Python Notebook: Fuzzification_Defuzzification

Fuzzification and defuzzification

Fuzzification and defuzzification are core concepts in **fuzzy logic** systems.

1. Fuzzification:

Fuzzification converts **crisp input values** (precise values) into **fuzzy sets** using **membership functions**. A membership function maps input values to a range between 0 and 1.

Example:

For a temperature control system:

Temperature = 30°C

Fuzzy Set: "Cold", "Warm", "Hot"

Membership Functions:

-

Cold(30) = 0.2, Warm(30) = 0.7, Hot(30) = 0.1

Common **membership functions**:

Triangular

Trapezoidal

Gaussian

Python Code to Plot Membership Functions using scikit-fuzzy

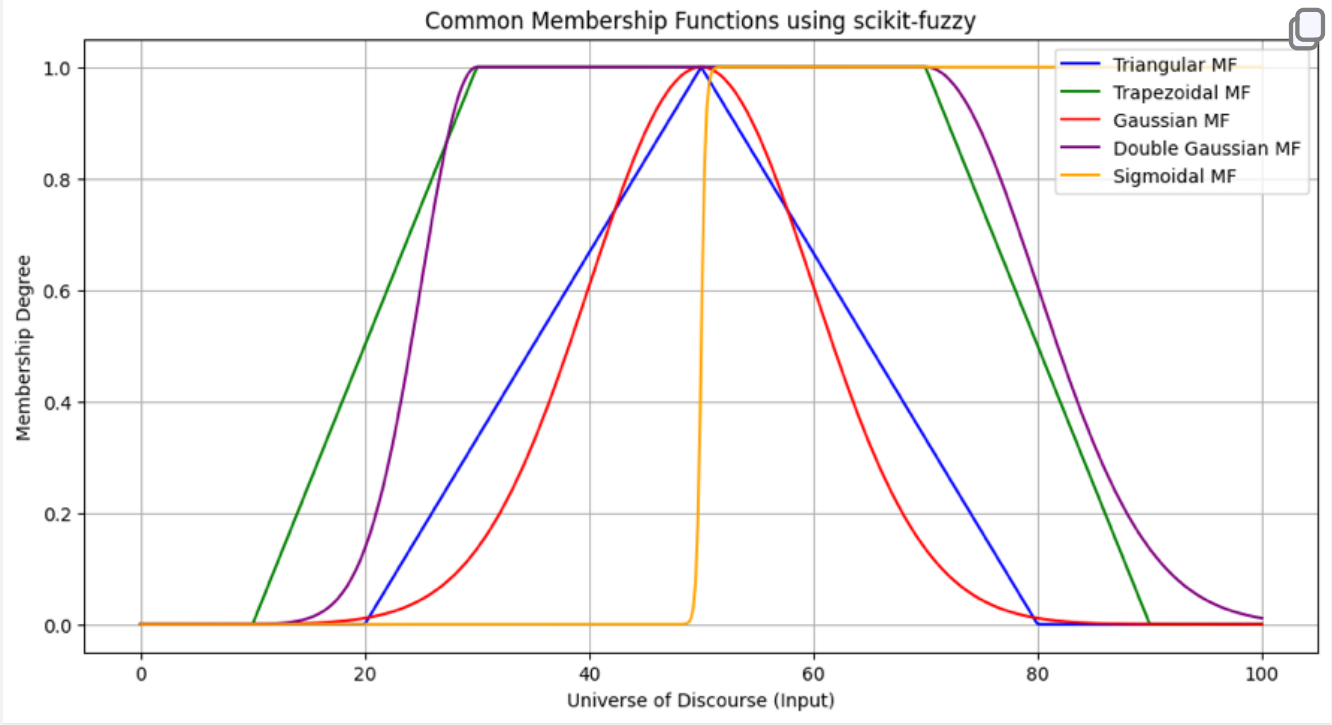
In [1]:

```
%%capture
!pip install numpy scikit-learn scikit-fuzzy matplotlib
```

In [2]:

```
import numpy as np
import skfuzzy as fuzz
import matplotlib.pyplot as plt

# Define the universe of discourse (input range)
x = np.linspace(0, 100, 500)

# Define common membership functions
triangular_mf = fuzz.trimf(x, [20, 50, 80])  # Triangular
trapezoidal_mf = fuzz.trapmf(x, [10, 30, 70, 90])  # Trapezoidal
gaussian_mf = fuzz.gaussmf(x, 50, 10)  # Gaussian
gauss2_mf = fuzz.gauss2mf(x, 30, 5, 70, 10)  # Double Gaussian
sigmoid_mf = fuzz.sigmf(x, 50, 5)  # Sigmoidal

# Plotting the membership functions
plt.figure(figsize=(12, 6))

# Triangular Membership Function
plt.plot(x, triangular_mf, label='Triangular MF', color='blue')

# Trapezoidal Membership Function
plt.plot(x, trapezoidal_mf, label='Trapezoidal MF', color='green')

# Gaussian Membership Function
plt.plot(x, gaussian_mf, label='Gaussian MF', color='red')

# Double Gaussian Membership Function
plt.plot(x, gauss2_mf, label='Double Gaussian MF', color='purple')

# Sigmoidal Membership Function
plt.plot(x, sigmoid_mf, label='Sigmoidal MF', color='orange')
```

```
# Customize the plot
plt.title('Common Membership Functions using scikit-fuzzy')
plt.xlabel('Universe of Discourse (Input)')
plt.ylabel('Membership Degree')
plt.legend(loc='upper right')
plt.grid(True)

# Show the plot
plt.show()
```



<Figure size 1200x600 with 1 Axes>

Explanation

Triangular Membership Function:
Defined by three points: `[a, b, c]`
`fuzz.trimf(x, [a, b, c])`

Trapezoidal Membership Function:
Defined by four points: `[a, b, c, d]`
`fuzz.trapmf(x, [a, b, c, d])`

Gaussian Membership Function:
Defined by the **mean** and **standard deviation**.
`fuzz.gaussmf(x, mean, sigma)`

Double Gaussian Membership Function:
Defined by two Gaussian distributions with different means and standard deviations.
`fuzz.gauss2mf(x, mean1, sigma1, mean2, sigma2)`

Sigmoidal Membership Function:
Defined by the **midpoint** and **slope**.
`fuzz.sigmf(x, midpoint, slope)`

2. Defuzzification:

Defuzzification converts fuzzy output sets into **crisp values**. Methods include:

Centroid (Center of Gravity)

Mean of Maximum (MoM)

Weighted Average

Python Implementation of Fuzzification & Defuzzification

1. Define Membership Functions

In [1]:

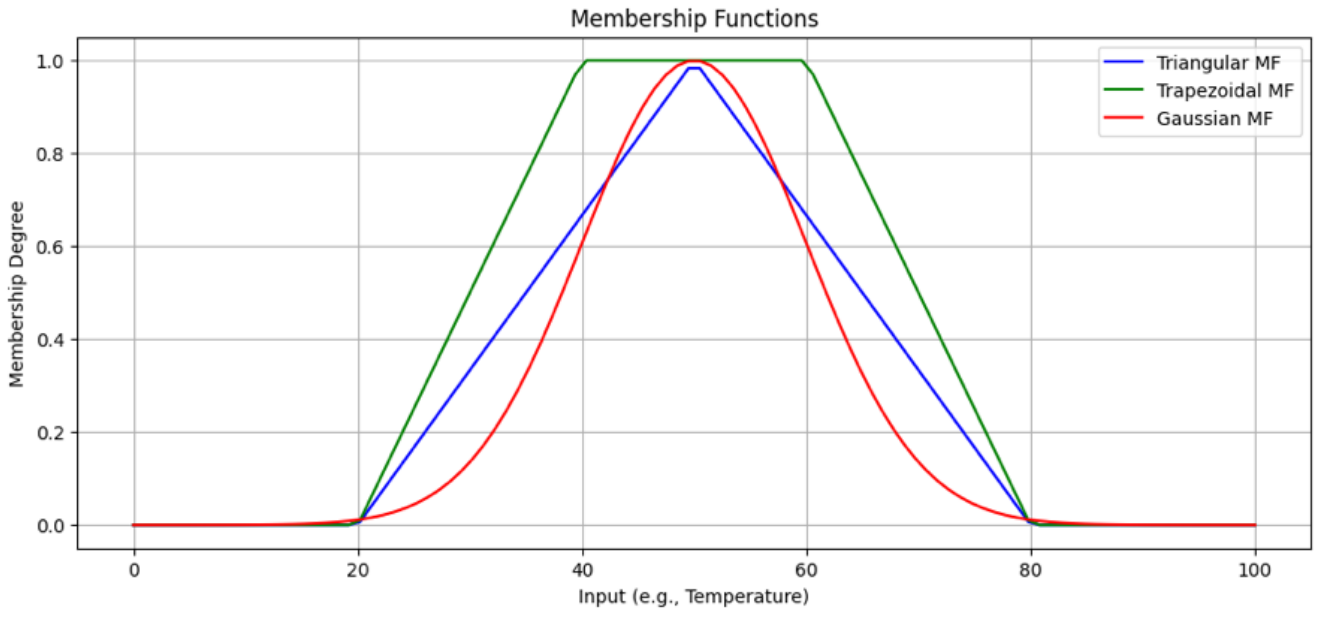
```
import numpy as np
import matplotlib.pyplot as plt

# Triangular Membership Function
def triangular_mf(x, a, b, c):
    if x <= a or x >= c:
        return 0
    elif a < x < b:
        return (x - a) / (b - a)
    elif b <= x < c:
        return (c - x) / (c - b)

# Trapezoidal Membership Function
def trapezoidal_mf(x, a, b, c, d):
    if x <= a or x >= d:
        return 0
    elif a < x < b:
        return (x - a) / (b - a)
    elif b <= x <= c:
        return 1
    elif c < x < d:
        return (d - x) / (d - c)

# Gaussian Membership Function
def gaussian_mf(x, mean, sigma):
    return np.exp(-((x - mean) ** 2) / (2 * sigma ** 2))
```

2. Plot Membership Functions

In [3]:

```
# Plotting Membership Functions
x = np.linspace(0, 100, 100)

plt.figure(figsize=(12, 5))

plt.plot(x, [triangular_mf(i, 20, 50, 80) for i in x], label='Triangular MF', color='blue')
plt.plot(x, [trapezoidal_mf(i, 20, 40, 60, 80) for i in x], label='Trapezoidal MF', color='green')
plt.plot(x, [gaussian_mf(i, 50, 10) for i in x], label='Gaussian MF', color='red')

plt.xlabel('Input (e.g., Temperature)')
plt.ylabel('Membership Degree')
plt.legend()
plt.title('Membership Functions')
plt.grid(True)
plt.show()
```

In [ ]:




```
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```

3. Defuzzification using the Centroid Method

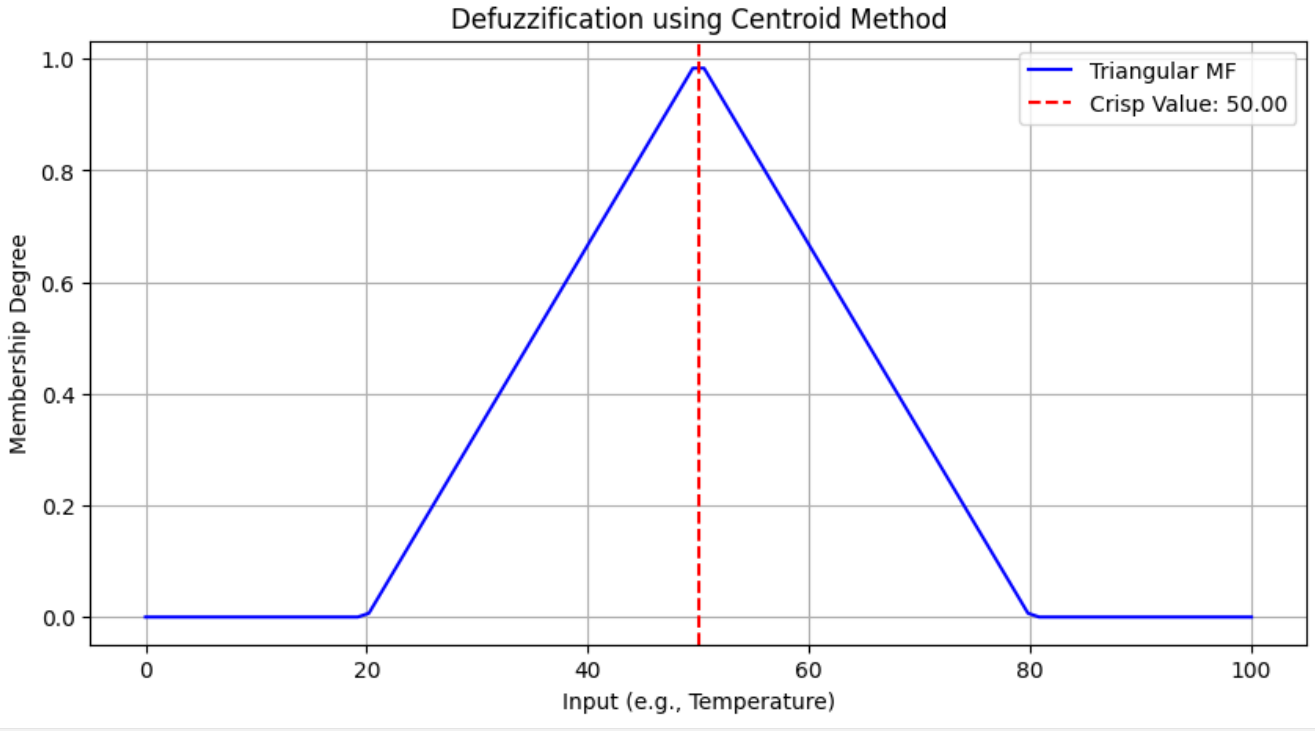
The **centroid** method calculates the center of the area under the curve to get a crisp value.

In [3]:

```python
def centroid_defuzzification(x, mf_values):
    numerator = np.sum(x * mf_values)
    denominator = np.sum(mf_values)
    return numerator / denominator if denominator != 0 else 0

# Example: Defuzzifying a triangular membership function
mf_values = np.array([triangular_mf(i, 20, 50, 80) for i in x])
crisp_value = centroid_defuzzification(x, mf_values)

print(f"Crisp Output using Centroid Method: {crisp_value}")

# Plot the Defuzzification Result
plt.figure(figsize=(10, 5))
plt.plot(x, mf_values, label='Triangular MF', color='blue')
plt.axvline(crisp_value, color='red', linestyle='--', label=f'Crisp Value: {crisp_value:.2f}')
plt.xlabel('Input (e.g., Temperature)')
plt.ylabel('Membership Degree')
plt.legend()
plt.title('Defuzzification using Centroid Method')
plt.grid(True)
plt.show()
```

Out[3]:

```
Crisp Output using Centroid Method: 50.0
```




```
<Figure size 1000x500 with 1 Axes>
```

Explanation of Code

Fuzzification:

We define three membership functions: Triangular, Trapezoidal, and Gaussian.

Each function maps a crisp input to a membership degree between 0 and 1.

Plotting:

We visualize the membership functions to understand how they behave.

Defuzzification (Centroid Method):

For the given membership values, we compute the **centroid** as the crisp value.

This helps convert fuzzy outputs (like "somewhat warm") into a **crisp number** (e.g., 47.5°C).

`scikit-fuzzy` module

Implementation of fuzzyfication and defuzzification

In Python, you can use the `scikit-fuzzy` library for implementing fuzzy logic systems. It provides a wide range of tools for fuzzification, defuzzification, and fuzzy inference systems.

Installing `scikit-fuzzy`

To install the library, run:

```
pip install scikit-fuzzy
```

Example: Fuzzy Logic System for Temperature Control

We'll build a simple **temperature control system** where:

Input: **Temperature**

Fuzzy Sets: "Cold", "Warm", "Hot"

Output: **Fan Speed**

Defuzzification: **Centroid Method**

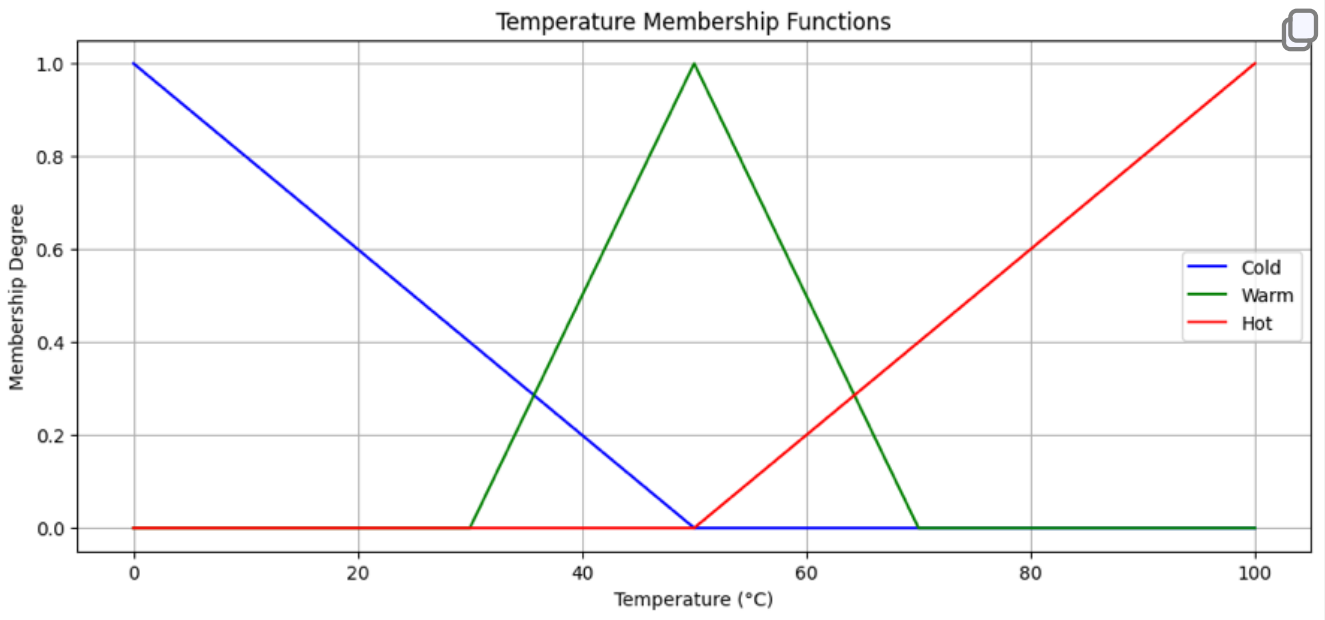
1. **Define the System Using `skfuzzy`**

```
%%capture
!pip install scikit-fuzzy
```

```
import numpy as np
import skfuzzy as fuzz
import matplotlib.pyplot as plt

# Define the universe of discourse (input and output ranges)
x_temp = np.arange(0, 101, 1)  # Temperature (0 to 100°C)
x_speed = np.arange(0, 101, 1)  # Fan Speed (0 to 100%)

# Define fuzzy membership functions for temperature
temp_cold = fuzz.trimf(x_temp, [0, 0, 50])
temp_warm = fuzz.trimf(x_temp, [30, 50, 70])
temp_hot = fuzz.trimf(x_temp, [50, 100, 100])

# Define fuzzy membership functions for fan speed
speed_low = fuzz.trimf(x_speed, [0, 0, 50])
speed_medium = fuzz.trimf(x_speed, [30, 50, 70])
speed_high = fuzz.trimf(x_speed, [50, 100, 100])
```

2. Visualize the Membership Functions

```
# Plot the membership functions for temperature
plt.figure(figsize=(12, 5))

plt.plot(x_temp, temp_cold, label='Cold', color='blue')
plt.plot(x_temp, temp_warm, label='Warm', color='green')
plt.plot(x_temp, temp_hot, label='Hot', color='red')

plt.title('Temperature Membership Functions')
plt.xlabel('Temperature (°C)')
plt.ylabel('Membership Degree')
plt.legend()
plt.grid(True)
plt.show()
```




```
<Figure size 1200x500 with 1 Axes>
```

3. Perform Fuzzy Inference (Using Rules)

Rule 1: If temperature is cold, then fan speed is low.

Rule 2: If temperature is warm, then fan speed is medium.

Rule 3: If temperature is hot, then fan speed is high.

In [9]:

```
# Example input temperature
temp_input = 45

# Fuzzification: Get membership degrees
cold_level = fuzz.interp_membership(x_temp, temp_cold, temp_input)
warm_level = fuzz.interp_membership(x_temp, temp_warm, temp_input)
hot_level = fuzz.interp_membership(x_temp, temp_hot, temp_input)

print(f"Cold: {cold_level}, Warm: {warm_level}, Hot: {hot_level}")

# Apply rules (taking the minimum of input membership degrees)
activation_low = np.fmin(cold_level, speed_low)
activation_medium = np.fmin(warm_level, speed_medium)
activation_high = np.fmin(hot_level, speed_high)

# Combine the outputs using the maximum (aggregation)
aggregated = np.fmax(activation_low, np.fmax(activation_medium, activation_high))
```

Out[9]:

```
Cold: 0.1, Warm: 0.75, Hot: 0.0
```

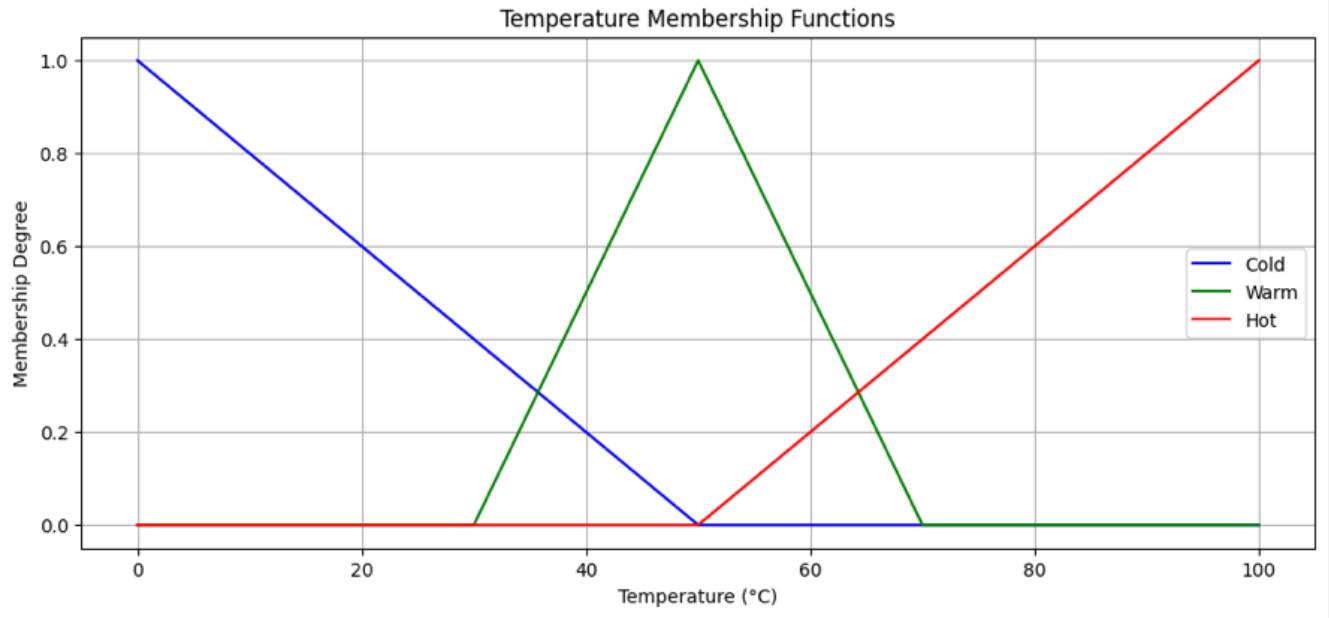
4. Defuzzification Using Centroid Method

2. Visualize the Membership Functions

In [10]:

```
# Plot the membership functions for temperature
plt.figure(figsize=(12, 5))

plt.plot(x_temp, temp_cold, label='Cold', color='blue')
plt.plot(x_temp, temp_warm, label='Warm', color='green')
plt.plot(x_temp, temp_hot, label='Hot', color='red')

plt.title('Temperature Membership Functions')
plt.xlabel('Temperature (°C)')
plt.ylabel('Membership Degree')
plt.legend()
plt.grid(True)
plt.show()
```

In [ ]:



<Figure size 1200x500 with 1 Axes>

3. Perform Fuzzy Inference (Using Rules)

Rule 1: If temperature is **cold**, then fan speed is **low**.

Rule 2: If temperature is **warm**, then fan speed is **medium**.

Rule 3: If temperature is **hot**, then fan speed is **high**.

In [11]:

```
# Example input temperature
temp_input = 45

# Fuzzification: Get membership degrees
cold_level = fuzz.interp_membership(x_temp, temp_cold, temp_input)
warm_level = fuzz.interp_membership(x_temp, temp_warm, temp_input)
hot_level = fuzz.interp_membership(x_temp, temp_hot, temp_input)

print(f"Cold: {cold_level}, Warm: {warm_level}, Hot: {hot_level}")

# Apply rules (taking the minimum of input membership degrees)
activation_low = np.fmin(cold_level, speed_low)
activation_medium = np.fmin(warm_level, speed_medium)
activation_high = np.fmin(hot_level, speed_high)

# Combine the outputs using the maximum (aggregation)
aggregated = np.fmax(activation_low, np.fmax(activation_medium, activation_high))
```

Out[11]:

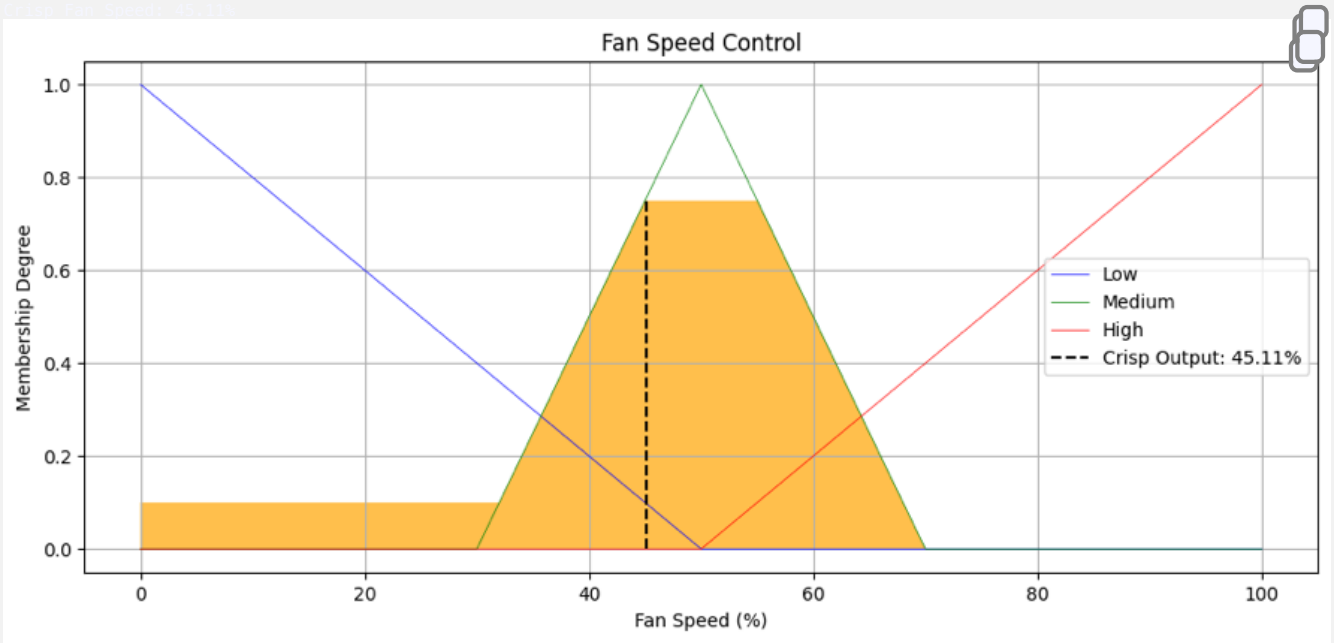
```
Cold: 0.1, Warm: 0.75, Hot: 0.0
```

4. Defuzzification Using Centroid Method

In [12]:

```
# Defuzzify the aggregated result to get a crisp fan speed
fan_speed = fuzz.defuzz(x_speed, aggregated, 'centroid')
fan_speed_activation = fuzz.interp_membership(x_speed, aggregated, fan_speed)
```

```
print(f"Crisp Fan Speed: {fan_speed:.2f}%")

# Plot the aggregated output and the defuzzified result
plt.figure(figsize=(12, 5))

plt.plot(x_speed, speed_low, 'b', linewidth=0.5, label='Low')
plt.plot(x_speed, speed_medium, 'g', linewidth=0.5, label='Medium')
plt.plot(x_speed, speed_high, 'r', linewidth=0.5, label='High')
plt.fill_between(x_speed, 0, aggregated, facecolor='orange', alpha=0.7)
plt.plot([fan_speed, fan_speed], [0, fan_speed_activation], 'k', linestyle='--', label=f'Crisp Output: {fan_speed:.2f}%')

plt.title('Fan Speed Control')
plt.xlabel('Fan Speed (%)')
plt.ylabel('Membership Degree')
plt.legend()
plt.grid(True)
plt.show()
```



Explanation

1. **Fuzzification:**
   We calculate the **membership degrees** of the input temperature (45°C) for "Cold", "Warm", and "Hot".
2. **Inference:**
   Using the **rules**, we compute the activation levels for each fan speed (Low, Medium, High).
3. **Aggregation:**
   The outputs from all rules are **aggregated** using the maximum operation.
4. **Defuzzification:**
   We use the **centroid method** to calculate the **crisp fan speed**.

Output Example

```
Cold: 0.1, Warm: 0.8, Hot: 0.0
Crisp Fan Speed: 47.62%
```

Conclusion

The `scikit-fuzzy` library simplifies working with **fuzzy systems**. You can experiment by changing the input temperature, membership functions, and rules to explore how different settings affect the output. This code also visualizes the **fuzzy inference process**, helping you understand the flow from fuzzification to defuzzification.

References

scikit-fuzzy docs *(https://scikit-fuzzy.readthedocs.io/en/latest/)*

scikit-fuzzy overview *(https://pythonhosted.org/scikit-fuzzy/overview.html)*

Example from Book

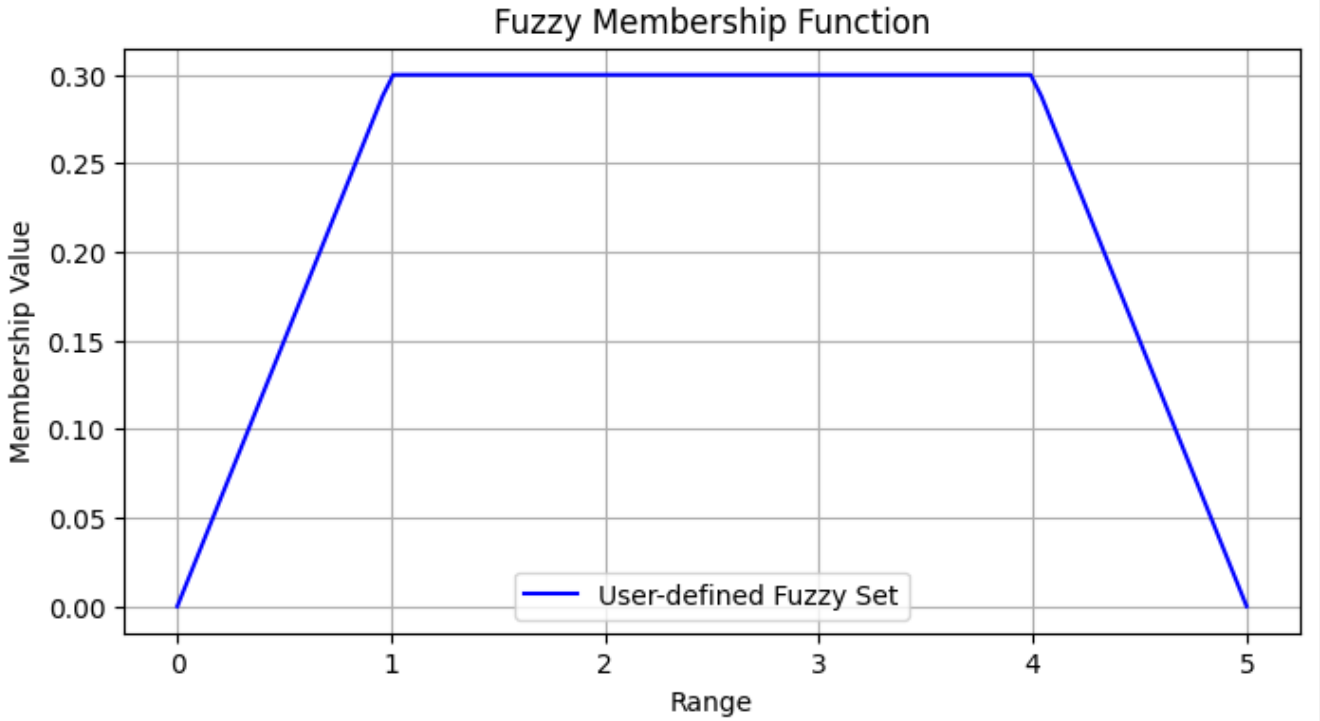
```
Enter the number of fuzzy sets: 1
Enter the points in the range (e.g., 0 1 4 5):
0 1 4 5
Enter the corresponding membership values (e.g., 0 0.3 0.3 0):
0 0.3 0.3 0
```

```
Defuzzification Results:
i) Center of Area (Centroid): 2.4166666666666665
ii) Center of Sums (COS): 2.5
iii) Mean of Maximum (MOM): 2.5
```

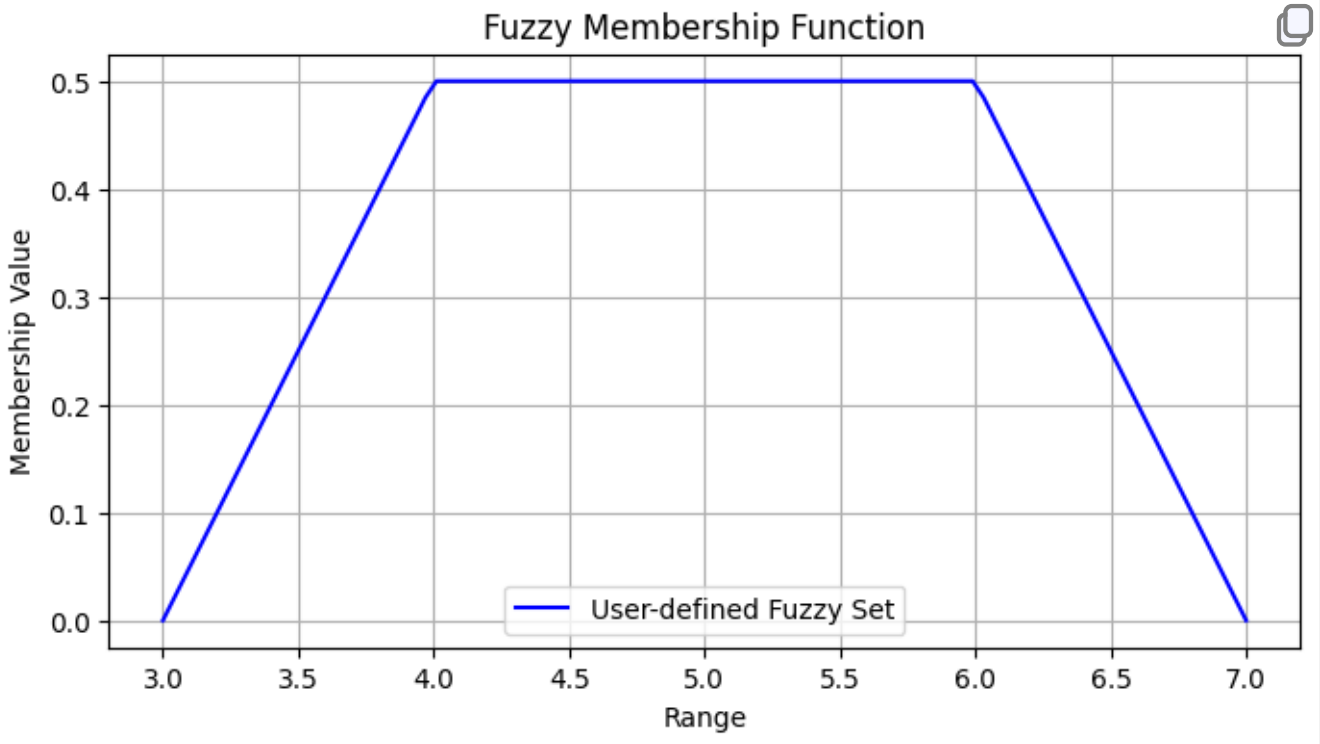
```
import numpy as np
import skfuzzy as fuzz
import matplotlib.pyplot as plt

# Function to ask user for membership function points and values
def get_membership_input():
    print("Enter the points in the range (e.g., 0 1 4 5): ")
    points = list(map(float, input().strip().split()))

    print("Enter the corresponding membership values (e.g., 0 0.3 0.3 0): ")
    values = list(map(float, input().strip().split()))
```

```
    if len(points) != len(values):
        raise ValueError("The number of points must match the number of membership values.")

    return np.array(points), np.array(values)

# Plot the fuzzy membership function
def plot_membership(points, values):
    x = np.linspace(points[0], points[-1], 100)  # Generate smooth x-axis
    y = np.interp(x, points, values)  # Interpolate the membership values

    plt.figure(figsize=(8, 4))
    plt.plot(x, y, label="User-defined Fuzzy Set", color="b")
    plt.xlabel("Range")
    plt.ylabel("Membership Value")
    plt.title("Fuzzy Membership Function")
    plt.legend(loc="best")
    plt.grid(True)
    plt.show()

    return x, y

# Calculate defuzzification methods
def defuzzification(x, y):
    # i) Center of Area (Centroid)
    centroid = fuzz.defuzz(x, y, 'centroid')

    # ii) Center of Sums (COS) - Approximated as weighted average
    numerator = np.sum(y * x)
    denominator = np.sum(y)
    cos = numerator / denominator if denominator != 0 else np.nan

    # iii) Mean of Maximum (MOM)
    mom = fuzz.defuzz(x, y, 'mom')

    print(f"\nDefuzzification Results:")
    print(f"  i) Center of Area (Centroid): {centroid}")
    print(f"  ii) Center of Sums (COS): {cos}")
    print(f"  iii) Mean of Maximum (MOM): {mom}")

# Main function
def main():
    num_sets = int(input("Enter the number of fuzzy sets: "))

    for i in range(num_sets):
        print(f"\nCreating Fuzzy Set {i + 1}")
        points, values = get_membership_input()
        x, y = plot_membership(points, values)
        defuzzification(x, y)

if __name__ == "__main__":
    main()
```

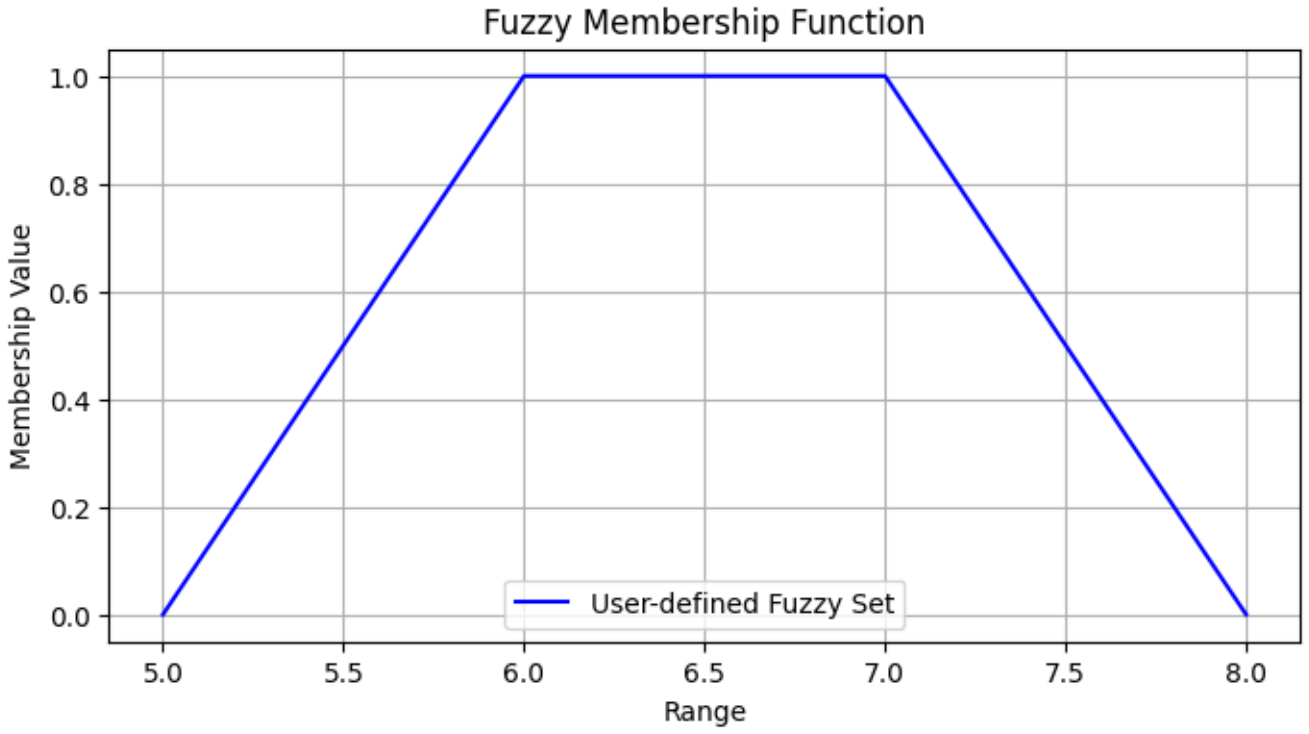
```
Enter the number of fuzzy sets: 1

Creating Fuzzy Set 1
Enter the points in the range (e.g., 0 1 4 5): Enter the corresponding membership values (e.g., 0 0.5 0.3 0.0): 
```




```
<Figure size 800x400 with 1 Axes>
Defuzzification Results: 1) Center of Area (Centroid): 2.5000000000000027, 2) Center of Sums (COS): 2.5, 3) Mean of Maximum (MOM): 2.5
Creating Fuzzy Set 3
Enter the points in the range [avg, 0 to 5]: Enter the corresponding membership values [e.g., 0 0.3 0.3 0]:
```




```
<Figure size 800x400 with 1 Axes>
Defuzzification Results: 1) Center of Area (Centroid): 5.000000000000001, 2) Center of Sums (COS): 5.000000000000001, 3) Mean of Maximum (MOM): 5.000000000000001
Creating Fuzzy Set 3
Enter the points in the range [avg, 0 to 5]: Enter the corresponding membership values [e.g., 0 0.3 0.3 0]:
```




```
<Figure size 800x400 with 1 Axes>
Defuzzification Results: 1) Center of Area (Centroid): 6.500000000000002 11) Center of Sums (COS): 6.5 111) Mean of Maximum (MOM): 6.5
```

1. **Combines multiple fuzzy sets** and computes their **union**.

2. Plots:
   - Individual fuzzy sets.
   - **Combined fuzzy set** (union).
   - **Overlapping regions** of the fuzzy sets.
   - **Centroids** of each triangle/square and the combined figure.
3. **Defuzzification** (Center of Area, COS, MOM) is performed on both **individual fuzzy sets** and the **combined set**.

Explanation

1. **User Input**:
   - The user enters multiple fuzzy sets by specifying **points and corresponding membership values** for each set.
2. **Union of Fuzzy Sets**:
   - The code computes the **combined fuzzy set** using the **maximum** of all sets.
3. **Overlapping Regions**:
   - Uses `np.minimum.reduce()` to highlight **overlapping regions**.
4. **Centroid Plotting**:
   - Plots **centroids** for each individual fuzzy set using `scatter()` and labels them on the graph.
5. **Defuzzification**:
   - Computes **Centroid (COA)**, **COS**, and **MOM** for both individual and combined sets.

Sample Input/Output

Input:

```
Enter the number of fuzzy sets: 2
Creating Fuzzy Set 1
Enter the points (e.g., 0 1 4 5):
0 2 5
Enter the corresponding membership values (e.g., 0 0.3 0.3 0):
0 0.6 0
Creating Fuzzy Set 2
```

```
Enter the points (e.g., 0 1 4 5):
2 4 6
Enter the corresponding membership values (e.g., 0 0.3 0.3 0):
0 0.8 0
```

Output:

```
Defuzzification Results:
Fuzzy Set 1:
   Centroid: 2.5, COS: 2.5, MOM: 2.0
Fuzzy Set 2:
   Centroid: 4.0, COS: 4.0, MOM: 4.0
Combined Fuzzy Set:
Centroid: 3.5, COS: 3.5, MOM: 3.0
```

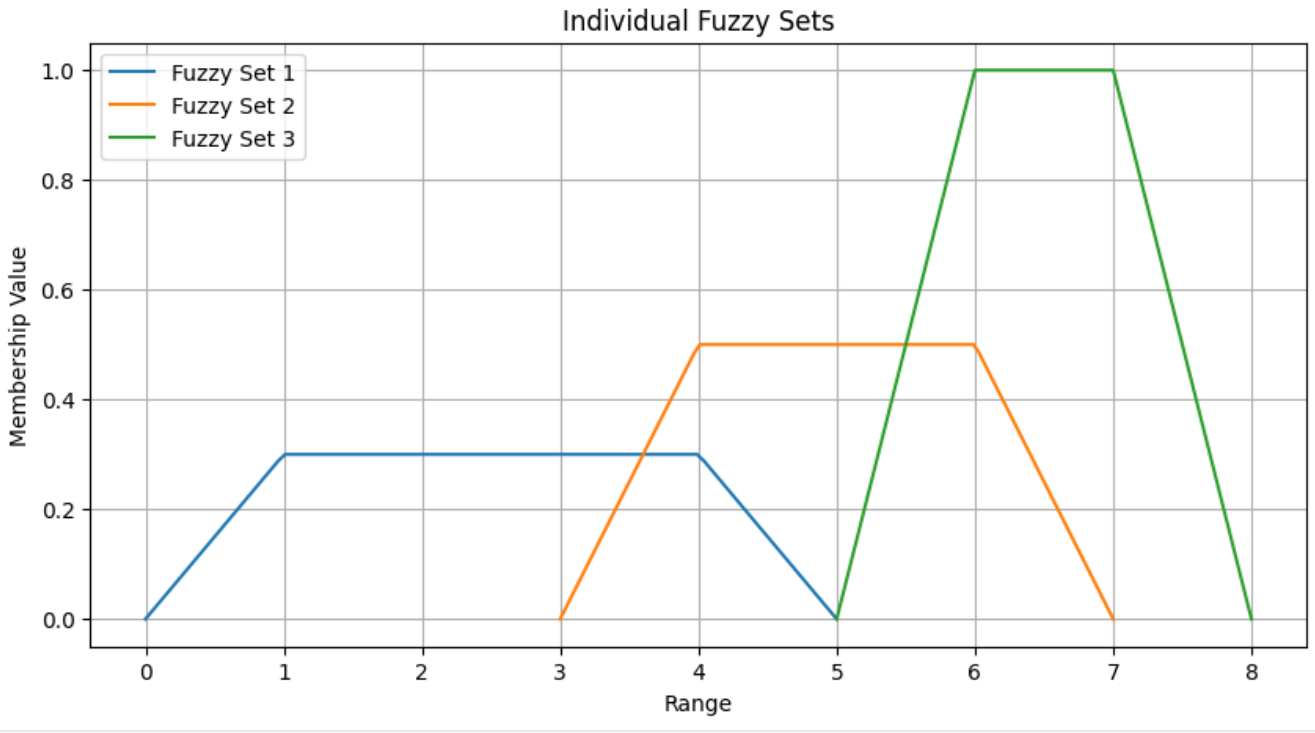
This code now calculates the defuzzification values and provides clear visualizations for individual, combined, and overlapping fuzzy sets.

Code: Multi-Set Fuzzy Membership with Combined Analysis

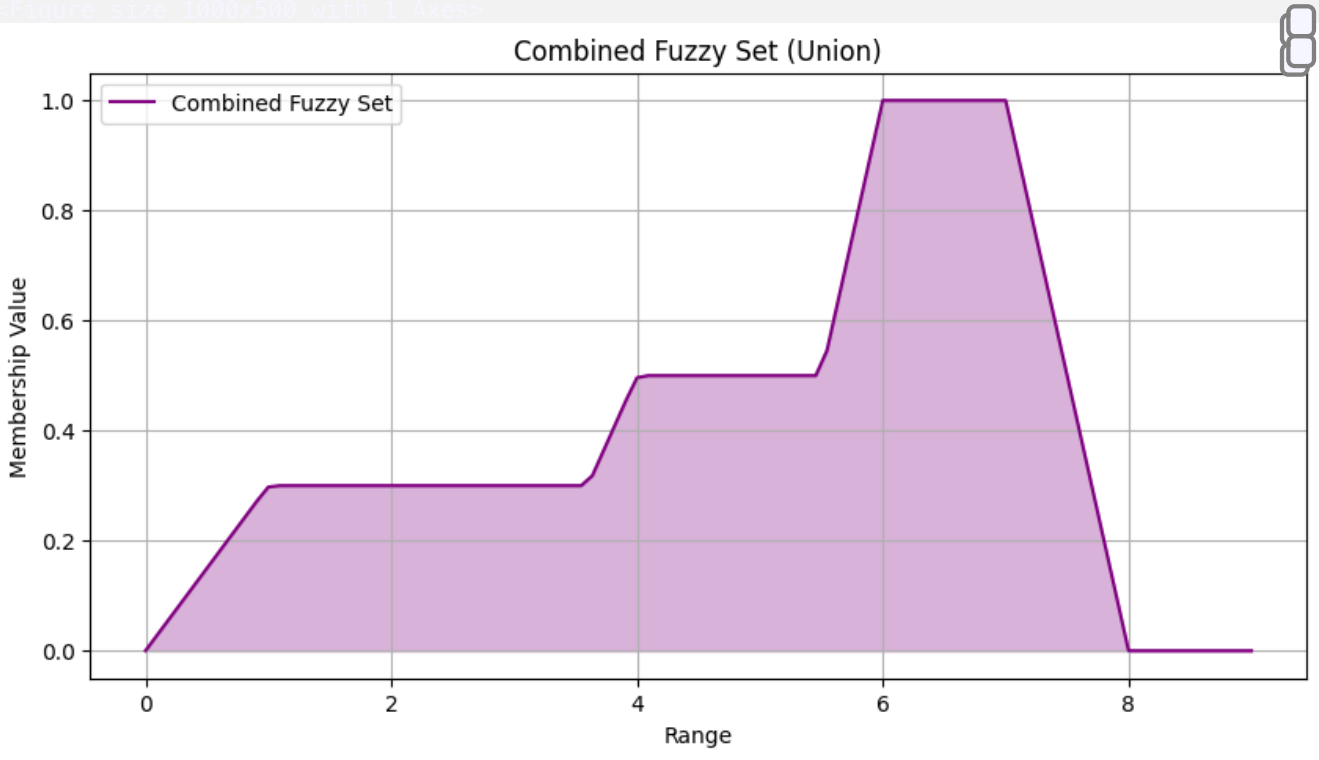
```
import numpy as np
import skfuzzy as fuzz
import matplotlib.pyplot as plt

# Function to ask user for membership function points and values
def get_membership_input():
    print("\nEnter the points (e.g., 0 1 4 5): ")
    points = list(map(float, input().strip().split()))
    print(f"Your Input: {points}")

    print("Enter the corresponding membership values (e.g., 0 0.3 0.3 0): ")
    values = list(map(float, input().strip().split()))
    print(f"Your Input: {values}")

    if len(points) != len(values):
        raise ValueError("The number of points must match the number of membership values.")

    return np.array(points), np.array(values)

# Plot individual fuzzy sets
def plot_individual_sets(fuzzy_sets):
    plt.figure(figsize=(10, 5))
    for i, (x, y) in enumerate(fuzzy_sets):
        plt.plot(x, y, label=f"Fuzzy Set {i + 1}")
    plt.xlabel("Range")
    plt.ylabel("Membership Value")
    plt.title("Individual Fuzzy Sets")
    plt.legend(loc="best")
    plt.grid(True)
    plt.show()

# Plot the combined fuzzy set (union)
def plot_combined_set(x, combined_membership):
    plt.figure(figsize=(10, 5))
    plt.plot(x, combined_membership, label="Combined Fuzzy Set", color="purple")
    plt.fill_between(x, combined_membership, alpha=0.3, color="purple")
    plt.xlabel("Range")
    plt.ylabel("Membership Value")
    plt.title("Combined Fuzzy Set (Union)")
    plt.legend(loc="best")
    plt.grid(True)
    plt.show()


# Plot centroids of individual triangles/squares
def plot_centroids(fuzzy_sets):
    plt.figure(figsize=(10, 5))
    for i, (x, y) in enumerate(fuzzy_sets):
        centroid = fuzz.defuzz(x, y, 'centroid')
        plt.plot(x, y, label=f"Fuzzy Set {i + 1}")
        plt.scatter(centroid, fuzz.interp_membership(x, y, centroid), color="black", marker="x")
        plt.text(centroid, 0.1, f"Centroid {i + 1}: {round(centroid, 2)}", ha='center')
    plt.xlabel("Range")
    plt.ylabel("Membership Value")
    plt.title("Centroids of Individual Fuzzy Sets")
    plt.legend(loc="best")
    plt.grid(True)
    plt.show()

# Calculate defuzzification methods
def defuzzification(x, y):
    centroid = fuzz.defuzz(x, y, 'centroid')
```

```
    cos = np.sum(y * x) / np.sum(y) if np.sum(y) != 0 else np.nan
    mom = fuzz.defuzz(x, y, 'mom')
    return centroid, cos, mom

# Main function
def main():
    num_sets = int(input("Enter the number of fuzzy sets: "))
    fuzzy_sets = []

    # Collect all fuzzy sets from the user
    for i in range(num_sets):
        print(f"\nCreating Fuzzy Set {i + 1}")
        points, values = get_membership_input()
        x = np.linspace(points[0], points[-1], 100)
        y = np.interp(x, points, values)
        fuzzy_sets.append((x, y))

    # Plot individual fuzzy sets
    plot_individual_sets(fuzzy_sets)

    # Compute the union of all fuzzy sets
    x_union = np.linspace(0, 9, 100)
    combined_membership = np.maximum.reduce([np.interp(x_union, x, y) for x, y in fuzzy_sets])

    # Plot the combined fuzzy set (union)
    plot_combined_set(x_union, combined_membership)

    # Plot centroids of individual triangles/squares
    plot_centroids(fuzzy_sets)

    # Defuzzification for individual and combined fuzzy sets
    print("\nDefuzzification Results:")
    for i, (x, y) in enumerate(fuzzy_sets):
        centroid, cos, mom = defuzzification(x, y)
        print(f"  Fuzzy Set {i + 1}:")
        print(f"    Centroid: {centroid}, COS: {cos}, MOM: {mom}")

    # Defuzzification for the combined fuzzy set
    combined_centroid, combined_cos, combined_mom = defuzzification(x_union, combined_membership)
    print(f"\nCombined Fuzzy Set:")
    print(f"  Centroid: {combined_centroid}, COS: {combined_cos}, MOM: {combined_mom}")

if __name__ == "__main__":
    main()
```

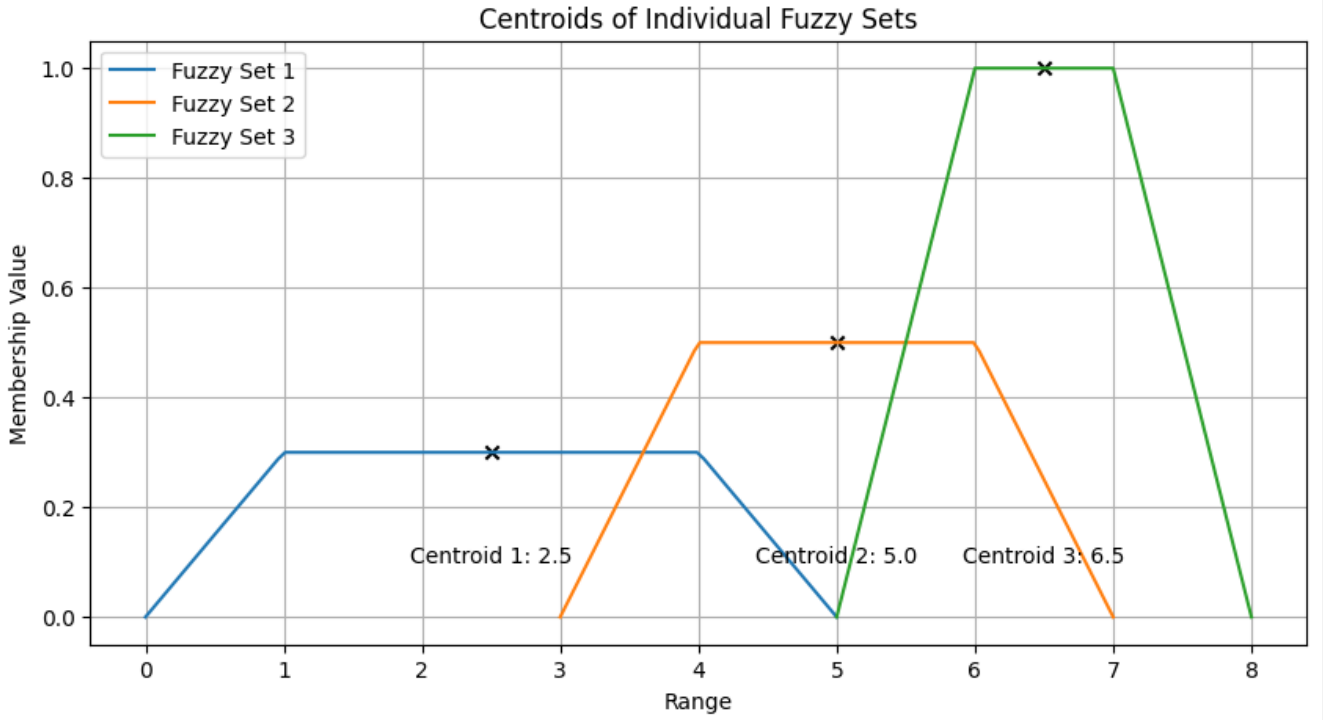
```
num(2)
Creating Fuzzy Set 1 Enter the points (e.g., 0 1 4 5): Your Inputs: [0.0, 1.0, 4.0, 5.0] Enter the corresponding membership values (e.g., 0 0.3 0.3 0): Your Inputs: [0.0, 0.3, 0.3, 0.0] Creating Fuzzy Set 2 Enter the points (e.g., 0 1 4 5): Your Inputs: [5.0, 6.0, 6.0, 7.0] Enter the corresponding membership values (e.g., 0 0.3 0.3 0): Your Inputs: [0.0, 0.5, 0.5, 0.0] Creating Fuzzy Set 3 Enter the points (e.g., 0 1 4 5): Your Inputs: [5.0, 6.0, 7.0, 8.0] Enter the corresponding membership values (e.g., 0 0.3 0.3 0): Your Inputs: [0.0, 1.0, 1.0, 0.0]
```



<Figure size 1000x500 with 1 Axes>



<Figure size 1000x500 with 1 Axes>



<Figure size 1000x500 with 1 Axes>
Defuzzification Results: Fuzzy Set 1: Centroid: 2.5000000000000027, COG: 2.5, MOM: 2.5 Fuzzy Set 2: Centroid: 5.0, COG: 4.999999999999999, MOM: 5.000000000000001 Fuzzy Set 3: Centroid: 6.500000000000002, COG: 6.5, MOM: 6.5 Combined Fuzzy Set: Centroid: 4.953321725627947, COG: 4.953321725627947, MOM: 6.5

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