queue, net: Network):
        i = 1
        while not q.empty():
            node = q.get()
            uid = node['id']

            if node['branches'] is not None:
                for key in node['branches'].keys():
                    n = node['branches'][key]
                    n['id'] = uid + i
                    title = f"{n['S']['cls_freq']} || " \
```

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```
                            f"{n['S']['entropy']:.3f} || " \
                            f"data: {[i + 1 for i in n['data']]}"
                    net.add_node(uid + i, label=n['label'], title=title)
                    net.add_edge(uid, uid + i)
                    i += 1
                    q.put(n)


def pre_processing(filepath: str) -> tuple[pd.DataFrame, dict]:
    data = []
    attrs = defaultdict(list)
    with open(filepath, mode='r') as fin:
        for line in fin:
            line = line.strip()

            if line.startswith("#attributes") or line.startswith("#target"):
                for l in fin:
                    l = l.strip().upper()
                    if len(l) == 0:
                        break
                    parts = l.split(":")
                    attrs[parts[0][1:]] = parts[1].strip().split(",")

            elif line.startswith("#data"):
                for l in fin:
                    l = l.strip().upper()
                    if len(l) == 0:
                        break
                    parts = l.split(",")
                    data.append(parts)

    df = pd.DataFrame(data)
    df.columns = list(attrs.keys())
    print(df.info())

    return df, attrs

```

Note: Please turn next page for rest of the codes:

```python
from collections import defaultdict

import graphviz
import pandas as pd
from sklearn import tree

from project3.decision_tree import DecisionTree, pre_processing


def custom_dtree(filename: str):
    print('****************************************************')
    print('\tCustom implementation of Decision Tree.')
    print('****************************************************')

    print('\nStep 1: Pre-processing and Initialization.')
    df, attr = pre_processing(filename)
    dt = DecisionTree(df, attr)

    print('\nStep 2: Training...', end='')
    dt.train()
    print('Done')

    print('\nStep 2: Plotting Tree...', end='')
    dt.plot_tree()
    print('Done')

    print('\nStep 3: Prediction.')
    q = 'a'
    inp = defaultdict(str)
    for item in attr:
        inp[item] = ''
    while q != 'q':
        for key in inp:
            val = input(f"{key}: ")
            inp[key] = val

        # dt.predict({'WIND': 'WEAK', 'WATER': 'MODERATE', 'AIR': 'WARMAIR', 'SKY': 'RAINY'})
        dt.predict(inp)
        q = input('Press "q" to quit, any key to continue: ')


def load_and_encode(filepath: str) -> tuple[pd.DataFrame, dict]:
    df, attrs = pre_processing(filepath)

    for col in attrs.keys():
        series = df[col].tolist()
        for i in range(len(series)):
            series[i] = attrs[col].index(series[i])
        df[f'{col}_encoded'] = series

    return df, attrs


def sklearn_dtree(filename: str):
    print('****************************************************')
    print('\tsklearn implementation of Decision Tree.')
    print('****************************************************')

```

```python
    print('\nStep 1: Pre-processing and Initialization.')
    df, attrs = load_and_encode(filename)
    cols = list(attrs.keys())
    print(df.head())

    print('\nStep 2: Training...', end='')
    x = []
    for i in df.index:
        x.append(df.iloc[i, len(cols):2*len(cols)-1].tolist())

    y = df[df.columns[-1]].tolist()

    dt = tree.DecisionTreeClassifier()
    dt = dt.fit(x, y)
    print('Done')

    print('\nStep 2: Plotting Tree...', end='')
    dot_tree = tree.export_graphviz(dt, out_file=None,
                                    feature_names=cols[:-1],
                                    class_names=cols[-1],
                                    filled=True, rounded=True,
                                    special_characters=True)
    graph = graphviz.Source(dot_tree)
    graph.render('decision_tree')
    print('Done')

    print('\nStep 3: Prediction.')
    q = 'a'
    inp = []
    while q != 'q':
        for key in cols[:-1]:
            val = input(f"{key}: ")
            inp.append(attrs[key].index(val.upper()))

        # dt.predict({'WIND': 'WEAK', 'WATER': 'MODERATE', 'AIR': 'WARMAIR', 'SKY': 'RAINY'})
        cls = dt.predict([inp])[0]
        print(f"Prediction: {attrs[cols[-1]][cls]}")
        q = input('Press "q" to quit, any key to continue: ')


def run():
    filename = input('Enter dataset name: ')
    custom_dtree(filename)
    sklearn_dtree(filename)

```

Thank You!!!