To refine my initial ambitious plan into a more focused and manageable project centred around planetary classification or, more broadly, space object classification using fuzzy logic, I have outlined a revised comprehensive plan. This plan will dial back the complexity and focus primarily on classifying celestial bodies, thereby streamlining the project to fit a more concise scope.

# Fuzzy Logic Main CW - Revised Plan Overview

## Possible Titles

"Celestial Bodies Classification: Simplifying Fuzzy Logic for Planetary and Space Objects"

"AstroFuzzy Simplified: Classifying Celestial Entities Using Fuzzy Logic"

"Fuzzy Cosmos: A Streamlined Approach to Classifying Planetary and Astronomical Objects"

# 1. Linguistic Variables Definition

Objective: Identify and define linguistic variables that represent the essential characteristics of celestial bodies. These variables will focus on attributes that are critical for classification but manageable in scope.

* Size: Small, Medium, Large
* Composition: Rocky, Gaseous, Ice
* Orbital Zone: Inner Solar System, Asteroid Belt, Outer Solar System

## Size

Description: Represents the physical dimensions of a celestial body, which can significantly affect its classification.

Categories: Small, Medium, Large

Rationale: Size influences whether a celestial body is classified as a dwarf planet, a planet, or a large moon. For instance, a 'Small' size may indicate a dwarf planet, 'Medium' could suggest a terrestrial planet, and 'Large' might classify as a gas giant or a major moon.

## Composition

Description: Describes the primary materials constituting a celestial body, influencing its surface features, atmosphere, and classification.

Categories: Rocky, Gaseous, Icy

Rationale: The composition is crucial for distinguishing between terrestrial planets (Rocky), gas giants (Gaseous), and icy bodies found in the outer solar system or as moons of giant planets (Icy).

## Orbital Zone

Description: Indicates the celestial body's location within the solar system or its equivalent if considering exoplanets.

Categories: Inner Solar System, Asteroid Belt, Outer Solar System

Rationale: The orbital zone helps differentiate bodies that orbit closer to the sun (and are more likely to be rocky due to solar wind stripping away light materials) from those in the outer solar system, which can retain gases and ices.

# 2. Membership Function Categorisation

Objective: Define the membership functions for each linguistic variable. Given the simplification, focus on Gaussian and triangular functions due to their general applicability and simplicity.

Each linguistic variable requires a membership function that captures the nuances of its categories:

* Size (Continuous): Use Gaussian functions to represent the continuum from small to large sizes.
* Composition (Discrete): Triangular functions to categorise planets into rocky, gaseous, or icy.
* Orbital Zone (Discrete): Triangular functions to distinguish between inner solar system, asteroid belt, and outer solar system locations.

## Size (Continuous)

Function Type: Gaussian

Implementation Detail: Define parameters such that the overlap between categories reflects the continuum from asteroids and dwarf planets to terrestrial planets and gas giants.

## Composition (Discrete)

Function Type: Triangular

Implementation Detail: Ensure clear delineation between the three categories, with some overlap to account for mixed compositions, such as icy-rocky bodies.

## Orbital Zone (Discrete)

Function Type: Triangular

Implementation Detail: This function should distinguish between the three zones while acknowledging the gradual transitions, such as the regions between the inner solar system and the asteroid belt or the asteroid belt and the outer solar system.

# 3. Rulebase Construction

Objective: Develop a rulebase that connects the linguistic variables to classifications. This will involve creating rules that are less complex and more direct in their classification approach.

## Examples:

If the size is small and composition is rocky and orbital zone is inner solar system, then classify as a terrestrial planet.

If the size is large and composition is gaseous, then classify as a gas giant.

## Rule Set 1: Basic Classification

This set focuses on straightforward classifications based on predominant characteristics.

If size is 'Small' and composition is 'Rocky', then classify as 'Dwarf Planet'.

If size is 'Medium' and composition is 'Rocky' and orbital zone is 'Inner Solar System', then classify as 'Terrestrial Planet'.

If size is 'Large' and composition is 'Gaseous', then classify as 'Gas Giant'.

If composition is 'Icy' and orbital zone is 'Outer Solar System', then classify as 'Icy Body' (which can include icy moons or dwarf planets).

If size is 'Medium' and composition is 'Icy' and orbital zone is 'Outer Solar System', then classify as 'Icy Moon'.

If size is 'Small' and orbital zone is 'Asteroid Belt', then classify as 'Asteroid'.

## Rule Set 2: Intermediate Classification with Overlaps

This set introduces more nuance by considering overlaps in the characteristics.

If size is 'Small' to 'Medium' and composition is 'Rocky', then classify as 'Dwarf Planet' or 'Terrestrial Planet', with a confidence factor depending on the exact size and composition.

If size is 'Medium' and composition is 'Gaseous' and orbital zone is 'Outer Solar System', then classify as 'Mini Gas Giant' or 'Large Icy Moon', depending on the exact size and orbital zone.

If size is 'Large' and composition is 'Rocky' and orbital zone is 'Inner Solar System', then classify as 'Super-Earth' or 'Terrestrial Planet', with a confidence factor based on size.

If size is 'Medium' and composition is 'Icy' and orbital zone is 'Inner to Outer Solar System', then classify as 'Icy Moon' or 'Water World', depending on exact orbital zone and size.

If orbital zone is 'Outer Solar System' and size ranges from 'Medium' to 'Large' and composition is 'Icy' or 'Gaseous', then classify as 'Icy Giant' or 'Gas Giant', with a confidence factor based on exact size and composition.

## Rule Set 3: Advanced Classification Considering Anomalies

This set accounts for less common or anomalous bodies that don't fit neatly into standard categories.

If size is 'Large' and composition is 'Rocky' and orbital zone is 'Outer Solar System', then classify as 'Rogue Planet' or 'Exoplanet', acknowledging the potential for such bodies to exist outside traditional solar system models.

If composition is 'Gaseous' and size ranges from 'Small' to 'Medium' and orbital zone is 'Inner Solar System', then classify as 'Lost Gas Giant' or 'Hot Neptune', considering the possibility of gas giants migrating close to their stars.

If size is 'Small' and composition is 'Icy' and orbital zone is 'Inner Solar System', then classify as 'Comet' or 'Captured Kuiper Belt Object', acknowledging the dynamic nature of solar system objects.

If size is 'Large' and composition is 'Rocky' and orbital zone is 'Asteroid Belt', then classify as 'Protoplanet' or 'Large Asteroid', considering the growth stage of planetary formation.

If orbital zone crosses between 'Inner Solar System' and 'Outer Solar System' and composition is mixed ('Rocky' and 'Icy'), then classify as 'Transitional Object', considering bodies that might have migrated or been affected by significant gravitational perturbations.

## Implementation Considerations

Confidence Factors: Given the overlaps and potential for ambiguity, assigning confidence levels to classifications can help in cases where a celestial body could fit into multiple categories.

Adaptive Rules: For bodies that exhibit characteristics of multiple categories (e.g., Pluto with traits of both dwarf planets and comets), I may consider implementing adaptive rules that adjust classifications based on additional factors like atmosphere presence or known geological activity.

Dynamic Classifications: It’s important to recognise that some classifications may change as more information becomes available or as celestial bodies undergo changes in their orbits, compositions, or other defining characteristics.

# 4. Fuzzy Inference System Implementation

Objective: Use MATLAB’s Fuzzy Logic Toolbox to implement the fuzzy inference system (FIS). Given the simplified scope, focus on creating a user-friendly system that allows input of celestial body characteristics and outputs their classification.

## Data Considerations & Analysis

To effectively test my fuzzy inference system (FIS) for planetary classification, I need data that reflect the characteristics of celestial bodies as defined by my inputs: Size, Composition, and OrbitalZone. This data should ideally cover a wide range of known celestial bodies, including planets, dwarf planets, moons, asteroids, and possibly exoplanets, to ensure that your system can handle the diversity of space objects. Here’s what the data might look like for each input variable:

### Example Test Data:

A close up of a computer screen

Description automatically generated

### 1. Size

For Size, which is normalised between 0 and 1, I would likely base this on the diameter or radius of the celestial body relative to some reference. In a testing dataset, sizes could be represented as follows, assuming Earth's diameter as a reference:

Small (e.g., Moon, Dwarf Planets): Values closer to 0, but greater than 0 to represent bodies significantly smaller than Earth.

Medium (e.g., Earth, Venus): Values around 0.5 to represent sizes similar to Earth.

Large (e.g., Jupiter, Saturn): Values closer to 1, representing significantly larger sizes compared to Earth.

### 2. Composition

For Composition, I might categorise based on predominant material composition:

Rocky (Terrestrial planets like Earth, Mars): Categorised by a higher percentage of silicate rocks. Values might be closer to 0.

Gaseous (Gas giants like Jupiter, Saturn): Characterised by a significant amount of hydrogen and helium. Values would be around the middle of the scale, say 0.5.

Icy (Some moons and dwarf planets like Europa, Pluto): Bodies with a significant amount of water ice. Values would be closer to 1.

### 3. Orbital Zone

OrbitalZone could be defined based on the body's proximity to its star (for planets and exoplanets) or other primary celestial bodies:

Inner Solar System (Mercury, Venus, Earth, Mars): Values closer to 0, representing bodies within the inner solar system.

Asteroid Belt (Ceres and other asteroids): Intermediate values, representing objects located in the asteroid belt.

Outer Solar System (Jupiter and beyond, including Kuiper belt objects): Values closer to 1, representing bodies in the outer reaches of the solar system.

### Developed Dataset:

A screenshot of a table

Description automatically generated

# Research:

In the paper "A fuzzy Multi-Criteria Decision Making approach for Exo-Planetary Habitability," (Sánchez-Lozano, Moya and Rodríguez-Mozos, 2021), researchers tackle the complex task of ranking exoplanets based on their potential for habitability using fuzzy logic integrated with Multi-Criteria Decision-Making methodologies. They evaluate a significant number of exoplanets from the TEPCat database against a set of criteria, including composition and atmosphere, by comparing them to Earth as the ideal habitable world. The findings point to specific exoplanets, such as Kepler-442b and TRAPPIST-1e, as prime candidates for the search for biomarkers.

The system presented in the referenced paper utilises fuzzy logic within a Multi-Criteria Decision Making framework to prioritise exoplanets for habitability studies. In contrast, my system is aimed at classifying celestial bodies, potentially within our solar system, based on characteristics such as size, composition, and orbital zone. Both systems apply fuzzy logic to handle uncertainty and make decisions based on a range of inputs.

The methodology from the paper informs my work by demonstrating how fuzzy logic can handle complex, uncertain, and qualitative information to make informed decisions or classifications. It offers a perspective on how to approach the categorisation of bodies not just by their physical characteristics but also by their potential for specific conditions like habitability, which could be an interesting angle to explore in classifying planets or moons for further research or exploration.

# To Do:

Rulebase Completeness:

To ensure that your rulebase covers all possible combinations of input variables:

* Verify that each input variable (Size, Composition, OrbitalZone) has membership functions that adequately cover the entire input range.
* Check that each possible combination of input membership functions is represented by a rule in your rulebase.
* Ensure that there are no missing or redundant rules by systematically reviewing all possible combinations.

Confidence Scoring:

To incorporate confidence scoring based on the weight of each rule's conclusion:

* Assign a weight to each rule in your rulebase, representing the certainty or importance of that rule's conclusion.
* During the evaluation process, multiply the output value of each rule by its corresponding weight.
* Sum up the weighted output values from all applicable rules to obtain a weighted average as the final output.
* This weighted average reflects the system's confidence in the classification based on the combined certainty of the contributing rules.

Validation and Testing:

To validate and test the performance of your FIS, follow these steps:

* Gather a set of test data covering a range of input scenarios that are representative of real-world cases.
* Evaluate the FIS's performance by comparing its output classifications with expected outcomes for each test case.
* Analyse any discrepancies between predicted and expected results to identify areas for improvement.
* Adjust membership functions, rulebase, or defuzzification methods as necessary based on insights gained from the testing process.
* Repeat the validation process iteratively until the FIS demonstrates satisfactory performance across various input scenarios.

Look at classifying Stars instead.