Tipping based on Food and Service Quality

Consider three simple rules:

1. If the food is bad OR the service is poor, then the tip will be low
2. If the service is acceptable, then the tip will be medium
3. If the food is great OR the service is amazing, then the tip will be high.

Most people would agree on these rules, but the rules are fuzzy. Mapping the imprecise rules into a defined, actionable tip is a challenge. This is the kind of task at which fuzzy logic excels.

Required Libraries

https://pythonhosted.org/scikit-fuzzy/auto_examples/plot_tipping_problem.html

https://pythonhosted.org/scikit-fuzzy/auto_examples/plot_tipping_problem_newapi.html

Input variables

Two inputs

- food quality
- service

Output variable

the output variable is the tip amount.

Import Packages

```
!py -m pip install scikit-fuzzy
import numpy as np
import skfuzzy as fuzz
import matplotlib.pyplot as plt
```

```
Requirement already satisfied: scikit-fuzzy in c:\users\sehre\appdata\local\programs\python\python311\lib\site-packages (0.4
Requirement already satisfied: numpy>=1.6.0 in c:\users\sehre\appdata\local\programs\python\python311\lib\site-packages (fro
Requirement already satisfied: scipy>=0.9.0 in c:\users\sehre\appdata\local\programs\python\python311\lib\site-packages (fro
Requirement already satisfied: networkx>=1.9.0 in c:\users\sehre\appdata\local\programs\python\python311\lib\site-packages (

[notice] A new release of pip is available: 23.3 -> 24.0
[notice] To update, run: python.exe -m pip install --upgrade pip
```

Generate universe variables

Remember, all possible values that a variable can take are referred to as Universe of Discourse, in the context of linguistic variables.

```
#   * Quality and service on subjective ranges [0, 10] -> using .5 as step
#   * Tip has a range of [0, 25] in units of percentage points
x_qual = np.arange(0, 10.5, .5)
x_serv = np.arange(0, 10.5, .5)
x_tip  = np.arange(0, 26, 1)
```

```
print(x_qual)
print(x_serv)
print(x_tip)
```

```
[ 0.   0.5  1.   1.5  2.   2.5  3.   3.5  4.   4.5  5.   5.5  6.   6.5
  7.   7.5  8.   8.5  9.   9.5 10. ]
[ 0.   0.5  1.   1.5  2.   2.5  3.   3.5  4.   4.5  5.   5.5  6.   6.5
```

```
  7.   7.5  8.   8.5  9.   9.5 10. ]
[ 0  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
 24 25]
```

Generate fuzzy membership functions

Triangular membership function (trinmf) is used for fuzzification of the variables

- food quality
  - low
  - medium
  - high
- service
  - low
  - medium
  - high
- tip amount
  - low
  - medium
  - high
- Triangular membership function Formula

$$f(x;a,b,c) = \begin{cases} 0, & x \le a \\ \frac{x-a}{b-a}, & a \le x \le b \\ \frac{c-x}{c-b}, & b \le x \le c \\ 0, & c \le x \end{cases}$$

- [abc]
- $a \leq b \leq c$
- zero for $x \leq a$ and $x \geq c$
- increases a to b
- decreases b to c

```
# Generate fuzzy membership functions
# food quality
qual_lo = fuzz.trimf(x_qual, abc=[0, 0, 5])
qual_md = fuzz.trimf(x_qual, abc=[0, 5, 10])
qual_hi = fuzz.trimf(x_qual, abc=[5, 10, 10])
# service quality
serv_lo = fuzz.trimf(x_serv, abc=[0, 0, 5])
serv_md = fuzz.trimf(x_serv, abc=[0, 5, 10])
serv_hi = fuzz.trimf(x_serv, abc=[5, 10, 10])
# tip
tip_lo = fuzz.trimf(x_tip, abc=[0, 0, 13])
tip_md = fuzz.trimf(x_tip, abc=[0, 13, 25])
tip_hi = fuzz.trimf(x_tip, abc=[13, 25, 25])
```

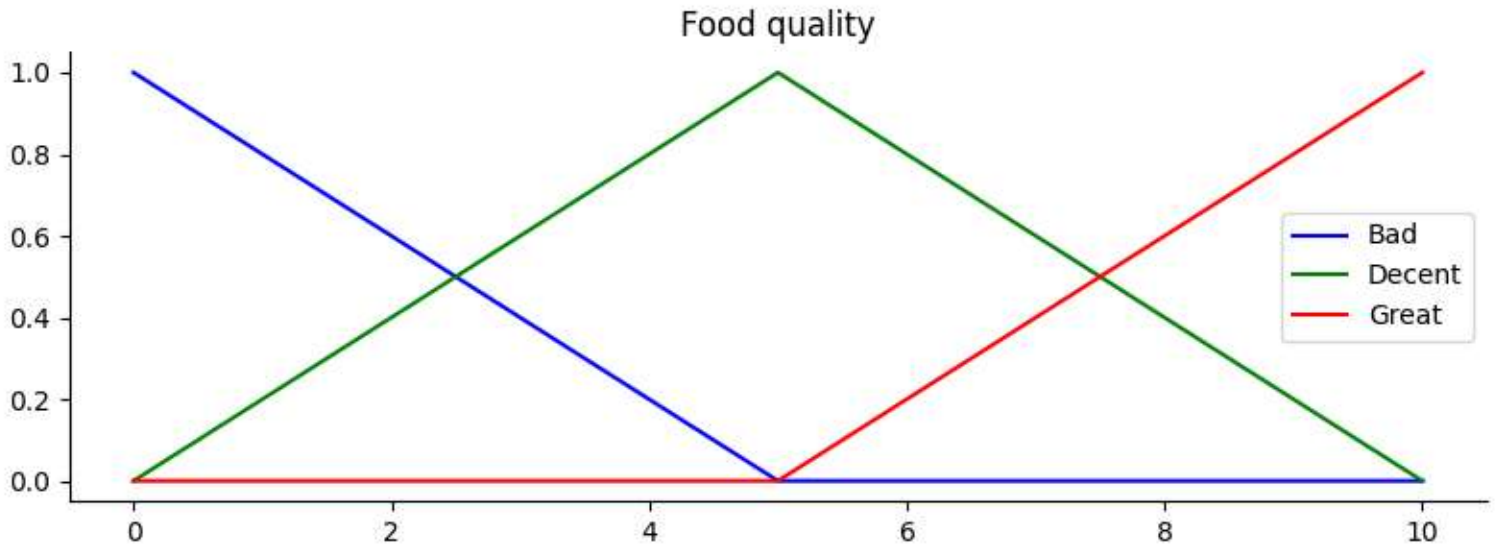
Have a look on the food quality membership functions for low, medium and high

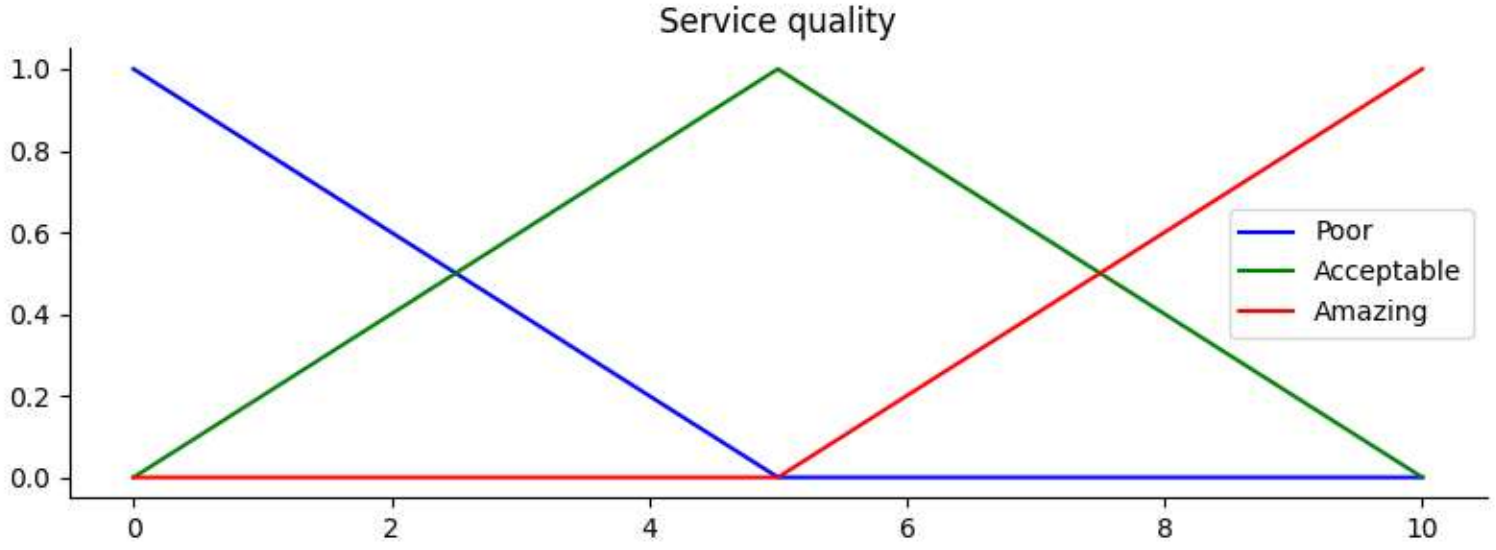
```
print('x_qual',x_qual)
print('qual_lo', qual_lo)
print('qual_md',qual_md)
print('qual_hi',qual_hi)
```

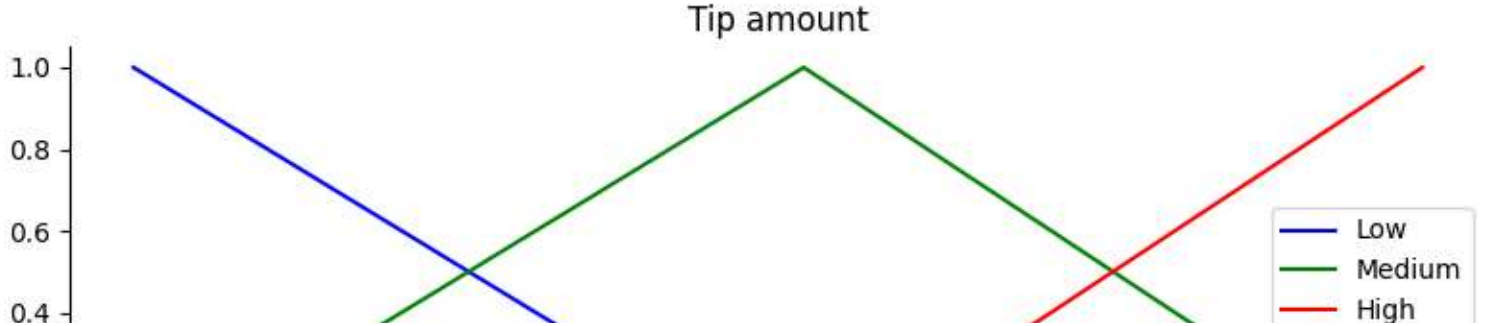
```
x_qual [ 0.   0.5  1.   1.5  2.   2.5  3.   3.5  4.   4.5  5.   5.5  6.   6.5
  7.   7.5  8.   8.5  9.   9.5 10. ]
qual_lo [1.  0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.  0.  0.  0.  0.  0.  0.  0.
 0.  0.  0. ]
qual_md [0.  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.  0.9 0.8 0.7 0.6 0.5 0.4 0.3
 0.2 0.1 0. ]
qual_hi [0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.1 0.2 0.3 0.4 0.5 0.6 0.7
 0.8 0.9 1. ]
```

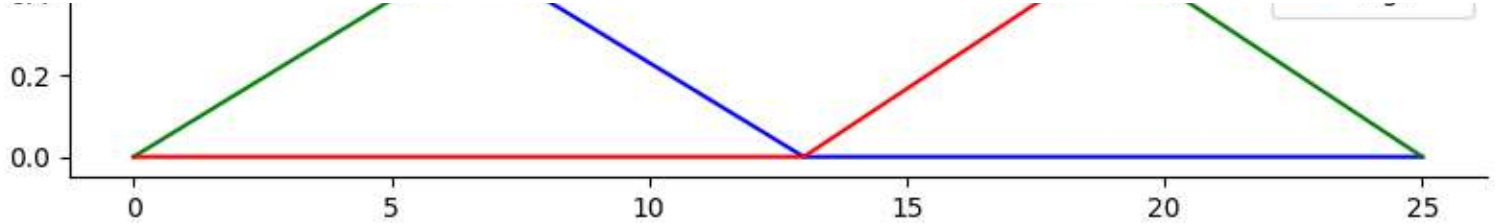
Visualize these universes and membership functions

```
# Visualize these universes and membership functions
fig, (ax0, ax1, ax2) = plt.subplots(nrows=3, figsize=(8, 9))

ax0.plot(x_qual, qual_lo, 'b', linewidth=1.5, label='Bad')
ax0.plot(x_qual, qual_md, 'g', linewidth=1.5, label='Decent')
ax0.plot(x_qual, qual_hi, 'r', linewidth=1.5, label='Great')
ax0.set_title('Food quality')
ax0.legend()

ax1.plot(x_serv, serv_lo, 'b', linewidth=1.5, label='Poor')
ax1.plot(x_serv, serv_md, 'g', linewidth=1.5, label='Acceptable')
ax1.plot(x_serv, serv_hi, 'r', linewidth=1.5, label='Amazing')
ax1.set_title('Service quality')
ax1.legend()

ax2.plot(x_tip, tip_lo, 'b', linewidth=1.5, label='Low')
ax2.plot(x_tip, tip_md, 'g', linewidth=1.5, label='Medium')
ax2.plot(x_tip, tip_hi, 'r', linewidth=1.5, label='High')
ax2.set_title('Tip amount')
ax2.legend()

# Turn off top/right axes
for ax in (ax0, ax1, ax2):
    ax.spines['top'].set_visible(False)
    ax.spines['right'].set_visible(False)
    ax.get_xaxis().tick_bottom()
    ax.get_yaxis().tick_left()

plt.tight_layout()
```


Food quality
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
Bad
Decent
Great


Service quality
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
Poor
Acceptable
Amazing


Tip amount
1.0
0.8
0.6
0.4
Low
Medium
High



Fuzzy Rule based Tipping

Now, to make these triangles useful, we define the fuzzy relationship between input and output variables. For the purposes of our example, consider three simple rules:

1. If the food is bad OR the service is poor, then the tip will be low
2. If the service is acceptable, then the tip will be medium
3. If the food is great OR the service is amazing, then the tip will be high.

Most people would agree on these rules, but the rules are fuzzy. Mapping the imprecise rules into a defined, actionable tip is a challenge. This is the kind of task at which fuzzy logic excels.

Question 1

What would the tip be in the following circumstance:

- Food quality was 6.5
- Service was 9.8

Fuzzification: interp_membership function

interpolate

Find the degree of membership u(xx) for a given value of x = xx.

We need the activation of our fuzzy membership functions at these values. The exact values 6.5 and 9.8 do not exist on our universes...
This is what fuzz.interp_membership exists for!

```
qual_level_lo = fuzz.interp_membership(x_qual, qual_lo, 6.5)
qual_level_md = fuzz.interp_membership(x_qual, qual_md, 6.5)
qual_level_hi = fuzz.interp_membership(x_qual, qual_hi, 6.5)
print(qual_level_lo, qual_level_md, qual_level_hi)
```

```
0.0 0.7 0.3
```

```
serv_level_lo = fuzz.interp_membership(x_serv, serv_lo, 9.8)
serv_level_md = fuzz.interp_membership(x_serv, serv_md, 9.8)
serv_level_hi = fuzz.interp_membership(x_serv, serv_hi, 9.8)
print(serv_level_lo, serv_level_md, serv_level_hi)
```

```
0.0 0.03999999999999986 0.9600000000000002
```

Rule Evaluation (Inference)

1. If the food is bad OR the service is poor, then the tip will be low

```
import math

active_rule1 = np.fmax(qual_level_lo, serv_level_lo) # fuzzy-max = Boolean OR
print('active_rule1', active_rule1)
# Now we apply this by clipping the top off the corresponding output
# membership function with `np.fmin`
print('tip_lo')
print('consequent', tip_lo.round(2))
tip_activation_lo = np.fmin(active_rule1, tip_lo)  # fuzzy-min = Boolean AND
print('Rule 1: tip_activation_lo')
print(tip_activation_lo)
```

```
active_rule1 0.0
tip_lo
consequent [1.   0.92 0.85 0.77 0.69 0.62 0.54 0.46 0.38 0.31 0.23 0.15 0.08 0.
```

```
 0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  ]
Rule 1: tip_activation_lo
[0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
 0. 0.]
```

2. If the service is acceptable, then the tip will be medium

```
# For rule 2 we connect acceptable service to medium tipping
tip_activation_md = np.fmin(serv_level_md, tip_md) # fuzzy-min = Boolean AND

print('antecedent (serv_level_md)')
print(serv_level_md.round(4))
print(tip_md.round(1))
print(tip_activation_md)
```

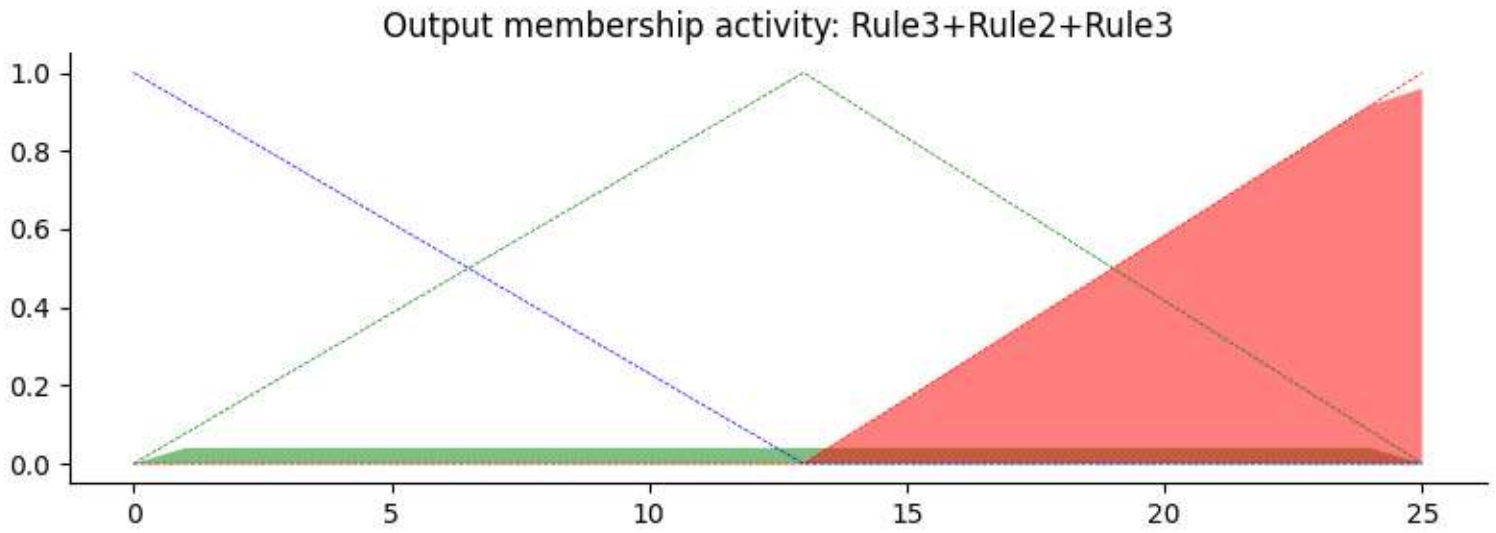
```
antecedent (serv_level_md)
0.04
[0.  0.1 0.2 0.2 0.3 0.4 0.5 0.5 0.6 0.7 0.8 0.8 0.9 1.  0.9 0.8 0.8 0.7
 0.6 0.5 0.4 0.3 0.2 0.2 0.1 0. ]
[0.   0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.  ]
```

3. If the food is great OR the service is amazing, then the tip will be high.

```
# For rule 3 we connect high service OR high food with high tipping
active_rule3 = np.fmax(qual_level_hi, serv_level_hi) # fuzzy-max = Boolean OR
print('active_rule3', active_rule3)
print(tip_hi)
tip_activation_hi = np.fmin(active_rule3, tip_hi)
print(tip_activation_hi)
```

```
active_rule3 0.9600000000000002
[0.         0.         0.         0.         0.         0.
 0.         0.         0.         0.         0.         0.
 0.         0.         0.08333333 0.16666667 0.25       0.33333333
 0.41666667 0.5        0.58333333 0.66666667 0.75       0.83333333
 0.91666667 1.        ]
```

```
     [0.         0.         0.         0.         0.         0.
      0.         0.         0.         0.         0.         0.
      0.         0.         0.08333333 0.16666667 0.25       0.33333333
      0.41666667 0.5        0.58333333 0.66666667 0.75       0.83333333
      0.91666667 0.96      ]


tip0 = np.zeros_like(x_tip)
# Visualize this
fig, ax0 = plt.subplots(figsize=(8, 3))
ax0.fill_between(x=x_tip, y1=tip0, y2=tip_activation_lo, facecolor='b', alpha=0.5)
ax0.plot(x_tip, tip_lo, 'b', linewidth=0.5, linestyle='--', )
ax0.fill_between(x_tip, tip0, tip_activation_md, facecolor='g', alpha=0.5)
ax0.plot(x_tip, tip_md, 'g', linewidth=0.5, linestyle='--')
ax0.fill_between(x_tip, tip0, tip_activation_hi, facecolor='r', alpha=0.5)
ax0.plot(x_tip, tip_hi, 'r', linewidth=0.5, linestyle='--')
ax0.set_title('Output membership activity: Rule3+Rule2+Rule3')

# Turn off top/right axes
for ax in (ax0,):
    ax.spines['top'].set_visible(False)
    ax.spines['right'].set_visible(False)
    ax.get_xaxis().tick_bottom()
    ax.get_yaxis().tick_left()

plt.tight_layout()
```



Aggregation (Composition)

- Aggregate all three output membership functions together

```
aggregated = np.fmax(tip_activation_lo, np.fmax(tip_activation_md, tip_activation_hi))
print(aggregated)
```

```
[0.         0.04       0.04       0.04       0.04       0.04
 0.04       0.04       0.04       0.04       0.04       0.04
 0.04       0.04       0.08333333 0.16666667 0.25       0.33333333
 0.41666667 0.5        0.58333333 0.66666667 0.75       0.83333333
 0.91666667 0.96      ]
```

Defuzzification

Calculate defuzzified result using the centroid method

```
tip = fuzz.defuzz(x_tip, aggregated, 'centroid')
print(tip)
# tip = fuzz.defuzz(x_tip, aggregated, 'som')
# print(tip)
# tip = fuzz.defuzz(x_tip, aggregated, 'mom')
# print(tip)
# tip = fuzz.defuzz(x_tip, aggregated, 'lom')
# print(tip)
```

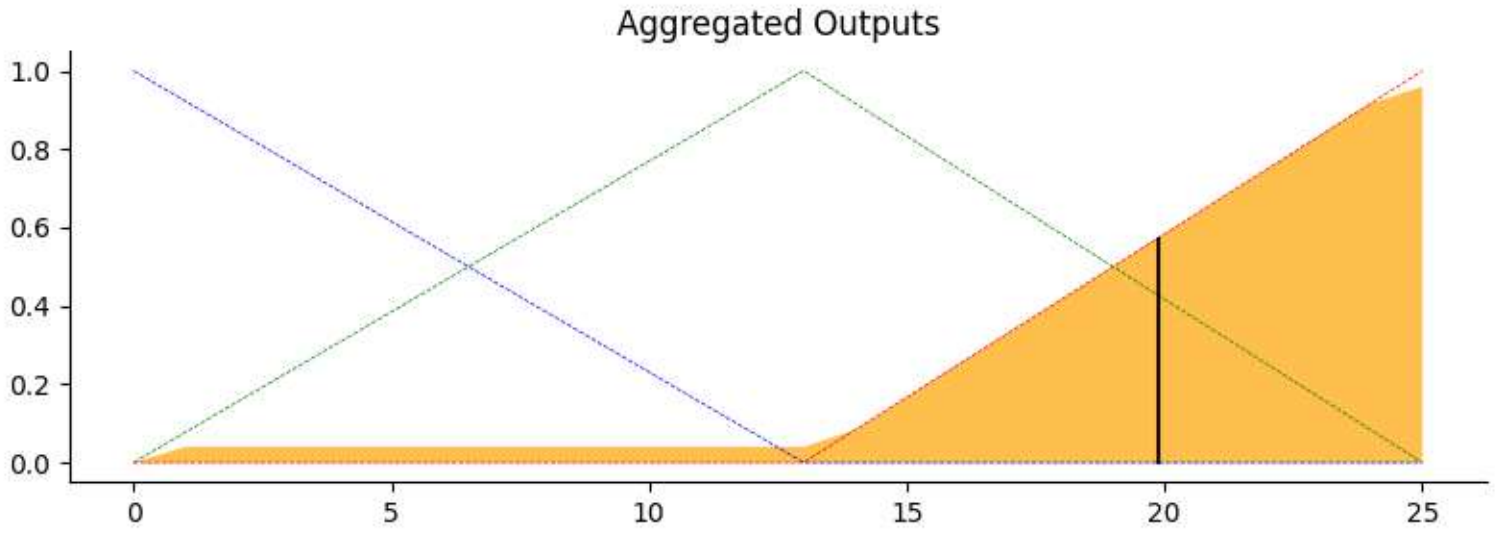
```
19.86871794871795
```

Plot the output

```
tip_activation = fuzz.interp_membership(x_tip, aggregated, tip)  # for plot
tip_activation
```

```
0.5723931623931626
```

```
# Visualize this
fig, ax0 = plt.subplots(figsize=(8, 3))

ax0.plot(x_tip, tip_lo, 'b', linewidth=0.5, linestyle='--', )
ax0.plot(x_tip, tip_md, 'g', linewidth=0.5, linestyle='--')
ax0.plot(x_tip, tip_hi, 'r', linewidth=0.5, linestyle='--')
ax0.fill_between(x_tip, tip0, aggregated, facecolor='Orange', alpha=0.7)
ax0.plot([tip, tip], [0, tip_activation], 'k', linewidth=1.5, alpha=0.9)
ax0.set_title('Aggregated Outputs')

# Turn off top/right axes
for ax in (ax0,):
    ax.spines['top'].set_visible(False)
    ax.spines['right'].set_visible(False)
    ax.get_xaxis().tick_bottom()
    ax.get_yaxis().tick_left()

plt.tight_layout()
```



Control API

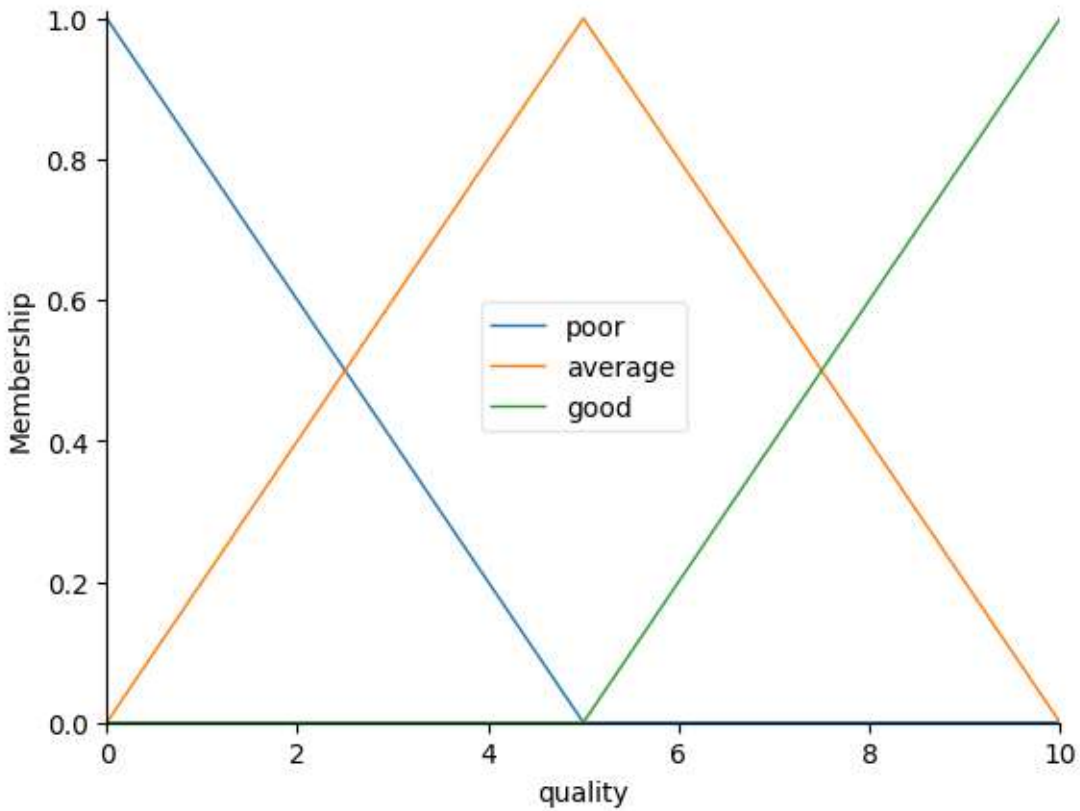
UofD

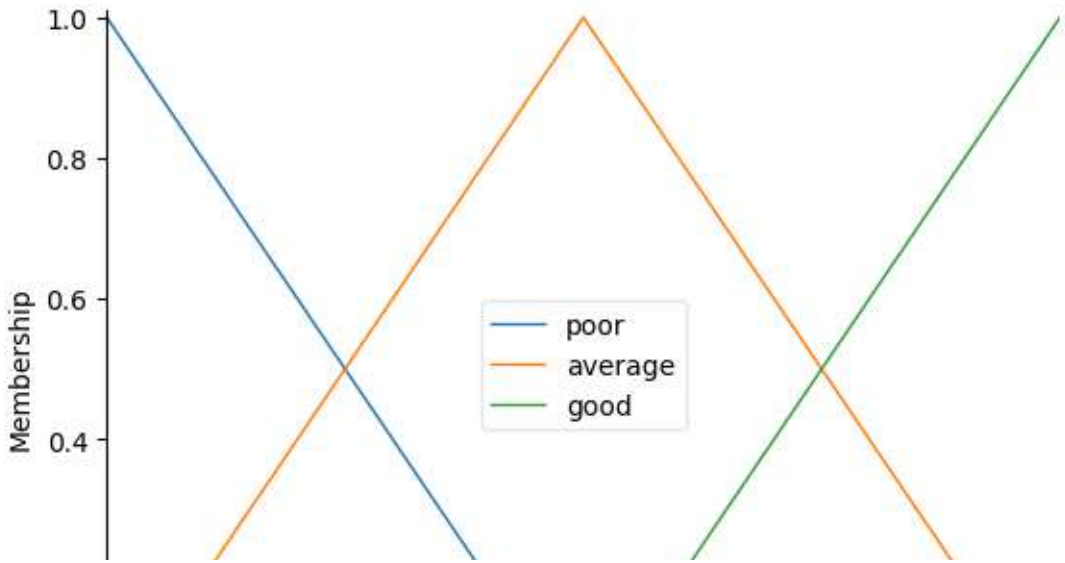
```
from skfuzzy import control as ctrl
# New Antecedent/Consequent objects hold universe variables and membership
# functions
quality = ctrl.Antecedent(np.arange(0, 11, 1), 'quality')
service = ctrl.Antecedent(np.arange(0, 11, 1), 'service')
tip = ctrl.Consequent(np.arange(0, 26, 1), 'tip')
```

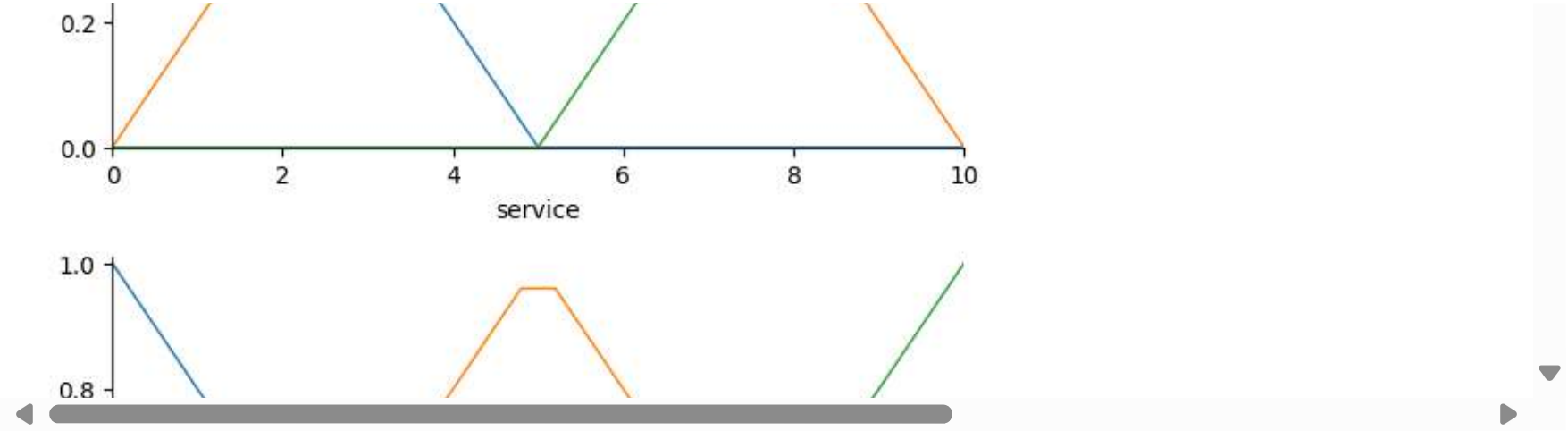
Membership Functions

```
# Auto-membership function population is possible with .automf(3, 5, or 7)
quality.automf(3)
quality.view()
service.automf(3)
service.view()
tip.automf(3)
tip.view()
```

```
c:\Users\sehre\AppData\Local\Programs\Python\Python311\Lib\site-packages\skfuzzy\control\fuzzyvariable.py:122: UserW
  fig.show()
```







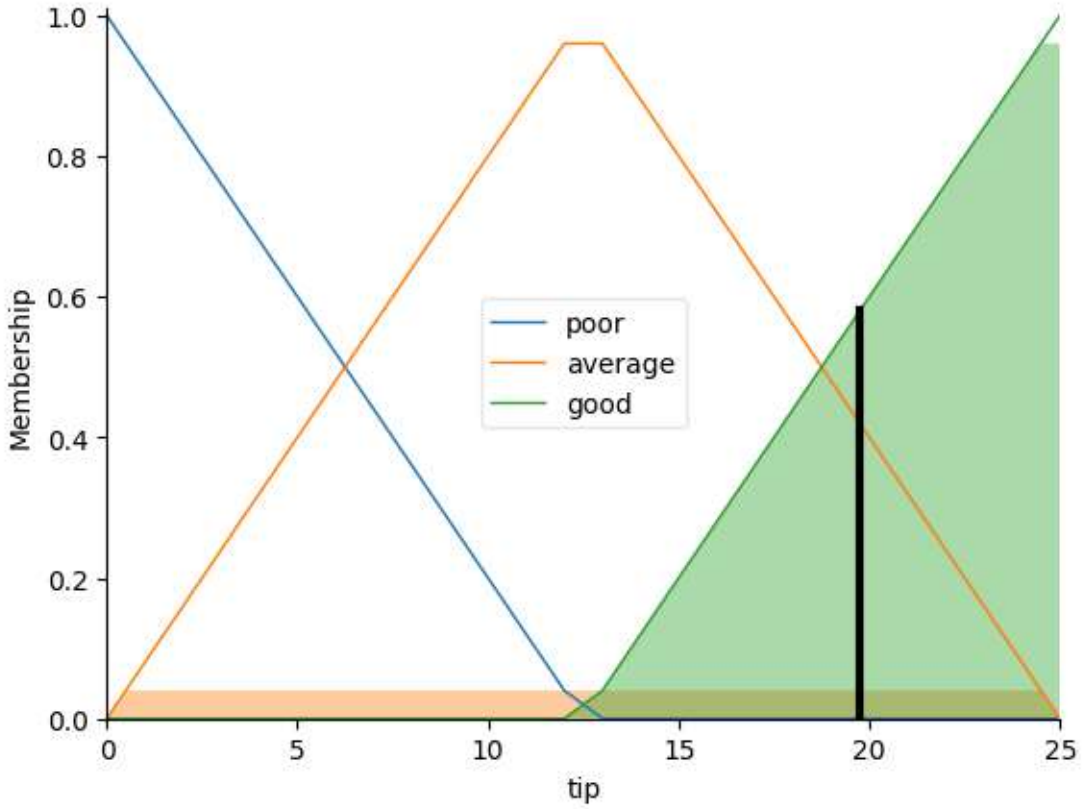
Rules

```
rule1 = ctrl.Rule(quality['poor'] | service['poor'], tip['poor'])
rule2 = ctrl.Rule(service['average'], tip['average'])
rule3 = ctrl.Rule(service['good'] | quality['good'], tip['good'])
```

Control System

```
tipping_ctrl = ctrl.ControlSystem([rule1, rule2, rule3])
tipping = ctrl.ControlSystemSimulation(tipping_ctrl)
tipping.input['quality'] = 6.5
tipping.input['service'] = 9.8

# Crunch the numbers
tipping.compute()
print (tipping.output['tip'])
tip.view(sim=tipping)
```

```
19.76409495548962
```



Write 2 nested for loops :

1. from 0 to 10 with step .5 (20)
2. from 0 to 10 with step .5 (20)

invokes the fuzzy logic and creates the tip amount

df:

foodQ | Service Quality | Tip Payment

0 0 ? 0.5 0.5 ? . . ? . . ? . . ? . . ? . . ?

visualize :

a. scatter plot foodq - servq x, y

b. parallel coordinates - fq, sq, tip

Lab 3 - submit as pdf

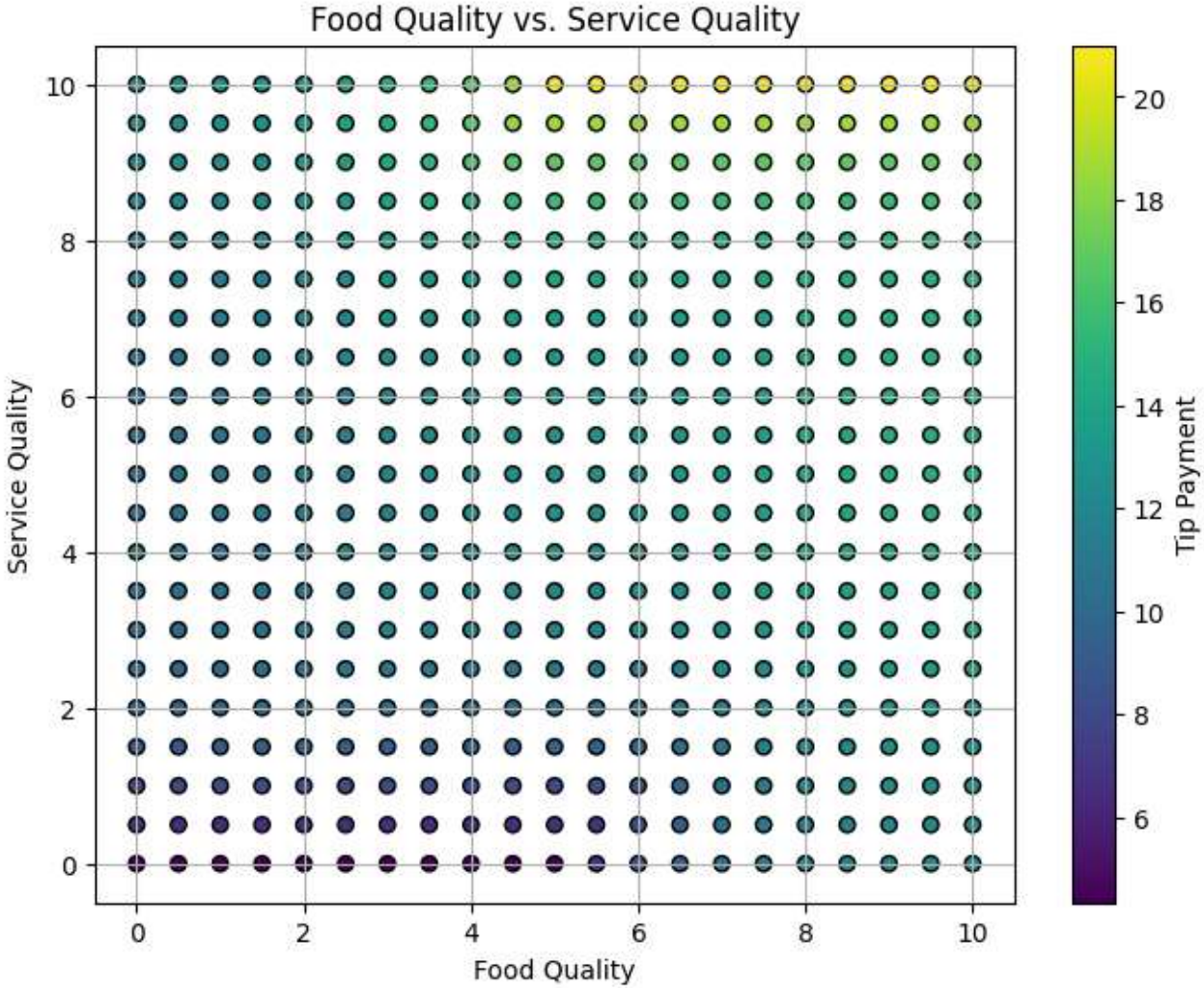
```
print(x_qual)
print(x_serv)
print(x_tip)
```

```
import pandas as pd

results = []
for food_quality in x_qual:
    for service_quality in x_serv:
        # Fuzzification
        qual_level_lo = fuzz.interp_membership(x_qual, qual_lo, food_quality)
        qual_level_md = fuzz.interp_membership(x_qual, qual_md, food_quality)
        qual_level_hi = fuzz.interp_membership(x_qual, qual_hi, food_quality)

        serv_level_lo = fuzz.interp_membership(x_serv, serv_lo, service_quality)
        serv_level_md = fuzz.interp_membership(x_serv, serv_md, service_quality)
        serv_level_hi = fuzz.interp_membership(x_serv, serv_hi, service_quality)

        # Rule Evaluation
        active_rule1 = np.fmax(qual_level_lo, serv_level_lo)
        tip_activation_lo = np.fmin(active_rule1, tip_lo)
        tip_activation_md = np.fmin(serv_level_md, tip_md)

        active_rule3 = np.fmax(qual_level_hi, serv_level_hi)
        tip_activation_hi = np.fmin(active_rule3, tip_hi)
        aggregated = np.fmax(tip_activation_lo, np.fmax(tip_activation_md, tip_activation_hi))
        tip = fuzz.defuzz(x_tip, aggregated, 'centroid')
        results.append([food_quality, service_quality, tip])

df = pd.DataFrame(results, columns=['Food Quality', 'Service Quality', 'Tip Payment'])

print(df)
```

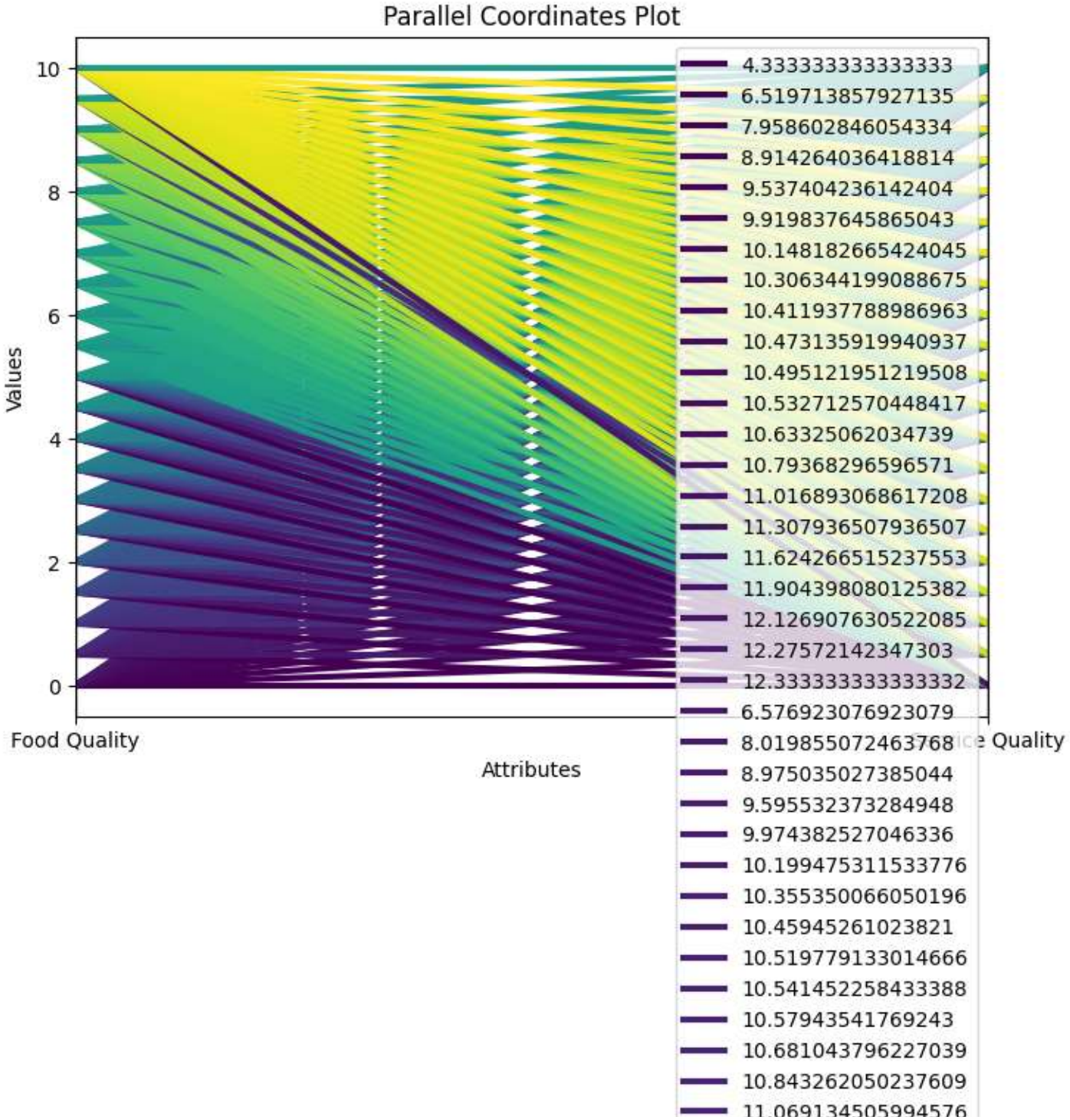
```
     Food Quality  Service Quality  Tip Payment
0             0.0              0.0     4.333333
1             0.0              0.5     6.519714
2             0.0              1.0     7.958603
3             0.0              1.5     8.914264
4             0.0              2.0     9.537404
..            ...              ...          ...
436          10.0              8.0    15.475674
437          10.0              8.5    16.063443
438          10.0              9.0    17.028537
439          10.0              9.5    18.551942
```

```
     440          10.0             10.0    21.000000

     [441 rows x 3 columns]
```

```
import matplotlib.pyplot as plt
from pandas.plotting import parallel_coordinates

# Scatter plot of Food Quality vs. Service Quality
plt.figure(figsize=(8, 6))
plt.scatter(df['Food Quality'], df['Service Quality'], c=df['Tip Payment'], cmap='viridis', edgecolor='k')
plt.colorbar(label='Tip Payment')
plt.xlabel('Food Quality')
plt.ylabel('Service Quality')
plt.title('Food Quality vs. Service Quality')
plt.grid(True)
plt.show()
```




```
# Parallel coordinates plot
plt.figure(figsize=(8, 6))
parallel_coordinates(df, 'Tip Payment', colormap='viridis', linewidth=3)
plt.xlabel('Attributes')
plt.ylabel('Values')
plt.title('Parallel Coordinates Plot')
plt.grid(False)
plt.show()
```


Parallel Coordinates Plot
Values
Attributes
Food Quality
4.333333333333333
6.519713857927135
7.958602846054334
8.914264036418814
9.537404236142404
9.919837645865043
10.148182665424045
10.306344199088675
10.411937788986963
10.473135919940937
10.495121951219508
10.532712570448417
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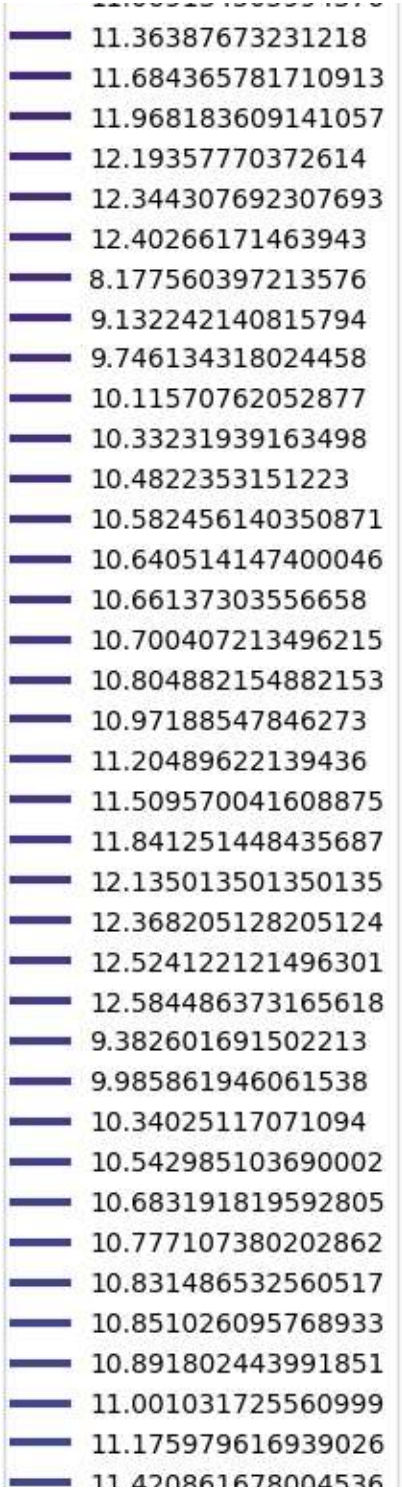
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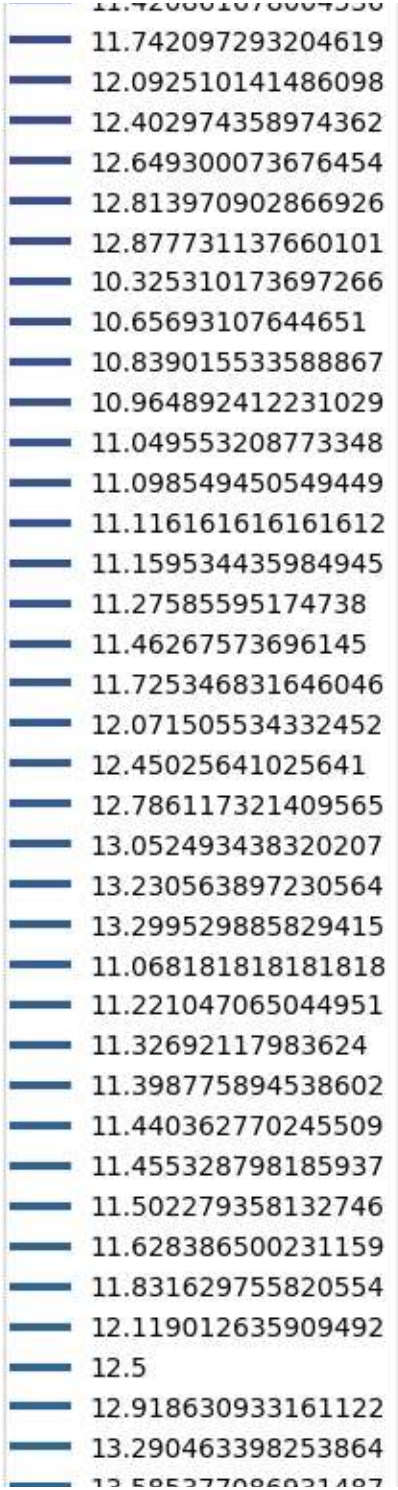
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