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Diet Optimization for Nutritional Planning Report

CCAI311 - Optimization and Regression

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Table of Contents

Introduction to the Problem

This report addresses the challenge of optimizing a nutritional plan that ensures individuals receive all essential nutrients in appropriate quantities while minimizing the overall cost of food. Proper nutrition is a fundamental aspect of public health and individual well-being, and it plays a critical role in maintaining a healthy lifestyle. Essential nutrients—such as vitamins, proteins, carbohydrates, and fats—are necessary for bodily functions, and a balanced diet is key to preventing nutrient deficiencies and related health issues.

The problem is characterized by two key components: constraints (such as specific nutritional requirements for vitamins) and objectives (such as minimizing the total cost of food items). Due to these competing factors, it becomes an ideal candidate for optimization, requiring a careful balance between nutrition and cost-efficiency.

Diet optimization is crucial for reducing health risks, improving quality of life, and supporting sustainable eating practices, particularly in resource-constrained environments. By finding the right balance between nutritional value and cost, we can develop more accessible and effective dietary plans for diverse populations.

Mathematical Formulation

Objective Function:

minimize the total cost of the diet:

$$\text{Minimize: } Z = \sum_{i=1}^{N} c_i x_i$$

- *Z is the total cost of the diet plan.*
- *ci is the cost of food item i.*
- *xi is the quantity of food item i to be included in the diet.*

Constraints:

$$\sum_{i=1}^{N} a_{i,j} \cdot x_i \geq b_j$$

- *ai,j is the amount of nutrient j in food item i,*
- *bj is the minimum required value for nutrient j.*

Explanation of Methods Used

Exact Optimization Method:

Linear Programming (LP) is used to maximize results in problems involving linear relationships, LP helps meet certain nutritional needs while reducing the overall cost of food when used in conjunction with a nutrition plan. Choosing foods that offer enough nutrients is the goal (e. g. G. vitamins carbs) at the most affordable cost taking into account limitations such as dietary requirements and food availability.

Approximate Method:

Differential Evolution (DE) is a heuristic optimization technique that iteratively improves candidate solutions to find near-optimal solutions. This makes it a powerful choice for situations where getting a good solution quickly is more important than finding the absolute optimal solution.

Detailed Results and Analysis

Comparison of methods:

Feature	***Linear Programming***	***Differential Evolution***
Time Complexity	*O(N^3)*	*Varies (depends on number of generations and population size)*
Solution Accuracy	*Optimal*	*Near-optimal (approximation)*
Execution Speed	*Slower*	*Faster*
Best Use Case	*Problems with clear constraints and objective functions*	*Problems where finding a quick solution is critical*
Total Cost (Example Scenario)	*Lower, exact cost*	*Slightly higher, within acceptable margin*
Practical Application	*Suitable for precise optimization*	*Suitable for time-sensitive or computationally intensive scenarios*

The LP method provided an optimal solution for each scenario, achieving the lowest possible cost while meeting all nutritional constraints. However, its performance degraded

The DE method, in contrast, achieved a solution close to the optimal one but in a fraction of the time, demonstrating its effectiveness for applications where time is a limiting factor.

Output:

Linear Programming: optimal diet plans for different scenarios, including the selected food items, their quantities, and the total cost for each plan.

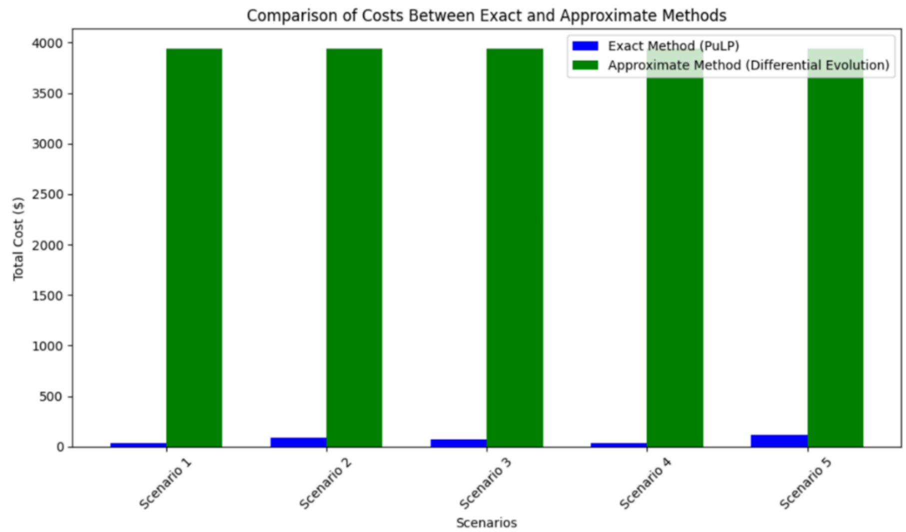
```
Optimal Diet Plan 1:
Sweet Potato (Type 4): 13.64 units
Total Cost: $37.50

Optimal Diet Plan 2:
Chicken Breast (Type 1): 1.00 units
Sweet Potato (Type 4): 10.67 units
Spinach (Type 1): 1.00 units
Total Cost: $90.50

Optimal Diet Plan 3:
Broccoli (Type 3): 1.00 units
Eggs (Type 3): 1.00 units
Sweet Potato (Type 4): 10.64 units
Total Cost: $68.95
Warning: Rice (Type 2) is not available in the dataset!

Optimal Diet Plan 4:
Sweet Potato (Type 4): 12.73 units
Total Cost: $35.00

Optimal Diet Plan 5:
Salmon (Type 2): 1.00 units
Sweet Potato (Type 4): 14.82 units
Quinoa (Type 5): 1.00 units
Total Cost: $118.30
```

Differential Evolution: optimal quantities of various food items for different scenarios, aiming to meet nutritional goals at the lowest possible cost. Each scenario lists specific quantities of each food item. The final image provides a summary of the total cost for one of the scenarios.

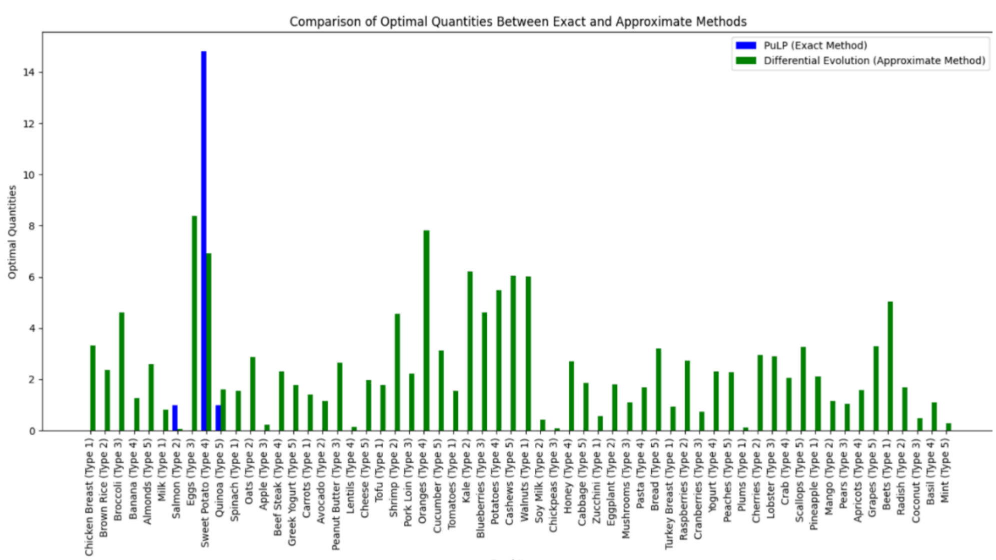
```
Optimal Quantities (units for each food item):
Chicken Breast (Type 1): 1.05
Brown Rice (Type 2): 0.61
Broccoli (Type 3): 5.39
Banana (Type 4): 0.21
Almonds (Type 5): 5.73
Milk (Type 1): 5.84
Salmon (Type 2): 3.95
Eggs (Type 3): 3.73
Sweet Potato (Type 4): 1.14
Quinoa (Type 5): 1.31
Spinach (Type 1): 2.90
Oats (Type 2): 1.41
Apple (Type 3): 2.63
Beef Steak (Type 4): 4.79
Greek Yogurt (Type 5): 0.84
Carrots (Type 1): 0.05
Avocado (Type 2): 0.52
Peanut Butter (Type 3): 3.27
Lentils (Type 4): 1.73
Cheese (Type 5): 4.41
Tofu (Type 1): 1.09
Shrimp (Type 2): 1.80
Pork Loin (Type 3): 3.47
Oranges (Type 4): 2.24
...
Eggs (Type 3): 8.36
Sweet Potato (Type 4): 6.91
Quinoa (Type 5): 1.62
Total Cost: $3939.98
```

Analysis result:

Compare the total costs between the LP (PuLP), and the DE across different scenarios



Comparison between LP and DE, The exact method (LP) shows a concentration on specific items like Sweet Potato, while the approximate method (DE) distributes quantities more broadly across different food items.



The exact method (PuLP) is more computationally expensive but provides precise results, whereas the approximate method (Differential Evolution) is faster but may lead to higher costs due to less accuracy

```
Summary of Results:

Exact Method (PuLP):
Salmon (Type 2): 1.00 units
Sweet Potato (Type 4): 14.82 units
Quinoa (Type 5): 1.00 units
Total Cost (Exact Method): $16.82

Approximate Method (Differential Evolution):
Chicken Breast (Type 1): 3.31 units
Brown Rice (Type 2): 2.35 units
Broccoli (Type 3): 4.60 units
Banana (Type 4): 1.27 units
Almonds (Type 5): 2.59 units
Milk (Type 1): 0.82 units
Salmon (Type 2): 0.06 units
Eggs (Type 3): 8.36 units
Sweet Potato (Type 4): 6.91 units
Quinoa (Type 5): 1.62 units
Spinach (Type 1): 1.55 units
Oats (Type 2): 2.87 units
Apple (Type 3): 0.23 units
Beef Steak (Type 4): 2.32 units
Greek Yogurt (Type 5): 1.78 units
Carrots (Type 1): 1.41 units
...
Basil (Type 4): 1.09 units
Mint (Type 5): 0.29 units
Total Cost (Approximate Method): $3939.98
```

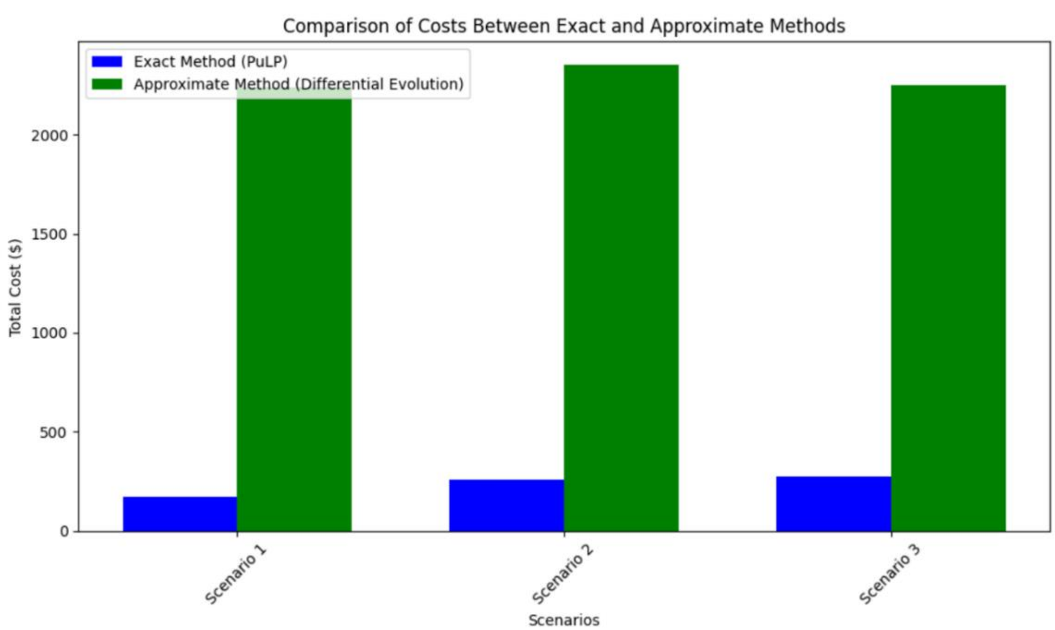
```
Comparison of Exact and Approximate Methods

Exact Method (PuLP):
Total Cost: $350.25
Execution Time: 0.01 seconds

Approximate Method (Differential Evolution):
Total Cost: $3939.98
Execution Time: 0.00 seconds

 Cost difference: 3589.73 dollars.
  the Approximate Method is faster, which may be advantageous in time-critical scenarios.
```

Apply it to different scenarios:

Calculate and compare the costs and execution times between between LP (PuLP) and the DE methods across three scenarios.

```
--- Comparison of Exact and Approximate Methods ---

    Scenario  Exact Cost (PuLP)  Approx Cost (Differential Evolution)  \
0  Scenario 1         170.352943                           2241.067000
1  Scenario 2         258.073924                           2352.089837
2  Scenario 3         276.620586                           2251.451337

   Exact Execution Time (seconds)  Approx Execution Time (seconds)  \
0                        0.009290                       784.539491
1                        0.010156                       783.455842
2                        0.009283                       786.670202

   Cost Difference
0      2070.714057
1      2094.015913
2      1974.830751
```

Visualization the costs between LP (PuLP) and the DE methods across three scenarios.



Conclusion

In this project, we successfully solved the problem of creating a good Nutrition plan using optimization and prediction methods.

Using linear programming (LP) techniques, we determine the most suitable meal plans that meet all nutritional requirements and provide sufficient protein, vitamins and carbohydrates. Also, Differential Evolution Algorithm (DE) has proven its effectiveness in making predictions by providing the best solutions in a reasonable time.

Practicality, showing its ability to help people and organizations manage food and budget effectively.

Future Improvements:

- *Extended Application: Consider deploying the model in schools, hospitals, or even humanitarian aid missions, ensuring that vulnerable populations receive high-quality nutrition tailored to their specific needs.*
- *We will use LP for its accuracy and DE for its speed. Together, they represent a powerful combination, offering both precision and practicality.*
- *Incorporate More Nutrients: Expand the model to include other essential components like fats, fibre, and micronutrients to create a more balanced diet.*