UNIVERSITY OF MUMBAI

DEPARTMENT OF COMPUTER SCIENCE

मुंबई विद्यापीठ

University of Mumbai

Re-accredited with A++ Grade

(CGPA 3.65) by NAAC (3rd Cycle 2021)

M.Sc. Computer Science – Semester III

Fuzzy Systems

JOURNAL

2024-2025

Seat No. ____________________

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CERTIFICATE

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Subject In-charge

____

Head of Department

____

External Examiner

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Note : Install necessary python modules with “pip install scikit-fuzzy numpy matplotlib scipy networkx” command.

Practical - 1

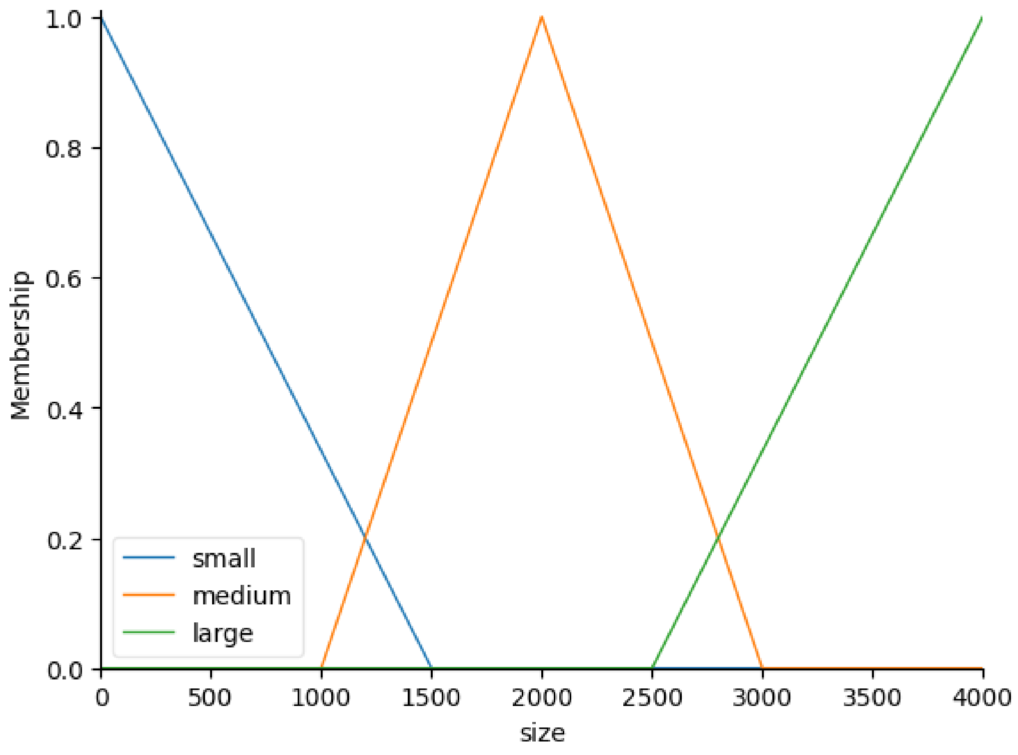
Aim: Develop a Fuzzy Sets model for House Pricing example

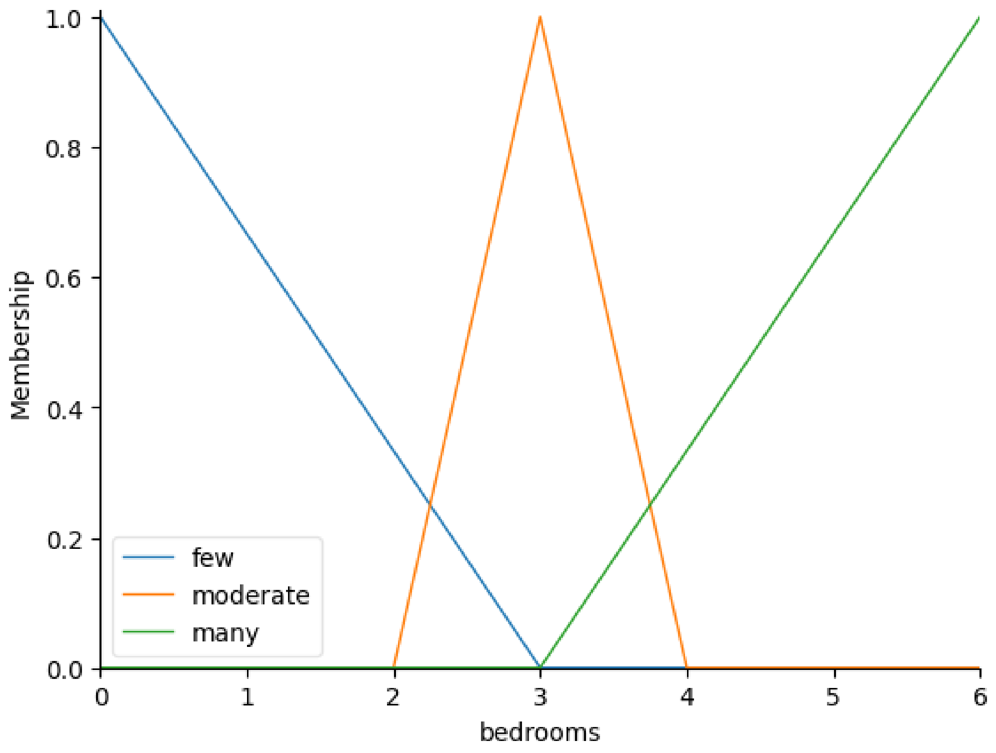
Program:

```
import numpy as np
import skfuzzy as fuzz
from skfuzzy import control as ctrl
import matplotlib.pyplot as plt
# Define input variables (antecedents) and output (consequent)
size = ctrl.Antecedent(np.arange(0, 4001, 1), 'size')  # 0-4000 sq.ft
bedrooms = ctrl.Antecedent(np.arange(0, 7, 1), 'bedrooms')  # 0-6 bedrooms
location = ctrl.Antecedent(np.arange(0, 1.1, 0.1), 'location')  # 0 (rural) to 1 (urban)
price = ctrl.Consequent(np.arange(100000, 800001, 1000), 'price')  # $100k-$800k
# Define fuzzy membership functions
# --------------------------------------------------------------------
# Size: small, medium, large
size['small'] = fuzz.trimf(size.universe, [0, 0, 1500])
size['medium'] = fuzz.trimf(size.universe, [1000, 2000, 3000])
size['large'] = fuzz.trimf(size.universe, [2500, 4000, 4000])
# Bedrooms: few, moderate, many
bedrooms['few'] = fuzz.trimf(bedrooms.universe, [0, 0, 3])
bedrooms['moderate'] = fuzz.trimf(bedrooms.universe, [2, 3, 4])
bedrooms['many'] = fuzz.trimf(bedrooms.universe, [3, 6, 6])
# Location: rural, suburban, urban
location['rural'] = fuzz.trimf(location.universe, [0, 0, 0.4])
location['suburban'] = fuzz.trimf(location.universe, [0.3, 0.5, 0.7])
location['urban'] = fuzz.trimf(location.universe, [0.6, 1, 1])
# Price: low, medium, high
price['low'] = fuzz.trimf(price.universe, [100000, 100000, 350000])
price['medium'] = fuzz.trimf(price.universe, [250000, 450000, 650000])
price['high'] = fuzz.trimf(price.universe, [500000, 800000, 800000])
Visualize membership functions (optional)
size.view()
bedrooms.view()
location.view()
price.view()
plt.show()
# Define fuzzy rules
# --------------------------------------------------------------------
rule1 = ctrl.Rule(
    size['small'] & bedrooms['few'] & location['rural'],
    price['low']
)
rule2 = ctrl.Rule(
    size['medium'] & bedrooms['moderate'] & location['suburban'],
    price['medium']
)
rule3 = ctrl.Rule(
    size['large'] & bedrooms['many'] & location['urban'],
    price['high']
)
rule4 = ctrl.Rule(
    size['medium'] & bedrooms['moderate'] & location['urban'],
    price['high']
)
# Create control system
```

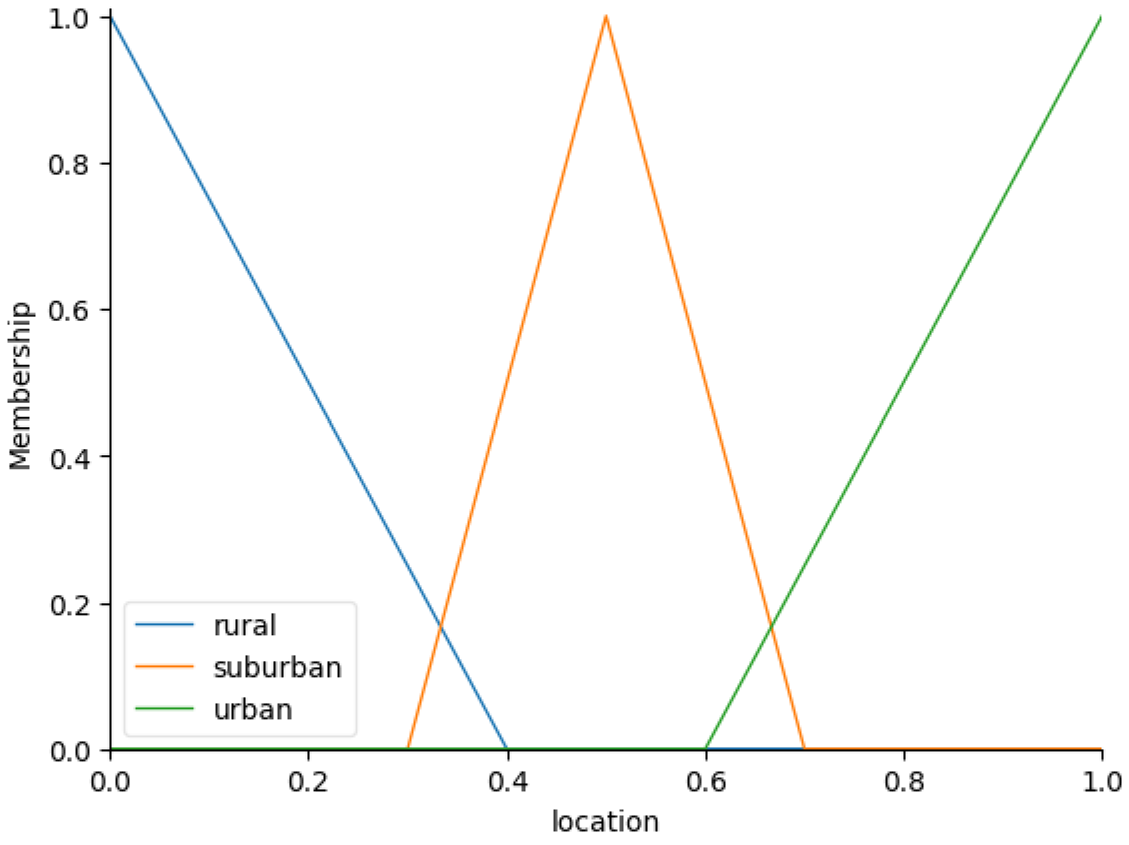
```
price_ctrl = ctrl.ControlSystem([rule1, rule2, rule3, rule4])
pricing = ctrl.ControlSystemSimulation(price_ctrl)
# Set input values and compute
# -------------------------------------------------------------------
pricing.input['size'] = 1200     # 1200 sq.ft
pricing.input['bedrooms'] = 3    # 3 bedrooms
pricing.input['location'] = 0.5  # Suburban (0.5)
pricing.compute()
# Print output
print("Estimated Price: $%.2f" % pricing.output['price'])
 price.view(sim=pricing)
 plt.show()
```

Output:

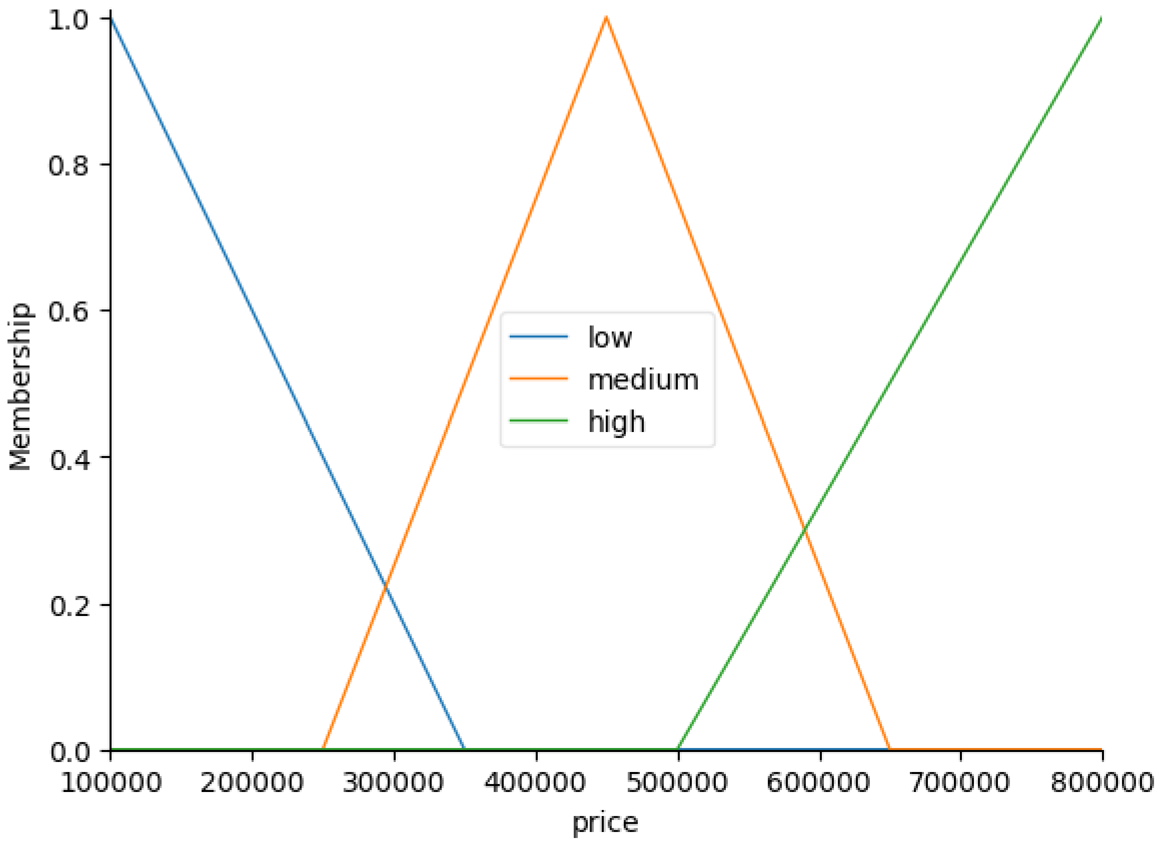




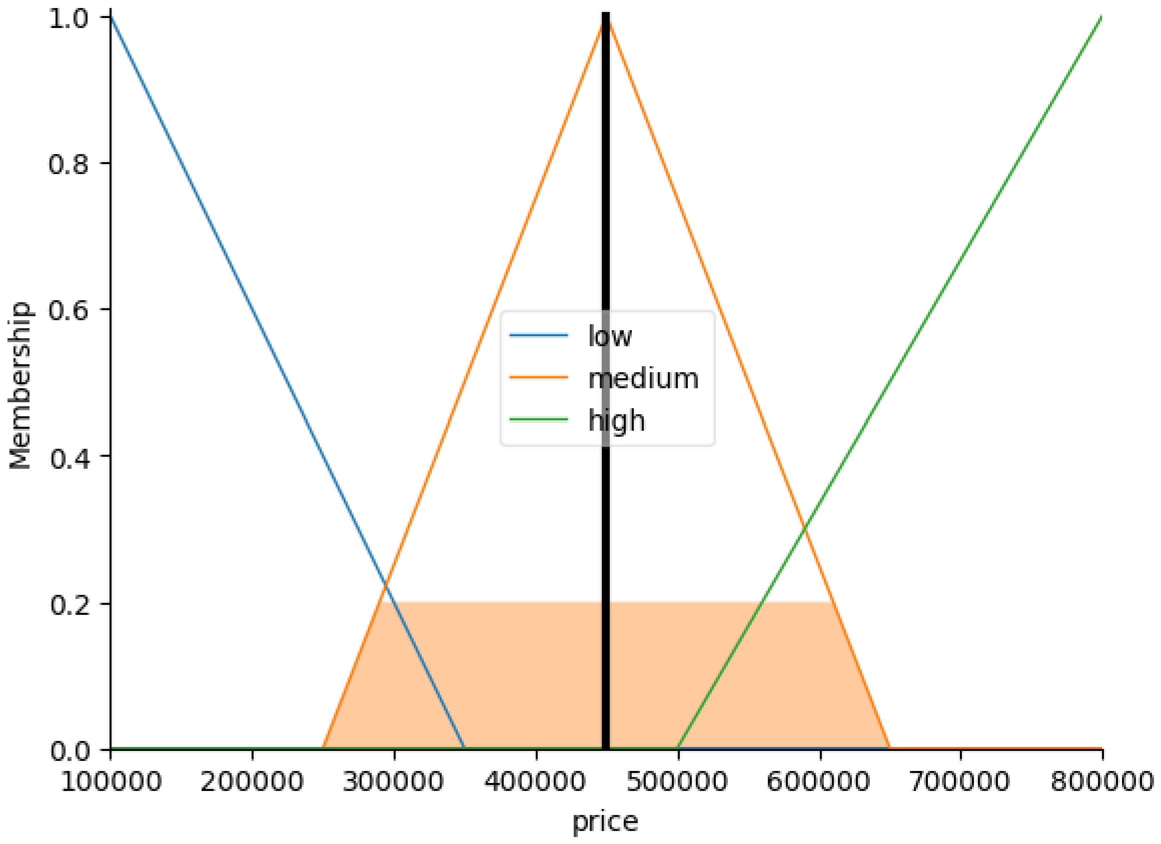
1.0
0.8
0.6
0.4
0.2
0.0
Membership
0
1
2
3
4
5
6
bedrooms
few
moderate
many



1.0
0.8
0.6
0.4
0.2
0.0
Membership
0.0
0.2
0.4
0.6
0.8
1.0
location
rural
suburban
urban



```
Estimated Price: $450000.00
```



Practical - 2

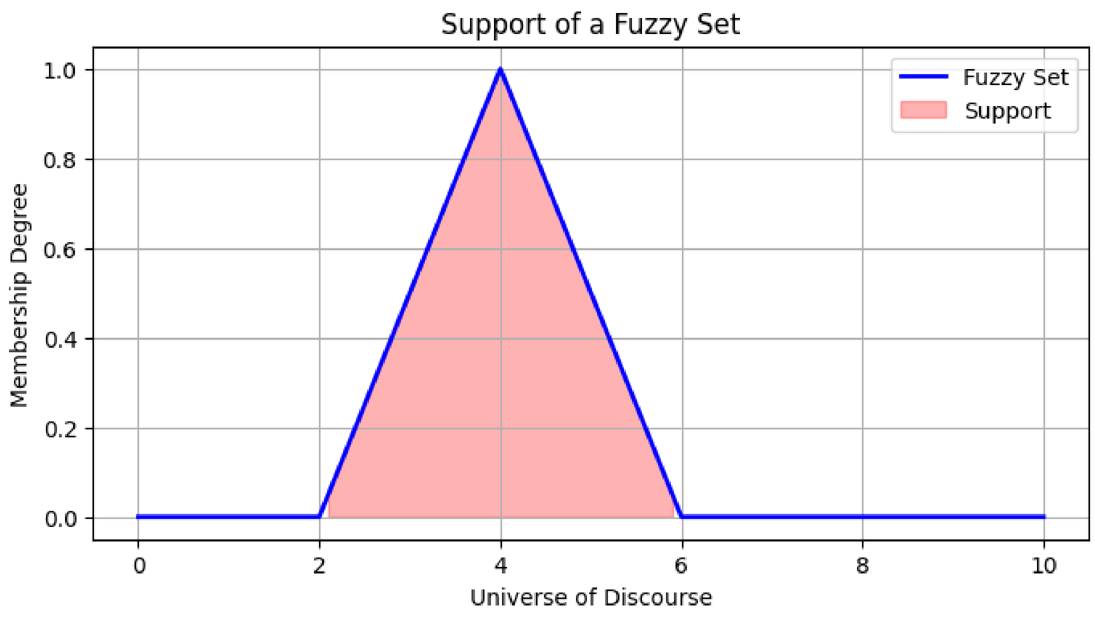
Aim: Calculate support in fuzzy logic.

Program:

```
import numpy as np
import skfuzzy as fuzz
import matplotlib.pyplot as plt
# Define the universe of discourse (e.g., house sizes from 0 to 10)
universe = np.arange(0, 10.1, 0.1)
# Create a triangular fuzzy set (membership function)
membership = fuzz.trimf(universe, [2, 4, 6])
# Calculate the support (elements where membership > 0)
support = universe[membership > 0]
# Print the support range
print("Support of the fuzzy set:")
print(f"Start: {support[0]:.1f}, End: {support[-1]:.1f}")
print("All support points:", np.round(support, 1))
# Plot the fuzzy set and highlight the support
plt.figure(figsize=(8, 4))
plt.plot(universe, membership, 'b', linewidth=2, label='Fuzzy Set')
plt.fill_between(support, membership[membership > 0], color='red', alpha=0.3, label='Support')
plt.xlabel('Universe of Discourse')
plt.ylabel('Membership Degree')
plt.title('Support of a Fuzzy Set')
plt.legend()
plt.grid(True)
plt.show()
```

Output:

```
Support of the fuzzy set:
Start: 2.1, End: 5.9
All support points: [2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.  3.1 3.2 3.3 3.4 3.5 3.6 3.7 3.8 3.9 4.  4.1 4.2
 4.3 4.4 4.5 4.6 4.7 4.8 4.9 5.  5.1 5.2 5.3 5.4 5.5 5.6 5.7 5.8 5.9]
```



Practical - 3

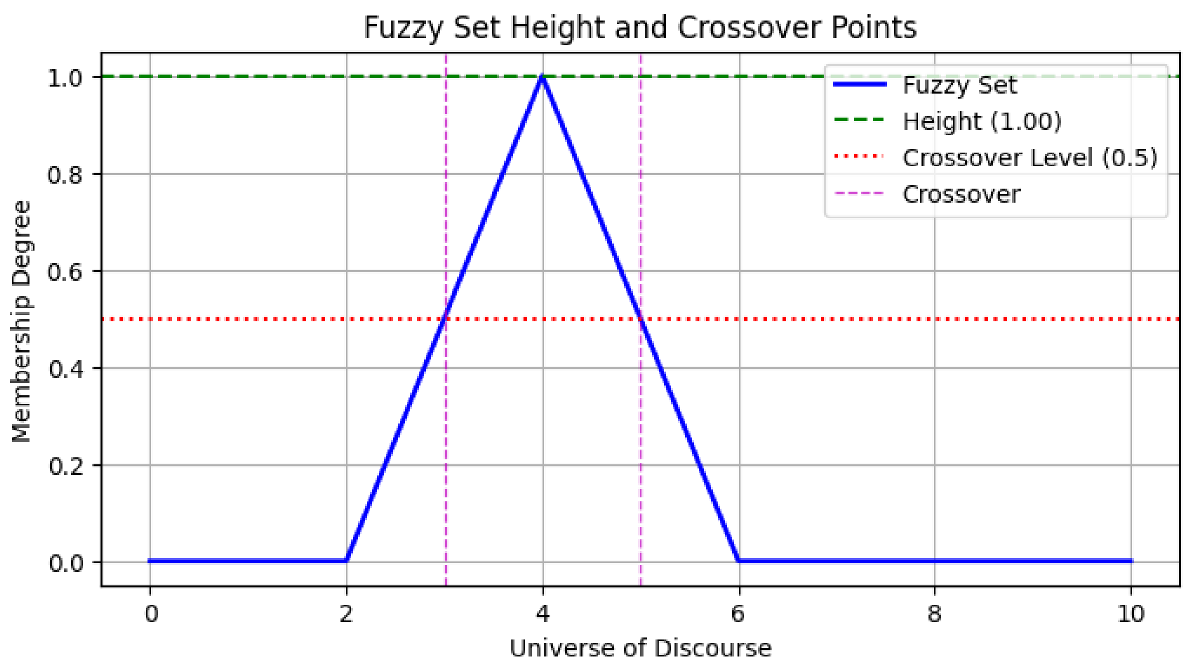
Aim: Calculate height and cross over in Fuzzy.

Program:

```
import numpy as np
import skfuzzy as fuzz
import matplotlib.pyplot as plt
# Define the universe of discourse (e.g., house sizes from 0 to 10)
universe = np.arange(0, 10.01, 0.01)
# Create a triangular fuzzy set (membership function)
membership = fuzz.trimf(universe, [2, 4, 6])  # Parameters: left, peak, right
# Calculate height (maximum membership value)
height = np.max(membership)
print(f"Height of the fuzzy set: {height:.2f}")
# Calculate crossover points (where membership = 0.5)
crossovers = []
diff = membership - 0.5  # Difference from 0.5
# Detect sign changes in the difference array
for i in range(len(universe) - 1):
    if diff[i] * diff[i+1] <= 0:  # Sign change or exact zero
        x1, x2 = universe[i], universe[i+1]
        m1, m2 = membership[i], membership[i+1]
        # Linear interpolation to find exact crossover
        if m1 != m2:  # Avoid division by zero
            x_cross = x1 + (0.5 - m1) * (x2 - x1) / (m2 - m1)
            crossovers.append(x_cross)
        else:
            # Handle flat regions (membership constant at 0.5)
            if np.isclose(m1, 0.5):
                crossovers.extend([x1, x2])
# Remove duplicates and sort
crossovers = sorted(list(set(crossovers)))
print("Crossover points:", np.round(crossovers, 2))
# Plot the fuzzy set, height, and crossover points
plt.figure(figsize=(8, 4))
plt.plot(universe, membership, 'b', linewidth=2, label='Fuzzy Set')
plt.axhline(y=height, color='g', linestyle='--', label=f'Height ({height:.2f})')
plt.axhline(y=0.5, color='r', linestyle=':', label='Crossover Level (0.5)')
for x in crossovers:
    plt.axvline(x=x, color='m', linestyle='--', linewidth=1, alpha=0.7, label='Crossover' if x ==
crossovers[0] else "")
plt.xlabel('Universe of Discourse')
plt.ylabel('Membership Degree')
plt.title('Fuzzy Set Height and Crossover Points')
plt.legend()
plt.grid(True)
plt.show()
```

Output:

```
Height of the fuzzy set: 1.00
Crossover points: [3. 5.]
```



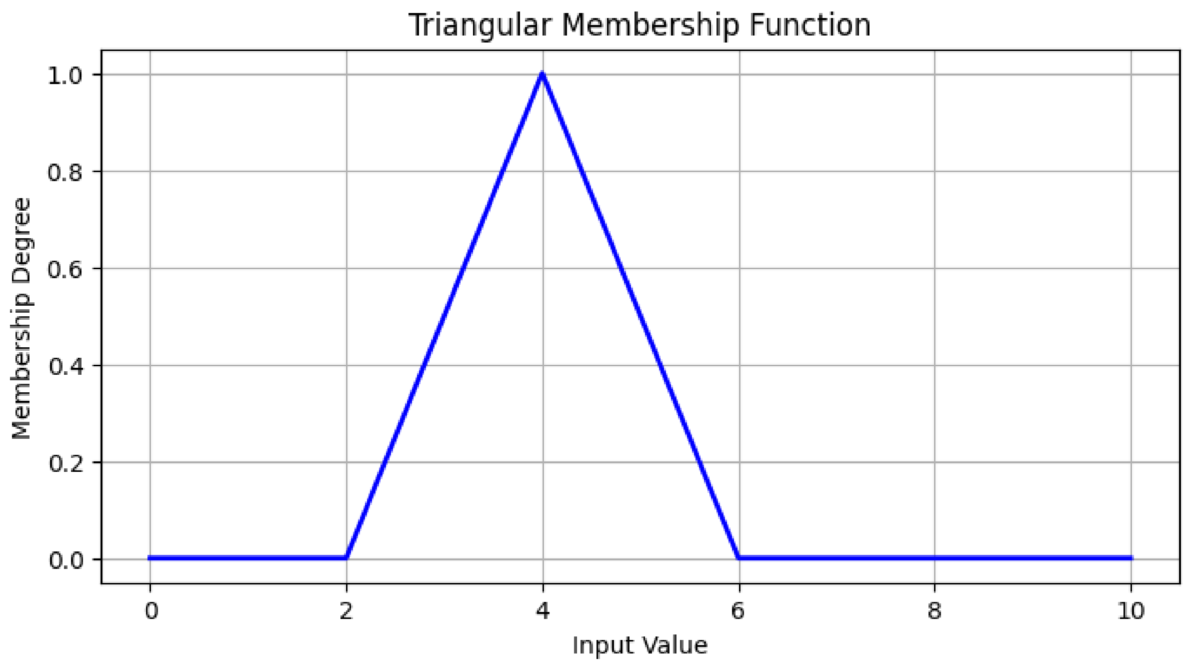
Practical – 4

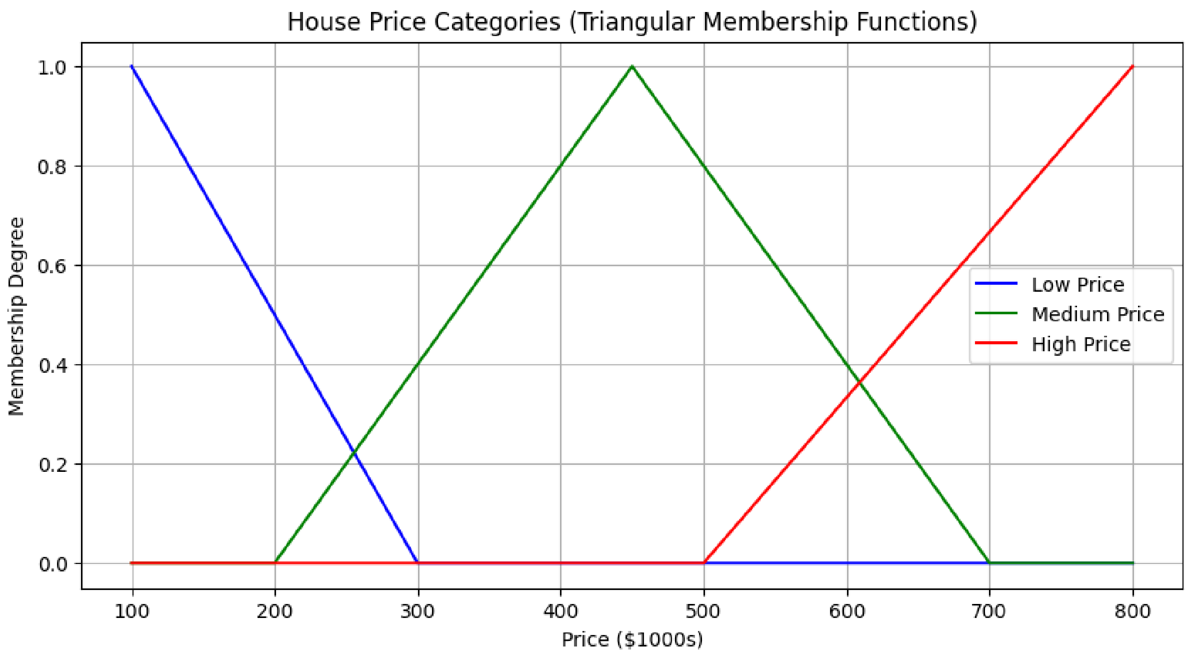
Aim: Create a triangular function using trimf.

Program:

```
import numpy as np
import skfuzzy as fuzz
import matplotlib.pyplot as plt
# Define the universe of discourse (input range)
universe = np.arange(0, 10.1, 0.1)  # 0 to 10 in steps of 0.1
# Create a triangular membership function
# Parameters: [left-foot, peak, right-foot]
triangular_mf = fuzz.trimf(universe, [2, 4, 6])
# Plot the membership function
plt.figure(figsize=(8, 4))
plt.plot(universe, triangular_mf, 'b', linewidth=2)
plt.title('Triangular Membership Function')
plt.xlabel('Input Value')
plt.ylabel('Membership Degree')
plt.grid(True)
plt.show()
# Define universe (house prices in thousands)
price_universe = np.arange(100, 801, 1)  # $100k to $800k
# Create triangular membership functions
low_price = fuzz.trimf(price_universe, [100, 100, 300])    # Low price
medium_price = fuzz.trimf(price_universe, [200, 450, 700]) # Medium price
high_price = fuzz.trimf(price_universe, [500, 800, 800])   # High price
# Plot all membership functions
plt.figure(figsize=(10, 5))
plt.plot(price_universe, low_price, 'b', label='Low Price')
plt.plot(price_universe, medium_price, 'g', label='Medium Price')
plt.plot(price_universe, high_price, 'r', label='High Price')
plt.title('House Price Categories (Triangular Membership Functions)')
plt.xlabel('Price ($1000s)')
plt.ylabel('Membership Degree')
plt.legend()
plt.grid(True)
plt.show()
```

Output:


Triangular Membership Function
1.0
0.8
0.6
0.4
0.2
0.0
Membership Degree
0
2
4
6
8
10
Input Value


House Price Categories (Triangular Membership Functions)
1.0
0.8
0.6
0.4
0.2
0.0
Membership Degree
100
200
300
400
500
600
700
800
Price ($1000s)
Low Price
Medium Price
High Price

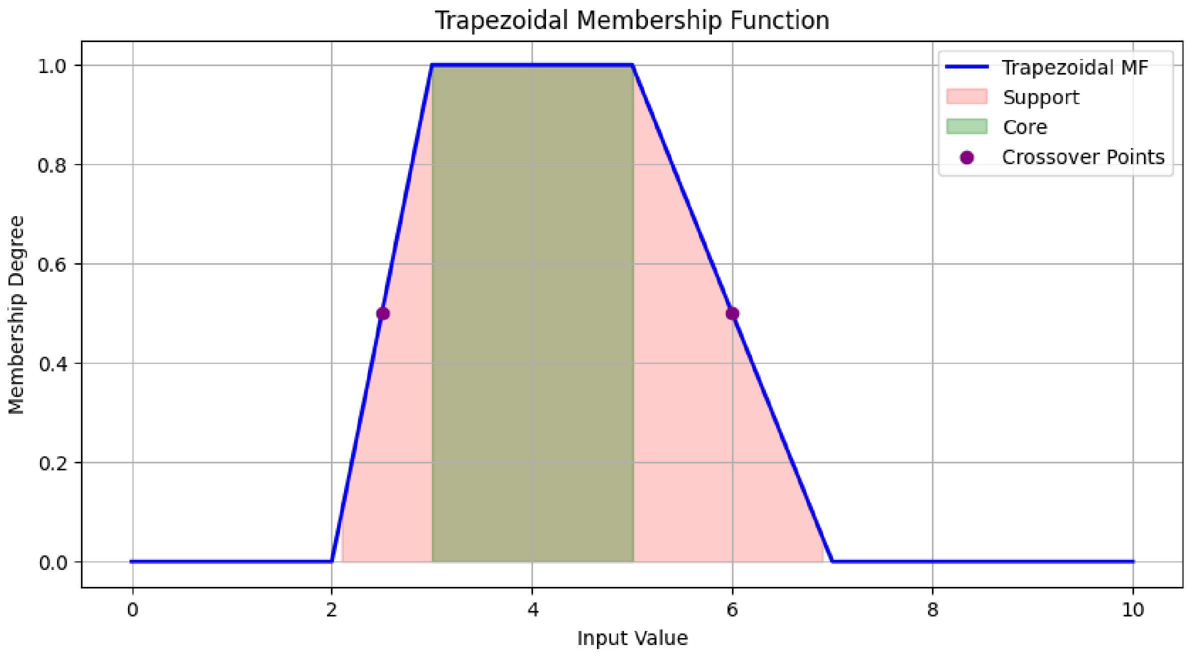
Practical - 5

Aim: Implement fuzzy_trapezodial_membership-function

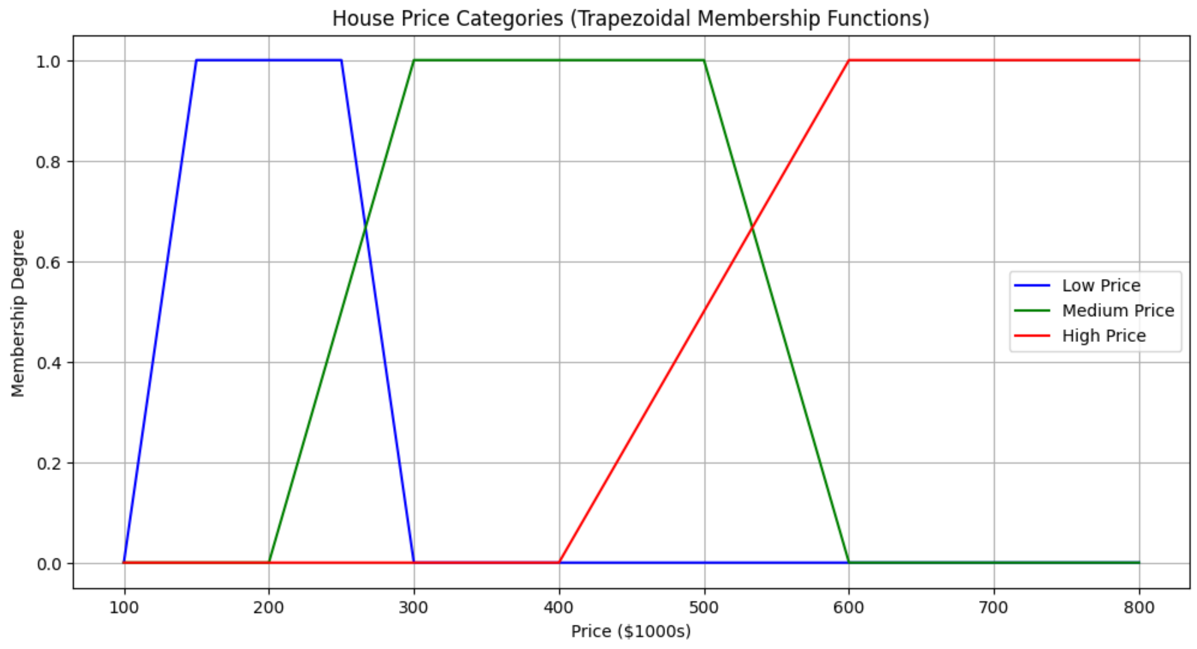
Program:

```
import numpy as np
import skfuzzy as fuzz
import matplotlib.pyplot as plt
# Define the universe of discourse (input range)
universe = np.arange(0, 10.1, 0.1)  # 0 to 10 in steps of 0.1
# Create a trapezoidal membership function
# Parameters: [left_foot, left_shoulder, right_shoulder, right_foot]
trapezoidal_mf = fuzz.trapmf(universe, [2, 3, 5, 7])
# Calculate properties
support = universe[trapezoidal_mf > 0]          # All points with membership > 0
core = universe[trapezoidal_mf == 1]            # All points with membership = 1
crossovers = universe[np.isclose(trapezoidal_mf, 0.5, atol=0.01)]  # Points ≈ 0.5
# Plot the membership function
plt.figure(figsize=(10, 5))
plt.plot(universe, trapezoidal_mf, 'b', linewidth=2, label='Trapezoidal MF')
plt.fill_between(support, trapezoidal_mf[trapezoidal_mf > 0], color='red', alpha=0.2, label='Support')
plt.fill_between(core, 1, color='green', alpha=0.3, label='Core')
plt.scatter(crossovers, [0.5]*len(crossovers), color='purple', zorder=5, label='Crossover Points')
plt.title('Trapezoidal Membership Function')
plt.xlabel('Input Value')
plt.ylabel('Membership Degree')
plt.legend()
plt.grid(True)
plt.show()
# Print properties
print("Support:", np.round(support[[0, -1]], 2))
print("Core:", np.round(core[[0, -1]], 2))
print("Crossover Points:", np.round(crossovers, 2))
# Define universe (house prices in $1000s)
price_universe = np.arange(100, 801, 1)
# Create trapezoidal membership functions
low_price = fuzz.trapmf(price_universe, [100, 150, 250, 300])
medium_price = fuzz.trapmf(price_universe, [200, 300, 500, 600])
high_price = fuzz.trapmf(price_universe, [400, 600, 800, 800])
# Plot all membership functions
plt.figure(figsize=(12, 6))
plt.plot(price_universe, low_price, 'b', label='Low Price')
plt.plot(price_universe, medium_price, 'g', label='Medium Price')
plt.plot(price_universe, high_price, 'r', label='High Price')
plt.title('House Price Categories (Trapezoidal Membership Functions)')
plt.xlabel('Price ($1000s)')
plt.ylabel('Membership Degree')
plt.legend()
plt.grid(True)
plt.show()
```

Output:



```
Support: [2.1 6.9]
Core: [3. 5.]
Crossover Points: [2.5 6. ]
```



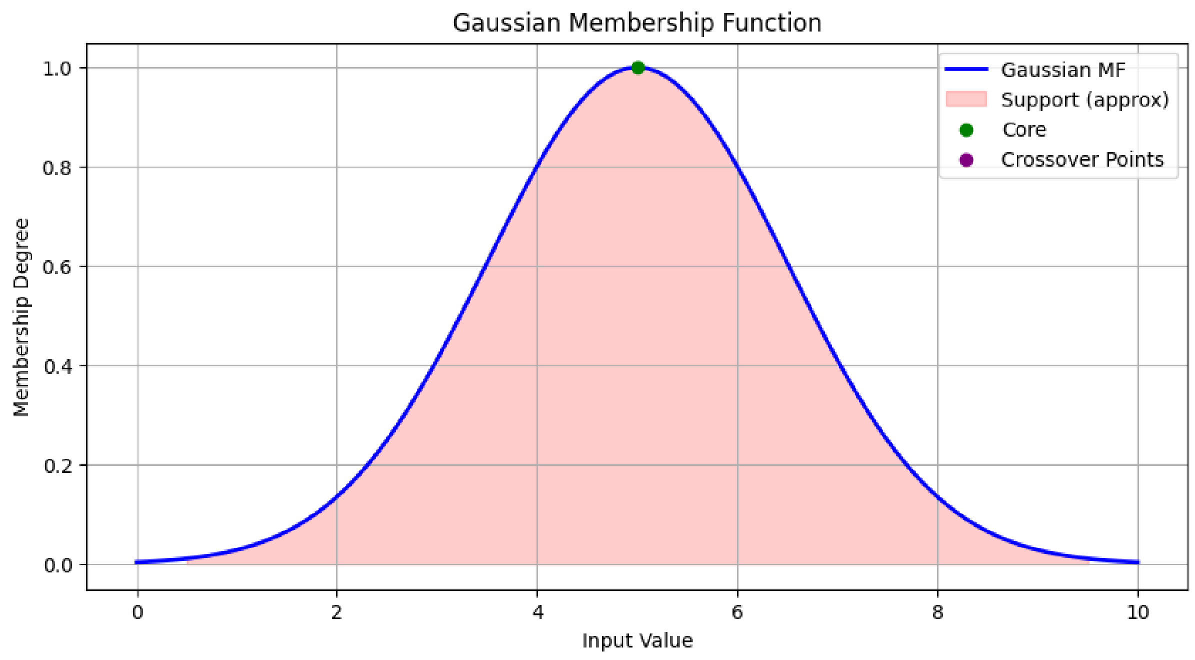
Practical - 6

Aim: Implement fuzzy_gaussian_membership_function

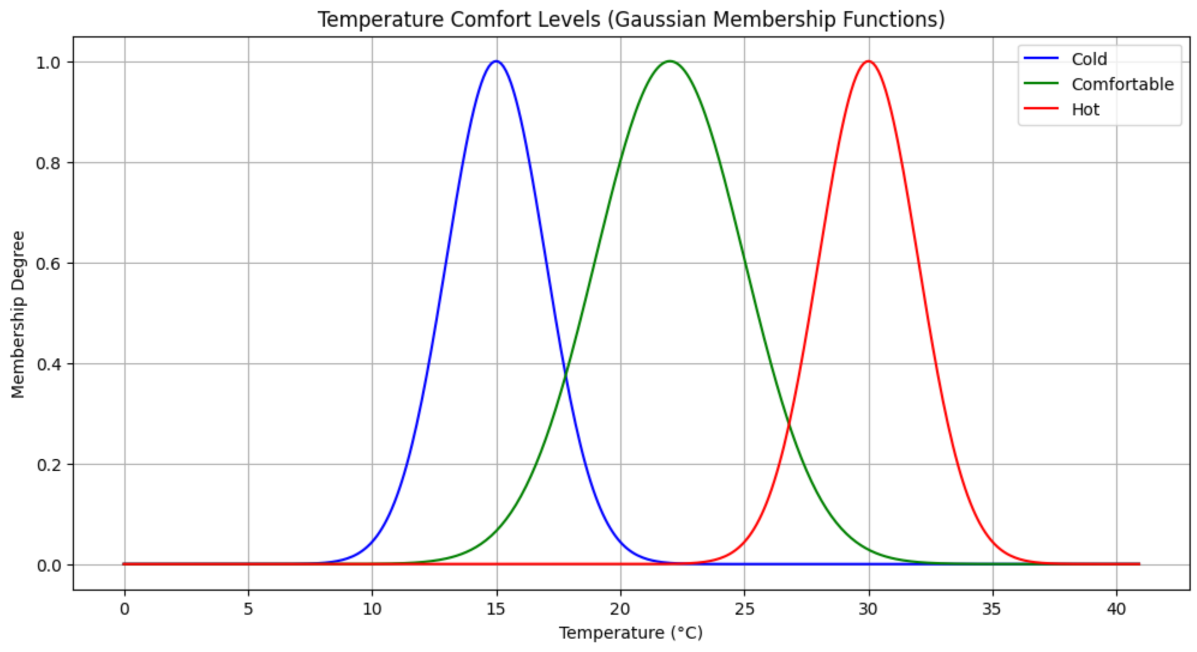
Program:

```
import numpy as np
import skfuzzy as fuzz
import matplotlib.pyplot as plt
# Define the universe of discourse (input range)
universe = np.arange(0, 10.1, 0.1)  # 0 to 10 in steps of 0.1
# Create a Gaussian membership function
# Parameters: [mean (center), sigma (spread)]
mean = 5.0    # Center of the Gaussian
sigma = 1.5   # Width (spread) of the curve
gaussian_mf = fuzz.gaussmf(universe, mean, sigma)
# Calculate properties
support = universe[gaussian_mf > 0.01]          # Approximate support (μ > 0.01)
core = universe[np.isclose(gaussian_mf, 1.0)]   # Core (μ = 1.0)
crossovers = universe[np.isclose(gaussian_mf, 0.5, atol=0.01)]  # μ ≈ 0.5
# Plot the membership function
plt.figure(figsize=(10, 5))
plt.plot(universe, gaussian_mf, 'b', linewidth=2, label='Gaussian MF')
plt.fill_between(support, gaussian_mf[gaussian_mf > 0.01], color='red', alpha=0.2, label='Support
(approx)')
plt.scatter(core, [1.0]*len(core), color='green', zorder=5, label='Core')
plt.scatter(crossovers, [0.5]*len(crossovers), color='purple', zorder=5, label='Crossover Points')
plt.title('Gaussian Membership Function')
plt.xlabel('Input Value')
plt.ylabel('Membership Degree')
plt.legend()
plt.grid(True)
plt.show()
# Print properties
print("Mean (Center):", mean)
print("Sigma (Spread):", sigma)
print("Crossover Points:", np.round(crossovers, 2))
# Define universe (temperature in °C)
temp_universe = np.arange(0, 41, 0.1)
# Create Gaussian membership functions
cold = fuzz.gaussmf(temp_universe, 15, 2)
comfortable = fuzz.gaussmf(temp_universe, 22, 3)
hot = fuzz.gaussmf(temp_universe, 30, 2)
# Plot all membership functions
plt.figure(figsize=(12, 6))
plt.plot(temp_universe, cold, 'b', label='Cold')
plt.plot(temp_universe, comfortable, 'g', label='Comfortable')
plt.plot(temp_universe, hot, 'r', label='Hot')
plt.title('Temperature Comfort Levels (Gaussian Membership Functions)')
plt.xlabel('Temperature (°C)')
plt.ylabel('Membership Degree')
plt.legend()
plt.grid(True)
plt.show()
```

Output:



```
Mean (Center): 5.0
Sigma (Spread): 1.5
Crossover Points: []
```



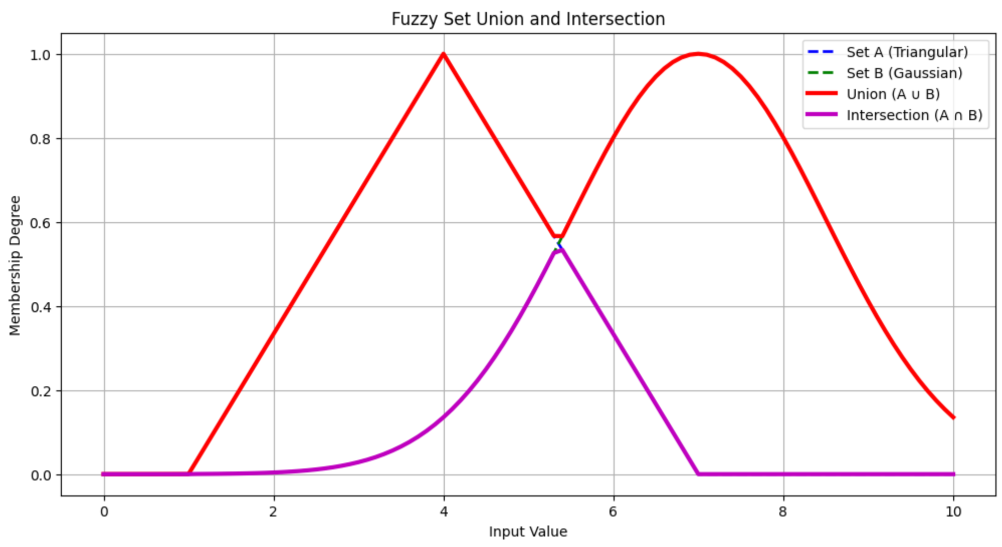
Practical - 7

Aim: Implement Fuzzy Sets Union Intersection

Program:

```
import numpy as np
import matplotlib.pyplot as plt
# Define the universe of discourse (input range)
universe = np.arange(0, 10.1, 0.1)  # 0 to 10 in steps of 0.1
# Create two fuzzy sets (membership functions)
# -------------------------------------------
# Fuzzy Set A: Triangular membership function
set_A = np.clip(1 - np.abs(universe - 4) / 3, 0, 1)  # Peak at 4, width 3
# Fuzzy Set B: Gaussian membership function
set_B = np.exp(-(universe - 7)**2 / (2 * 1.5**2))  # Mean=7, sigma=1.5
# Fuzzy Union (A ∪ B) = max(A, B)
fuzzy_union = np.maximum(set_A, set_B)
# Fuzzy Intersection (A ∩ B) = min(A, B)
fuzzy_intersection = np.minimum(set_A, set_B)
# Plot the results
# -------------------------------------------
plt.figure(figsize=(12, 6))
# Plot Fuzzy Set A and B
plt.plot(universe, set_A, 'b--', linewidth=2, label='Set A (Triangular)')
plt.plot(universe, set_B, 'g--', linewidth=2, label='Set B (Gaussian)')
# Plot Union and Intersection
plt.plot(universe, fuzzy_union, 'r', linewidth=3, label='Union (A ∪ B)')
plt.plot(universe, fuzzy_intersection, 'm', linewidth=3, label='Intersection (A ∩ B)')
plt.title('Fuzzy Set Union and Intersection')
plt.xlabel('Input Value')
plt.ylabel('Membership Degree')
plt.legend()
plt.grid(True)
plt.show()
```

Output:



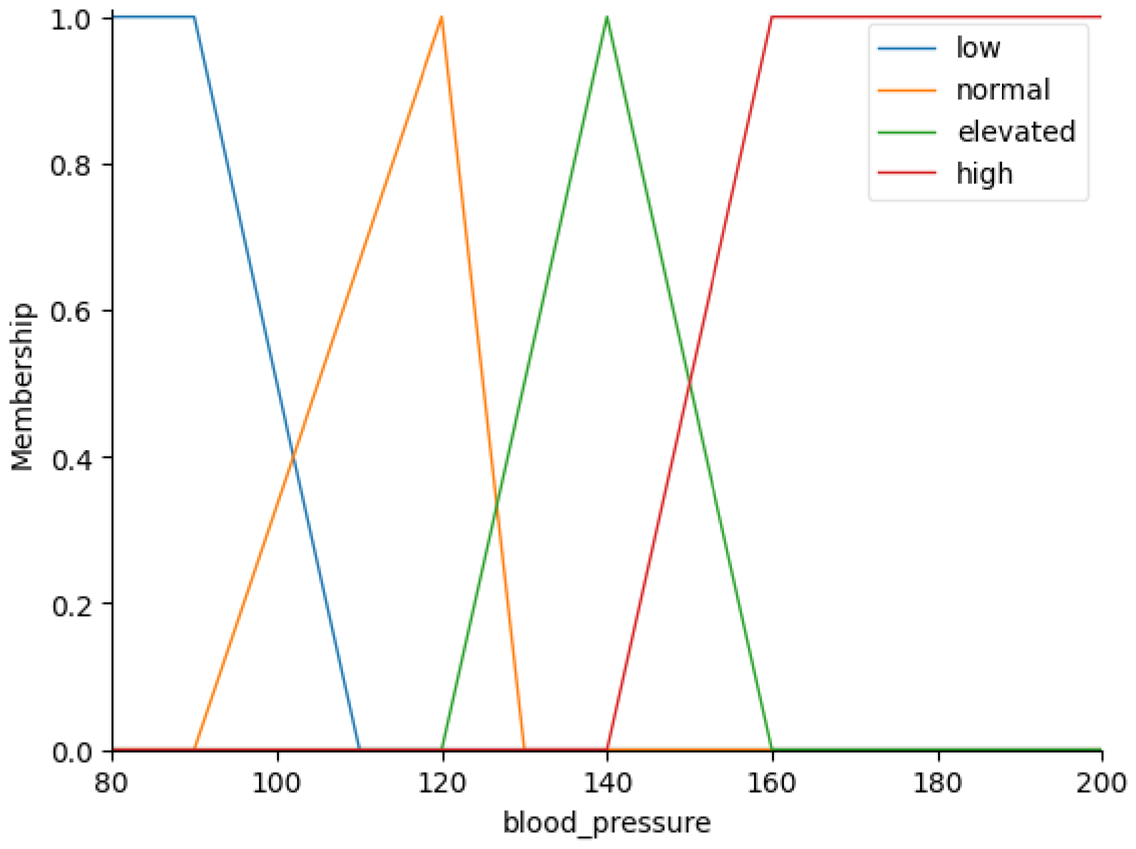
Practical - 8

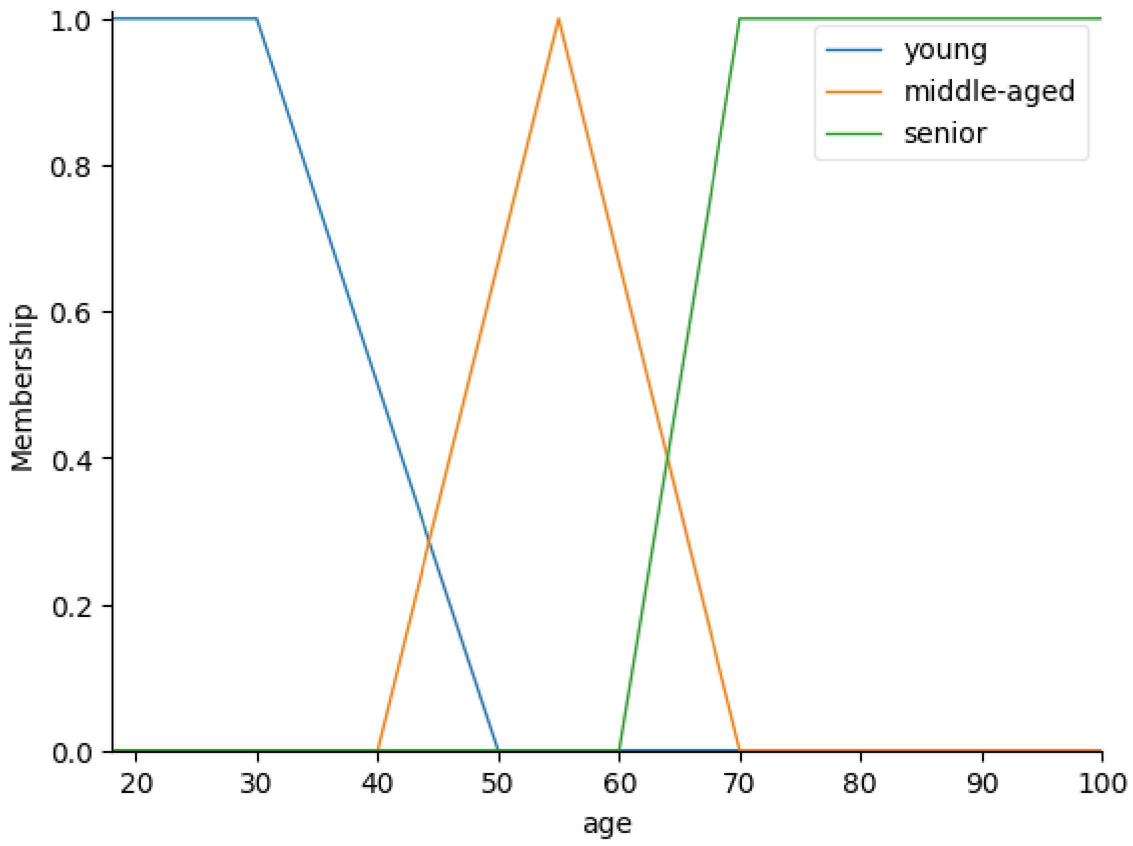
Aim: Implement fuzzy logic medical exam regarding the blood pressure and age

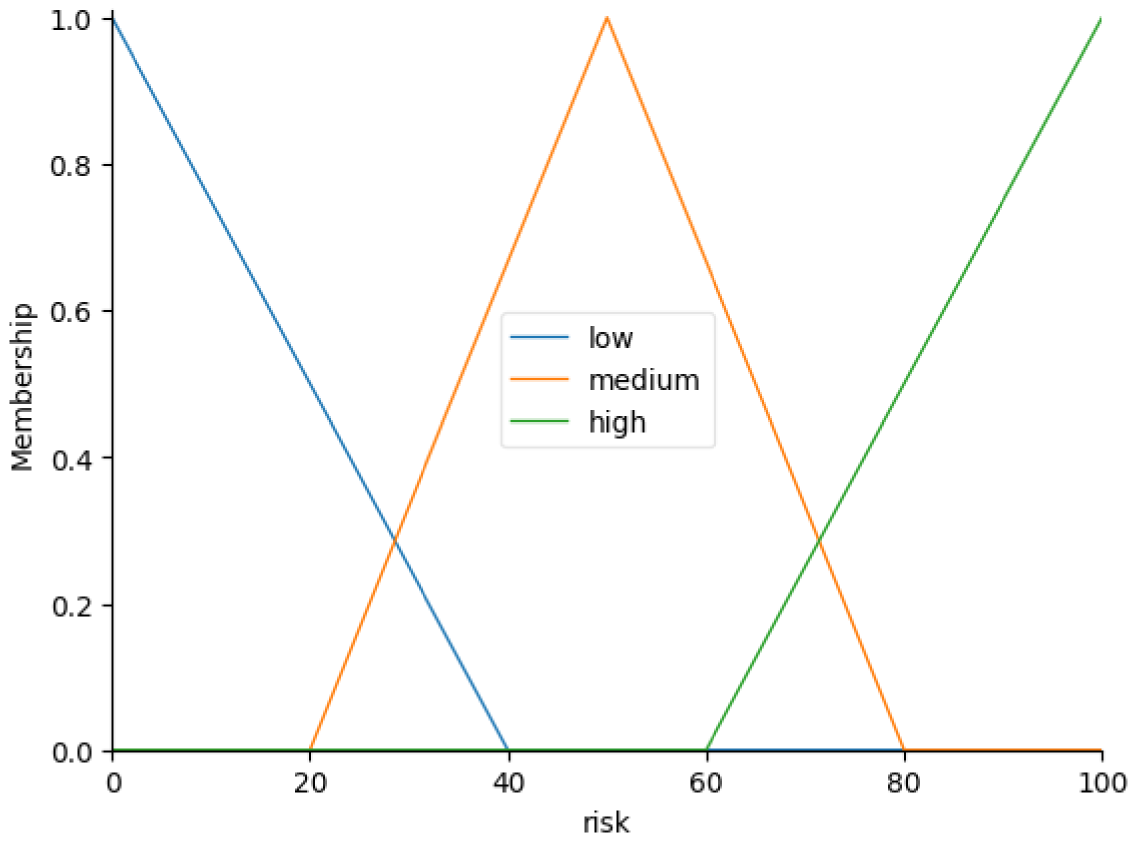
Program:

```
import numpy as np
import skfuzzy as fuzz
from skfuzzy import control as ctrl
import matplotlib.pyplot as plt
# Define input and output variables
# --------------------------------------------------------------------
# Antecedents (Inputs)
blood_pressure = ctrl.Antecedent(np.arange(80, 201, 1), 'blood_pressure')  # 80-200 mmHg
age = ctrl.Antecedent(np.arange(18, 101, 1), 'age')                        # 18-100 years
# Consequent (Output)
risk = ctrl.Consequent(np.arange(0, 101, 1), 'risk')                       # 0-100%
# Define fuzzy membership functions
# --------------------------------------------------------------------
# Blood Pressure Categories
blood_pressure['low'] = fuzz.trapmf(blood_pressure.universe, [80, 80, 90, 110])
blood_pressure['normal'] = fuzz.trimf(blood_pressure.universe, [90, 120, 130])
blood_pressure['elevated'] = fuzz.trimf(blood_pressure.universe, [120, 140, 160])
blood_pressure['high'] = fuzz.trapmf(blood_pressure.universe, [140, 160, 200, 200])
# Age Categories
age['young'] = fuzz.trapmf(age.universe, [18, 18, 30, 50])
age['middle-aged'] = fuzz.trimf(age.universe, [40, 55, 70])
age['senior'] = fuzz.trapmf(age.universe, [60, 70, 100, 100])
# Risk Level Categories
risk['low'] = fuzz.trimf(risk.universe, [0, 0, 40])
risk['medium'] = fuzz.trimf(risk.universe, [20, 50, 80])
risk['high'] = fuzz.trimf(risk.universe, [60, 100, 100])
# Visualize membership functions (optional)
blood_pressure.view()
age.view()
risk.view()
plt.show()
# Define fuzzy rules
# --------------------------------------------------------------------
rule1 = ctrl.Rule(
    blood_pressure['low'] & age['young'],
    risk['low']
)
rule2 = ctrl.Rule(
    blood_pressure['normal'] & (age['young'] | age['middle-aged']),
    risk['low']
)
rule3 = ctrl.Rule(
    blood_pressure['elevated'] & age['middle-aged'],
    risk['medium']
)
rule4 = ctrl.Rule(
    blood_pressure['high'] & (age['middle-aged'] | age['senior']),
    risk['high']
)
rule5 = ctrl.Rule(
    blood_pressure['elevated'] & age['senior'],
    risk['high']
)
# Create control system
# -------------------------------------------------------------------
risk_ctrl = ctrl.ControlSystem([rule1, rule2, rule3, rule4, rule5])
risk_assessment = ctrl.ControlSystemSimulation(risk_ctrl)
# Example 1: Young patient with normal BP
risk_assessment.input['blood_pressure'] = 115
risk_assessment.input['age'] = 28
risk_assessment.compute()
risk_level = risk_assessment.output['risk']
print(f"Patient Age: 28, BP: 115 mmHg")
print(f"Risk Level: {risk_level:.2f}% (Low Risk)")
risk.view(sim=risk_assessment)
plt.show()
# Example 2: Senior patient with high BP
risk_assessment.input['blood_pressure'] = 180
risk_assessment.input['age'] = 72
risk_assessment.compute()
risk_level = risk_assessment.output['risk']
print(f"\nPatient Age: 72, BP: 180 mmHg")
print(f"Risk Level: {risk_level:.2f}% (High Risk)")
risk.view(sim=risk_assessment)
plt.show()
```

Output:

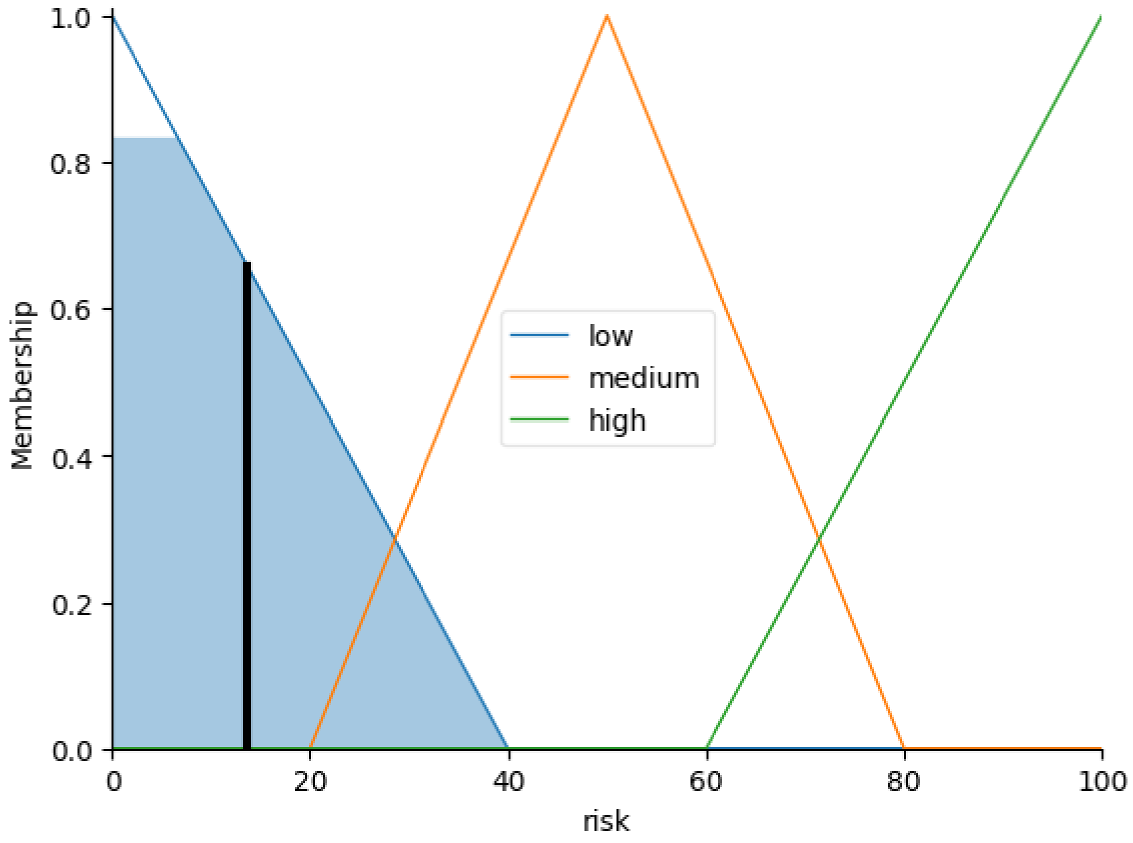




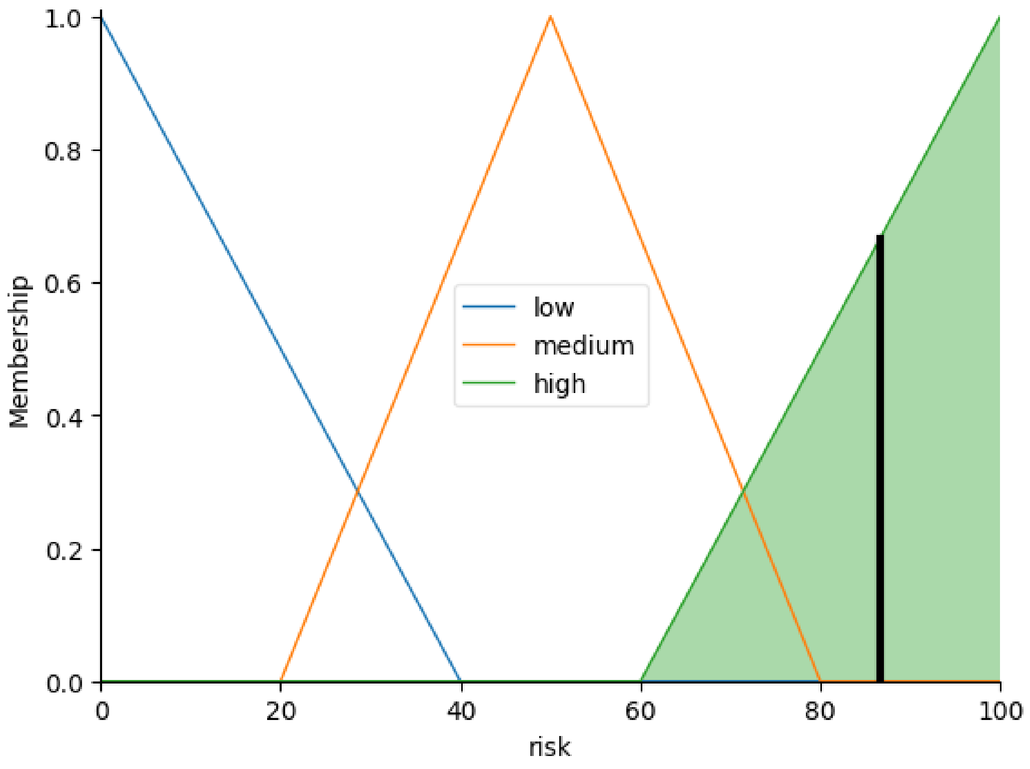


Patient Age: 28, BP: 115 mmHg

Risk Level: 13.65% (Low Risk)



Patient Age: 72, BP: 180 mmHg
Risk Level: 86.67% (High Risk)



Practical – 9

Aim: Implement Tipping Problem without Fuzzy Logic

Program:

```
def calculate_tip(service_rating, food_rating):

    # Validate inputs (0-10 scale)
    service_rating = max(0, min(10, service_rating))
    food_rating = max(0, min(10, food_rating))
    # Categorize service and food quality
    def categorize(rating):
        if rating <= 3:
            return "poor"
        elif 4 <= rating <= 6:
            return "average"
        else:
            return "excellent"
    service_category = categorize(service_rating)
    food_category = categorize(food_rating)
    # Define tipping rules
    tip_rules = {
        ("poor", "poor"): 5,
        ("average", "average"): 12,
        ("excellent", "excellent"): 20,
    }
    # Check for exact matches
    if (service_category, food_category) in tip_rules:
        return tip_rules[(service_category, food_category)]
    else:
        # Weighted average for mixed categories
        service_weight = (service_rating / 10) * 0.6  # Service contributes 60%
        food_weight = (food_rating / 10) * 0.4        # Food contributes 40%
        tip = 5 + (15 * (service_weight + food_weight))  # Tip range: 5%–20%
        return round(tip, 1)
# Example 1: Poor service and food
print("Example 1 (Poor Service & Food):")
tip = calculate_tip(2, 3)
print(f"Tip: {tip}%")  # Output: 5%
# Example 2: Excellent service and food
print("\nExample 2 (Excellent Service & Food):")
tip = calculate_tip(9, 8)
print(f"Tip: {tip}%")  # Output: 20%
# Example 3: Mixed ratings
print("\nExample 3 (Mixed Service & Food):")
tip = calculate_tip(5, 7)
print(f"Tip: {tip}%")  # Output: 13.2%
```

Output:

```
Example 1 (Poor Service & Food):
Tip: 5%
Example 2 (Excellent Service & Food):
Tip: 20%
Example 3 (Mixed Service & Food):
Tip: 13.7%
```

Practical – 10

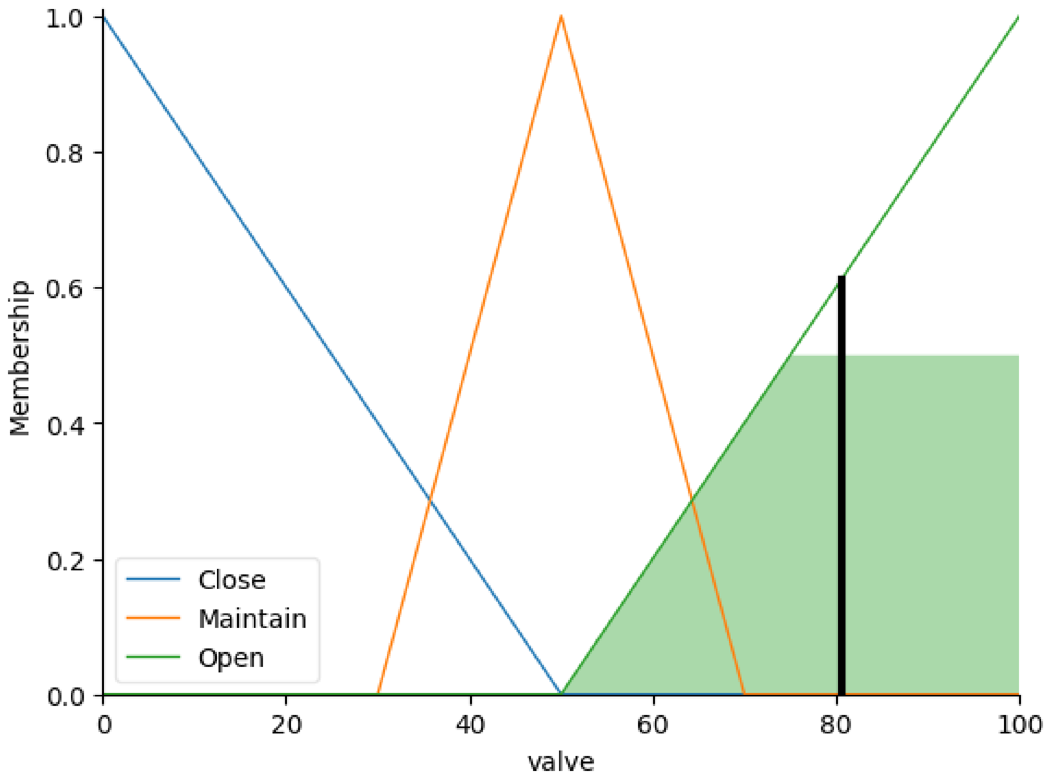
Aim: Implement Water Level Control in a Tank using Fuzzy Logic

Program:

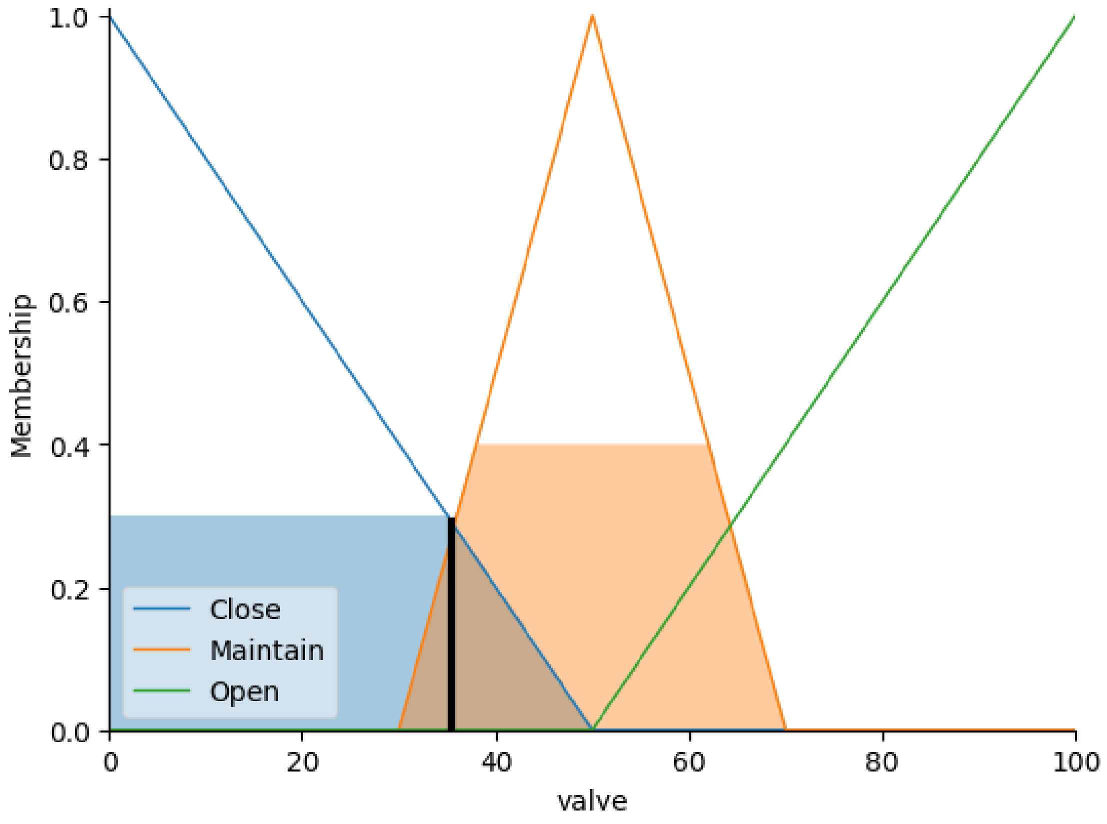
```
import numpy as np
import skfuzzy as fuzz
from skfuzzy import control as ctrl
import matplotlib.pyplot as plt
# Define input and output variables
# --------------------------------------------------------------------
# Input 1: Level Error (current level - setpoint)
level_error = ctrl.Antecedent(np.arange(-10, 11, 1), 'level_error')  # -10 cm to +10 cm
# Input 2: Rate of Change (derivative of level)
rate = ctrl.Antecedent(np.arange(-5, 5.1, 0.1), 'rate')            # -5 to +5 cm/min
# Output: Valve adjustment
valve = ctrl.Consequent(np.arange(0, 101, 1), 'valve')             # 0-100%
# Define fuzzy membership functions
# --------------------------------------------------------------------
# Level Error: Negative (below setpoint), Zero, Positive (above setpoint)
level_error['Negative'] = fuzz.trimf(level_error.universe, [-10, -10, 0])
level_error['Zero'] = fuzz.trimf(level_error.universe, [-5, 0, 5])
level_error['Positive'] = fuzz.trimf(level_error.universe, [0, 10, 10])
# Rate of Change: Decreasing, Steady, Increasing
rate['Decreasing'] = fuzz.trimf(rate.universe, [-5, -5, 0])
rate['Steady'] = fuzz.trimf(rate.universe, [-2.5, 0, 2.5])
rate['Increasing'] = fuzz.trimf(rate.universe, [0, 5, 5])
# Valve Adjustment: Close, Maintain, Open
valve['Close'] = fuzz.trimf(valve.universe, [0, 0, 50])
valve['Maintain'] = fuzz.trimf(valve.universe, [30, 50, 70])
valve['Open'] = fuzz.trimf(valve.universe, [50, 100, 100])
# Visualize membership functions (optional)
# level_error.view()
# rate.view()
# valve.view()
# plt.show()
# Define fuzzy rules
# --------------------------------------------------------------------
rule1 = ctrl.Rule(
    level_error['Negative'] & rate['Decreasing'],
    valve['Open']
)
rule2 = ctrl.Rule(
    level_error['Negative'] & rate['Steady'],
    valve['Open']
)
rule3 = ctrl.Rule(
    level_error['Negative'] & rate['Increasing'],
    valve['Maintain']
)
rule4 = ctrl.Rule(
    level_error['Zero'] & rate['Decreasing'],
    valve['Close']
)
rule5 = ctrl.Rule(
    level_error['Zero'] & rate['Steady'],
    valve['Maintain']
)
rule6 = ctrl.Rule(
    level_error['Zero'] & rate['Increasing'],
    valve['Open']
)
rule7 = ctrl.Rule(
    level_error['Positive'] & rate['Decreasing'],
    valve['Maintain']
)
rule8 = ctrl.Rule(
    level_error['Positive'] & rate['Steady'],
    valve['Close']
)
rule9 = ctrl.Rule(
    level_error['Positive'] & rate['Increasing'],
    valve['Close']
)
# Create control system
# ----------------------------------------------------------------------
tank_ctrl = ctrl.ControlSystem([rule1, rule2, rule3, rule4, rule5, rule6, rule7, rule8, rule9])
tank_sim = ctrl.ControlSystemSimulation(tank_ctrl)
# Example 1: Level is 5 cm below setpoint and decreasing
tank_sim.input['level_error'] = -5
tank_sim.input['rate'] = -2.5
tank_sim.compute()
valve_adjustment = tank_sim.output['valve']
print(f"Level Error: -5 cm, Rate: -2.5 cm/min")
print(f"Valve Adjustment: {valve_adjustment:.2f}% (Open)")
valve.view(sim=tank_sim)
plt.show()
# Example 2: Level is 3 cm above setpoint and steady
tank_sim.input['level_error'] = 3
tank_sim.input['rate'] = 0
tank_sim.compute()
valve_adjustment = tank_sim.output['valve']
print(f"\nLevel Error: +3 cm, Rate: 0 cm/min")
print(f"Valve Adjustment: {valve_adjustment:.2f}% (Close)")
valve.view(sim=tank_sim)
plt.show()
```

Output:

```
Level Error: -5 cm, Rate: -2.5 cm/min
Valve Adjustment: 80.56% (Open)
```



Level Error: +3 cm, Rate: 0 cm/min
Valve Adjustment: 35.41% (Close)


Membership
valve
Close
Maintain
Open