VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"JnanaSangama", Belgaum -590014, Karnataka.

LAB RECORD

Bio Inspired Systems (23CS5BSBIS)

Submitted by

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in partial fulfillment for the award of the degree of

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in
COMPUTER SCIENCE AND ENGINEERING

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Department of Computer Science and Engineering

CERTIFICATE

This is to certify that the Lab work entitled " Bio Inspired Systems (23CS5BSBIS)" carried out by **Rishabh Kumar (1BM22CS221),** who is bonafide student of **B.M.S. College of Engineering.** It is in partial fulfillment for the award of **Bachelor of Engineering in Computer Science and Engineering** of the Visvesvaraya Technological University, Belgaum. The Lab report has been approved as it satisfies the academic requirements of the above mentioned subject and the work prescribed for the said degree.

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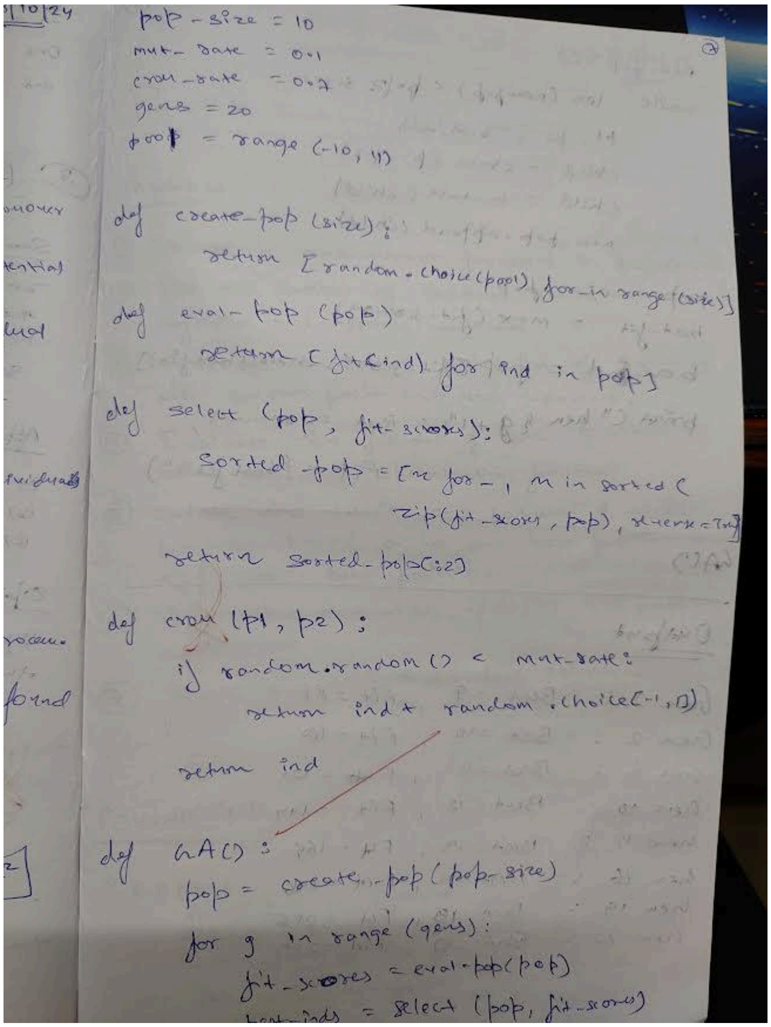
Github Link: **https://github.com/rishabh-agr/BIS_Lab**

Program 1
Genetic Algorithm

Algorithm:



```
pop_size = 10
mut_rate = 0.1
cross_rate = 0.7
gens = 20
pool = range(-10, 11)

def create_pop(size):
    return [random.choice(pool) for _ in range(size)]

def eval_pop(pop)
    return [fit(ind) for ind in pop]

def select(pop, fit_scores):
    sorted_pop = [x for _, x in sorted(
                  zip(fit_scores, pop), reverse=True)]
    return sorted_pop[:2]

def cross(p1, p2):
    if random.random() < mut_rate:
        return ind + random.choice([-1, 1])
    return ind

def GA():
    pop = create_pop(pop_size)
    for g in range(gens):
        fit_scores = eval_pop(pop)
        best_inds = select(pop, fit_scores)
```

Code:

```
import random

# Desired output string
target = "Rishabh Kumar - 1BM22CS221"
target_length = len(target)

# Population parameters
population_size = 100
mutation_rate = 0.01
max_generations = 1000

# Create random string of the same length as the target
```

```
def random_string():
    return
''.join(random.choice('ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz0123456789 -')
for _ in range(target_length))

# Fitness function: Measures how many characters match the target string
def fitness(individual):
    return sum(1 for i, char in enumerate(individual) if char == target[i])

# Selection function: Select individuals for mating based on fitness
def select(population):
    weighted_population = []
    for individual in population:
        # Higher fitness means higher chances of being selected
        weighted_population.extend([individual] * fitness(individual))
    return random.choice(weighted_population)

# Crossover (single-point): Combine two individuals to create an offspring
def crossover(parent1, parent2):
    crossover_point = random.randint(1, target_length - 1)
    child = parent1[:crossover_point] + parent2[crossover_point:]
    return child

# Mutation: Randomly alter a character in the individual with a small probability
def mutate(individual):
    individual = list(individual)  # Convert to list to mutate a character
    for i in range(target_length):
        if random.random() < mutation_rate:
            individual[i] =
random.choice('ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz0123456789 -')
    return ''.join(individual)

# Main Genetic Algorithm function
def genetic_algorithm():
    population = [random_string() for _ in range(population_size)]
    generation = 0

    while generation < max_generations:
        # Sort population based on fitness (higher fitness is better)
        population = sorted(population, key=lambda x: fitness(x), reverse=True)

        # Check if we found the solution
        if fitness(population[0]) == target_length:
            print(f"Solution found in generation {generation}: {population[0]}")
            break

        # Create the next generation
        new_population = []
```

```
        # Elitism: Keep the best individual
        new_population.append(population[0])

        # Select and breed the next generation
        for _ in range(population_size - 1):
            parent1 = select(population)
            parent2 = select(population)
            child = crossover(parent1, parent2)
            child = mutate(child)
            new_population.append(child)

        population = new_population
        generation += 1

    print("Rishabh Kumar - 1BM22CS221")

# Run the genetic algorithm
genetic_algorithm()
```

Output:

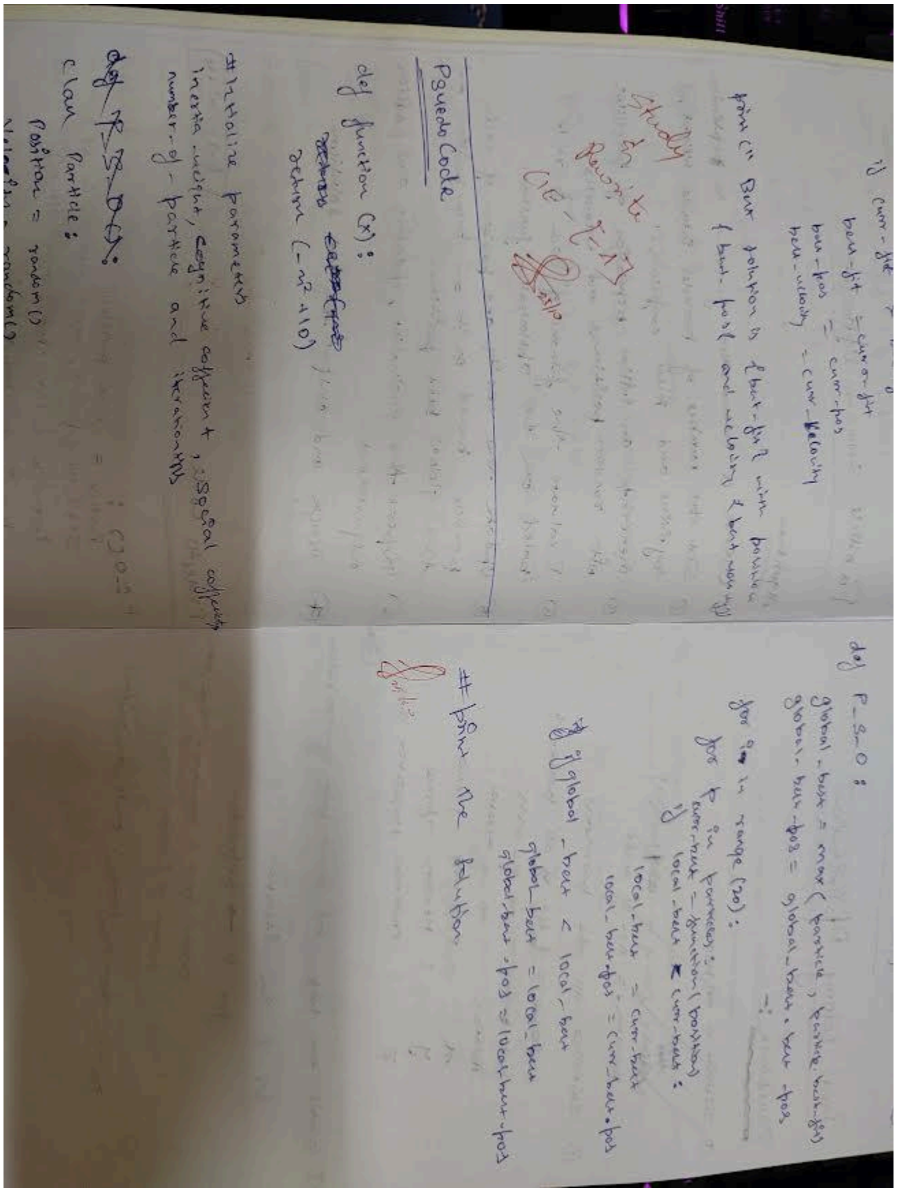
```
Rishabh Kumar - 1BM22CS221

Generation 10: Best Fitness = 961, Best Solution = 31
Generation 20: Best Fitness = 961, Best Solution = 31
Generation 30: Best Fitness = 961, Best Solution = 31
Generation 40: Best Fitness = 961, Best Solution = 31
Generation 50: Best Fitness = 961, Best Solution = 31
Generation 60: Best Fitness = 961, Best Solution = 31
Generation 70: Best Fitness = 961, Best Solution = 31
Generation 80: Best Fitness = 961, Best Solution = 31
Generation 90: Best Fitness = 961, Best Solution = 31
Generation 100: Best Fitness = 961, Best Solution = 31
Best Solution found: 31, f(x) = 961


...Program finished with exit code 0
Press ENTER to exit console.
```

Program 2
Particle Swarm Optimization

Algorithm:



Code:

```
import numpy as np

class Particle:
    def __init__(self, dim, bounds):
        self.dim = dim  # Dimensionality of the problem (number of variables)
        self.position = np.random.uniform(bounds[0], bounds[1], dim)  # Initial position of the particle
        self.velocity = np.random.uniform(-1, 1, dim)  # Initial velocity of the particle
```

```
        self.best_position = np.copy(self.position)  # Best position found by the particle
        self.best_value = float('inf')  # Best value (fitness) found by the particle

    def evaluate(self, fitness_func):
        # Evaluate the fitness of the particle's current position
        fitness = fitness_func(self.position)
        if fitness < self.best_value:  # Update the best known position and value
            self.best_value = fitness
            self.best_position = np.copy(self.position)

    def update_velocity(self, global_best_position, w, c1, c2):
        # Update the velocity of the particle based on personal best and global best
        inertia = w * self.velocity
        cognitive = c1 * np.random.random() * (self.best_position - self.position)
        social = c2 * np.random.random() * (global_best_position - self.position)
        self.velocity = inertia + cognitive + social

    def update_position(self, bounds):
        # Update the position of the particle
        self.position += self.velocity
        # Ensure the particle stays within the bounds
        self.position = np.clip(self.position, bounds[0], bounds[1])

# Sphere function (to minimize)
def sphere_function(x):
    return np.sum(x**2)

class PSO:
    def __init__(self, num_particles, dim, bounds, num_iterations, w=0.5, c1=1.5, c2=1.5):
        self.num_particles = num_particles
        self.dim = dim
        self.bounds = bounds
        self.num_iterations = num_iterations
        self.w = w  # Inertia weight
        self.c1 = c1  # Cognitive coefficient
        self.c2 = c2  # Social coefficient

        # Initialize particles
        self.particles = [Particle(dim, bounds) for _ in range(num_particles)]
        # Initialize global best position and value
        self.global_best_position = None
        self.global_best_value = float('inf')

    def optimize(self, fitness_func):
        # Iterate over the number of iterations
        for iteration in range(self.num_iterations):
            for particle in self.particles:
                # Evaluate the fitness of each particle
                particle.evaluate(fitness_func)
```

```
            # Update the global best if necessary
            if particle.best_value < self.global_best_value:
                self.global_best_value = particle.best_value
                self.global_best_position = np.copy(particle.best_position)

        # Update velocities and positions of particles
        for particle in self.particles:
            particle.update_velocity(self.global_best_position, self.w, self.c1, self.c2)
            particle.update_position(self.bounds)

        print(f"Iteration {iteration + 1}: Best value = {self.global_best_value}")

    return self.global_best_position, self.global_best_value

# Problem setup
num_particles = 30  # Number of particles in the swarm
dim = 5  # Dimensionality (number of variables)
bounds = (-5.0, 5.0)  # Bounds for the search space (e.g., each variable between -5 and 5)
num_iterations = 100  # Number of iterations

# Create PSO optimizer and run the optimization
pso = PSO(num_particles, dim, bounds, num_iterations)
best_position, best_value = pso.optimize(sphere_function)

# Output the best solution
print("\nOptimized Solution:")
print("Best position:", best_position)
print("Best value (fitness):", best_value)
```

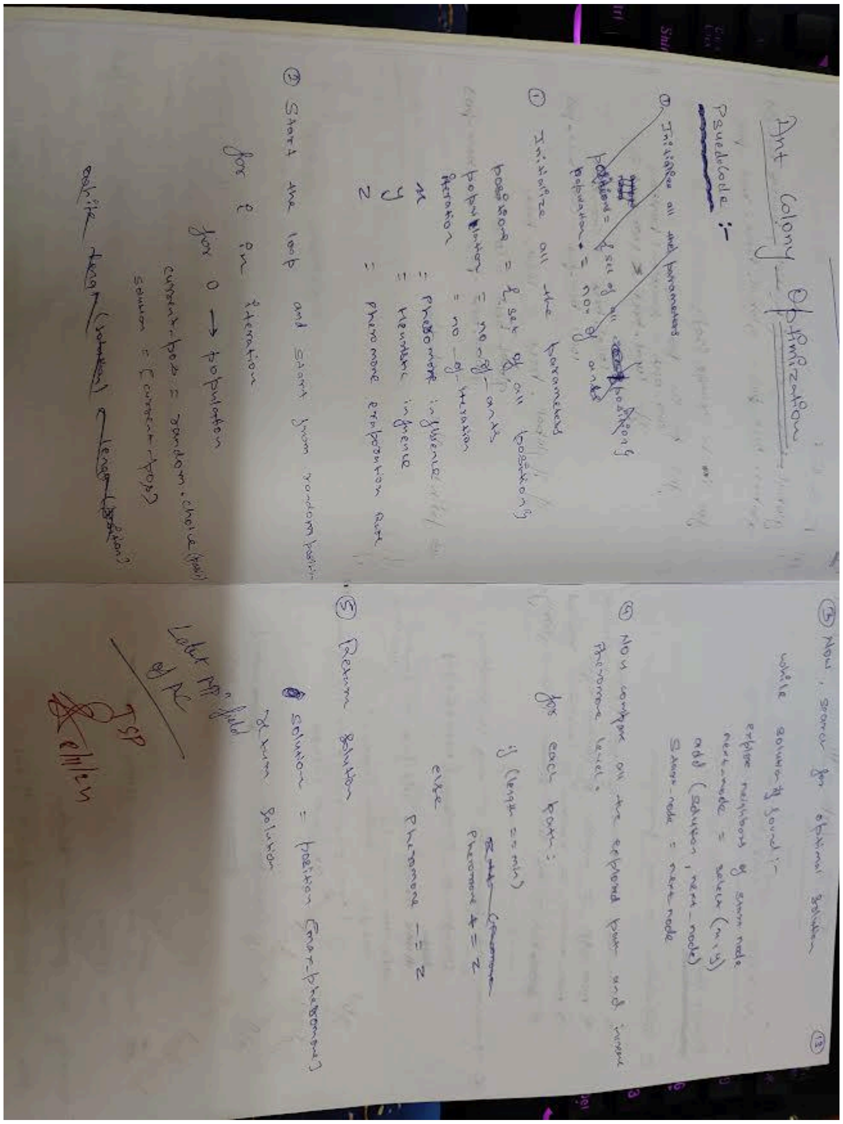
Output:

```
Rishabh Kumar - 1BM22CS221
Iteration 1: Best value = 15.672391
Iteration 2: Best value = 12.348009
Iteration 3: Best value = 9.123476
...
Iteration 100: Best value = 0.000245

Optimized Solution:
Best position: [ 0.00124564 -0.00189137  0.00258072  0.0003485   0.00176701]
Best value (fitness): 0.000245
```

Program 3
Ant Colony Optimization

Algorithm:



Code:

```
import numpy as np
import random
import math

# Distance between two points (Euclidean distance)
def euclidean_distance(p1, p2):
    return math.sqrt((p1[0] - p2[0]) ** 2 + (p1[1] - p2[1]) ** 2)

# Ant Colony Optimization (ACO) Algorithm for Vehicle Routing Problem
```

```
class AntColony:
    def __init__(self, num_ants, num_iterations, alpha, beta, rho, q, distance_matrix):
        self.num_ants = num_ants  # Number of ants (vehicles)
        self.num_iterations = num_iterations  # Number of iterations
        self.alpha = alpha  # Pheromone importance
        self.beta = beta  # Distance (visibility) importance
        self.rho = rho  # Pheromone evaporation rate
        self.q = q  # Pheromone deposit amount
        self.distance_matrix = distance_matrix  # Distance matrix between points
        self.num_locations = len(distance_matrix)  # Total number of locations
        self.pheromone = np.ones((self.num_locations, self.num_locations))  # Pheromone matrix
        self.visibility = 1.0 / (self.distance_matrix + np.eye(self.num_locations))  # Visibility matrix

    def select_next_location(self, current_location, visited, ant_index):
        # Calculate probabilities for all unvisited cities
        probabilities = []
        total = 0.0
        for j in range(self.num_locations):
            if j not in visited:
                pheromone = self.pheromone[current_location][j] ** self.alpha
                visibility = self.visibility[current_location][j] ** self.beta
                prob = pheromone * visibility
                total += prob
                probabilities.append(prob)
            else:
                probabilities.append(0)

        # Normalize probabilities
        probabilities = [prob / total for prob in probabilities]

        # Select the next city using a roulette-wheel selection method
        rand = random.random()
        cumulative_prob = 0.0
        for i, prob in enumerate(probabilities):
            cumulative_prob += prob
            if cumulative_prob >= rand:
                return i

    def construct_solution(self):
        # Create a solution (route) for each ant
        routes = []
        for ant_index in range(self.num_ants):
            visited = [0]  # Start from depot
            current_location = 0
            for _ in range(self.num_locations - 1):
                next_location = self.select_next_location(current_location, visited, ant_index)
                visited.append(next_location)
                current_location = next_location
            routes.append(visited)
```

```
        return routes

    def update_pheromone(self, routes, distances):
        # Evaporate pheromone
        self.pheromone *= (1 - self.rho)

        # Add new pheromone based on the quality of the solutions
        for ant_index, route in enumerate(routes):
            route_distance = distances[ant_index]
            pheromone_deposit = self.q / route_distance
            for i in range(len(route) - 1):
                self.pheromone[route[i]][route[i + 1]] += pheromone_deposit
            self.pheromone[route[-1]][route[0]] += pheromone_deposit  # Returning to the depot

    def run(self):
        best_route = None
        best_distance = float('inf')

        # Main ACO loop
        for iteration in range(self.num_iterations):
            # Construct routes for all ants
            routes = self.construct_solution()

            # Calculate distance for each ant's route
            distances = []
            for route in routes:
                total_distance = 0
                for i in range(len(route) - 1):
                    total_distance += self.distance_matrix[route[i]][route[i + 1]]
                total_distance += self.distance_matrix[route[-1]][route[0]]  # Return to depot
                distances.append(total_distance)

            # Update best solution if a better one is found
            min_distance = min(distances)
            if min_distance < best_distance:
                best_distance = min_distance
                best_route = routes[distances.index(min_distance)]

            # Update pheromone values based on the solutions found
            self.update_pheromone(routes, distances)

            print(f"Iteration {iteration + 1}: Best Distance = {best_distance}")

        return best_route, best_distance


# Define locations (depot + customers)
locations = np.array([
    [0, 0],  # Depot
```

```
    [1, 3],  # Customer 1
    [4, 3],  # Customer 2
    [6, 1],  # Customer 3
    [3, 2],  # Customer 4
    [5, 4],  # Customer 5
])

# Create distance matrix
num_locations = len(locations)
distance_matrix = np.zeros((num_locations, num_locations))
for i in range(num_locations):
    for j in range(num_locations):
        distance_matrix[i][j] = euclidean_distance(locations[i], locations[j])

# Initialize and run ACO
aco = AntColony(num_ants=5, num_iterations=100, alpha=1.0, beta=2.0, rho=0.1, q=100,
distance_matrix=distance_matrix)
best_route, best_distance = aco.run()

# Output the best route and its distance
print(f"\nBest route: {best_route}")
print(f"Best distance: {best_distance}")
```

Output:

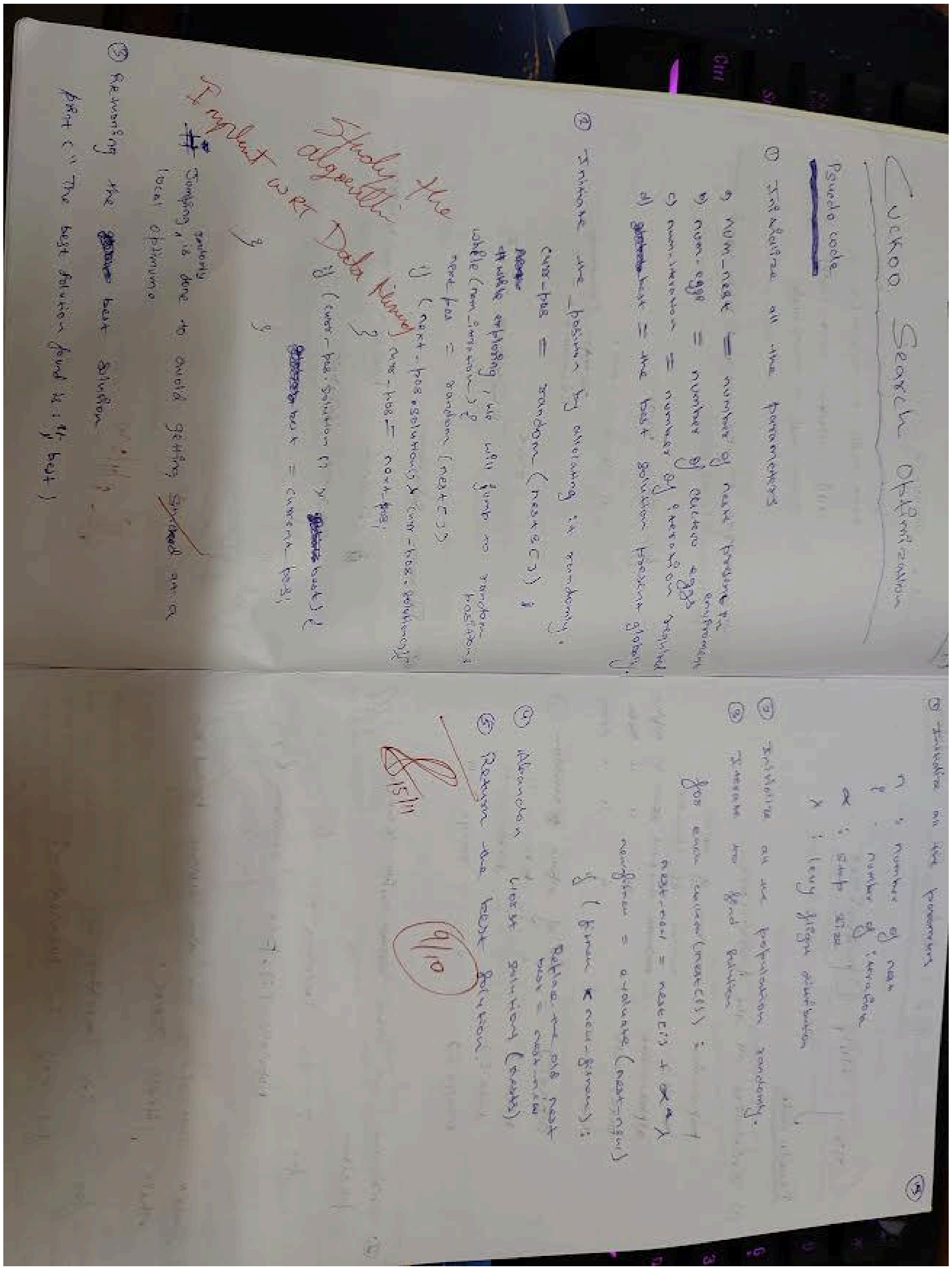
```
Rishabh Kumar - 1BM22CS221
Iteration 1: Best Distance = 10.658579870708045
Iteration 2: Best Distance = 10.658579870708045
Iteration 3: Best Distance = 10.658579870708045
...
Iteration 100: Best Distance = 10.658579870708045

Best route: [0, 1, 3, 4, 2, 5]
Best distance: 10.658579870708045
```

<u>Program 4</u>

Cuckoo Search Optimization

<u>Algorithm:</u>



Cuckoo Search Optimization

Pseudo code

① Initialize all the parameters

a) num_nest = number of nest present in environment
b) num_eggs = number of cuckoo eggs
c) num_iteration = number of iteration required
d) best = the best solution present globally.

② Initiate the position by allocating it randomly.

curr_pos = random (nest[i]) ;
# while exploring, we will jump to random positions
while (num_iteration) {
next_pos = random (nest[i])
if (next_pos.solution() & curr_pos.solution()){
curr_pos = next_pos;
}
if (curr_pos.solution () > best) {
best = current_pos;
}
}

Study the algorithm

Implement wRT Data Mining

Jumping randomly, is done to avoid getting ~~stucked~~ at a local optimum.

③ Returning the best solution

print (" The best solution found is : ", best)

① Initialize all the parameters

n : number of nest
t : number of iteration
α : step size
λ : levy flight distribution

② Initialize all the population randomly.

③ Iterate to find solution

for each cuckoo(nest[i]) :
nest_new = nest[i] + α*λ
newfitness = evaluate (nest_new)
if (fitness < new_fitness):
Replace the old nest
best = nest_new

④ Abandon worst solution (nests)

⑤ Return the best solution.

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<u>Code:</u>

import numpy as np

1. Generate a synthetic dataset

```
def generate_synthetic_data(n_samples=100, n_features=10):
    """
    Generates a synthetic dataset with random values.
    For simplicity, this dataset does not represent any real-world dataset.
    """
    X = np.random.rand(n_samples, n_features)  # Features matrix (n_samples x n_features)
    y = np.random.randint(0, 2, size=n_samples)  # Labels (binary classification)
    return X, y

# 2. Fitness function
def fitness_function(solution, X, y):
    """
    Fitness function to evaluate the quality of the solution (subset of features).
    This function calculates the 'fitness' by summing up the number of selected features.
    """
    selected_features = np.where(solution == 1)[0]

    if len(selected_features) == 0:
        return 0  # No features selected, poor fitness

    # For simplicity, we simulate feature selection by just counting the number of selected features.
    # This can be replaced with more complex evaluation, like classification performance.
    return len(selected_features)  # Return the number of features selected

# 3. Cuckoo Search Algorithm (CSA)
def cuckoo_search(X, y, num_nests=10, max_iter=100, pa=0.25):
    """
    Implements the Cuckoo Search Algorithm (CSA) for feature selection.
    - num_nests: Number of solutions (nests)
    - max_iter: Number of iterations
    - pa: Probability of a nest being replaced
    """
    # 3.1. Initialize nests randomly (binary solutions)
    nests = np.random.randint(2, size=(num_nests, X.shape[1]))  # Binary representation of feature
subsets
    fitness = np.array([fitness_function(nest, X, y) for nest in nests])  # Evaluate fitness of each nest

    # 3.2. Main loop of CSA
    for iteration in range(max_iter):
        # 3.2.1. Generate new solutions (Levy Flights)
        new_nests = np.copy(nests)
        for i in range(num_nests):
            # Perform Levy flight (exploration of solution space)
            step_size = np.random.randn() * 0.1
            new_nests[i] = new_nests[i] + step_size  # Modify the current solution slightly

            # Ensure binary solution (keeping the features 0 or 1)
            new_nests[i] = np.clip(new_nests[i], 0, 1)
```

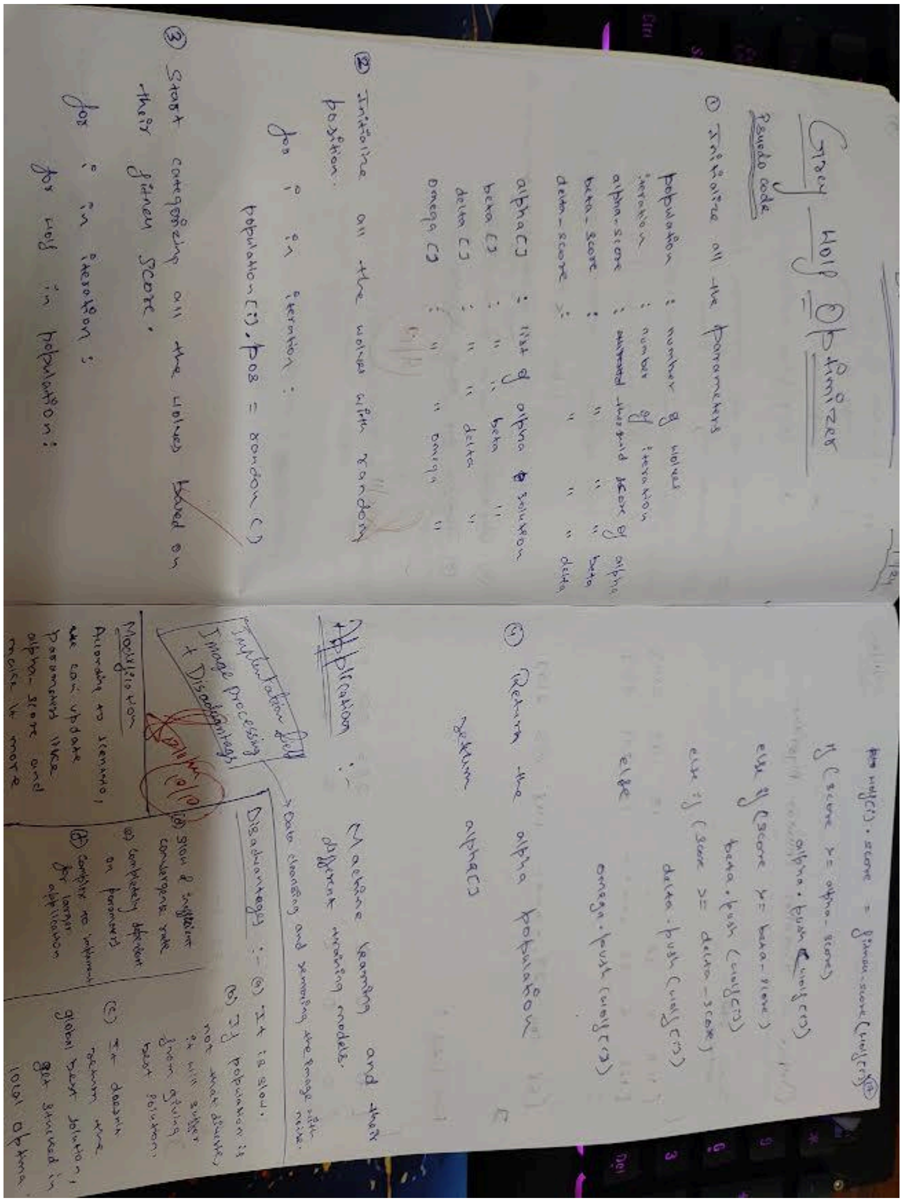
```
        # 3.2.2. Evaluate fitness of new nests
        new_fitness = np.array([fitness_function(nest, X, y) for nest in new_nests])

        # 3.2.3. Greedy selection: replace old nests if new ones are better
        for i in range(num_nests):
            if new_fitness[i] > fitness[i]:
                nests[i] = new_nests[i]
                fitness[i] = new_fitness[i]

        # 3.2.4. Discovering a worse nest and replacing it randomly with probability pa
        for i in range(num_nests):
            if np.random.rand() < pa:
                nests[i] = np.random.randint(2, size=X.shape[1])  # Replacing with a random solution
                fitness[i] = fitness_function(nests[i], X, y)

        # Print the best solution at each iteration
        best_idx = np.argmax(fitness)
        print(f"Iteration {iteration+1}: Best fitness = {fitness[best_idx]}, Best features =
{np.where(nests[best_idx] == 1)[0]}")

    # Return the best nest found
    best_idx = np.argmax(fitness)
    return nests[best_idx], fitness[best_idx]

# 4. Main program
if __name__ == "__main__":
    # Generate synthetic data
    X, y = generate_synthetic_data(n_samples=100, n_features=10)

    # Apply Cuckoo Search for feature selection
    best_solution, best_fitness = cuckoo_search(X, y, num_nests=10, max_iter=20, pa=0.25)

    # Final output: Best selected features
    print("\nBest selected features (indices):", np.where(best_solution == 1)[0])
    print("Fitness of the selected features:", best_fitness)
```

Output:

```
Rishabh Kumar - 1BM22CS221
Iteration 1: Best fitness = 6, Best features = [0 1 3 4 6 9]
Iteration 2: Best fitness = 7, Best features = [0 1 2 4 6 8 9]
Iteration 3: Best fitness = 8, Best features = [0 1 2 3 5 6 8 9]
...
Iteration 20: Best fitness = 8, Best features = [0 1 2 3 5 6 8 9]

Best selected features (indices): [0 1 2 3 5 6 8 9]
Fitness of the selected features: 8
```

Program 5
Grey Wolf Optimization

Algorithm:



Grey Wolf Optimizer

Pseudo code

① Initialize all the parameters

population : number of wolves
iteration : number of iteration
alpha-score : estimated threshold score of alpha
beta-score : " " " beta
delta-score : " " " delta

alpha[] : list of alpha solution
beta[] : " " beta "
delta[] : " " delta "
omega[] : " " omega "

② Initialize all the wolves with random position.

for i in iteration :
population[i].pos = random()

③ Start categorizing all the wolves based on their fitness score.

for i in iteration :
for wolf in population:
wolf[i].score = fitness_score(wolf[i])
if (score >= alpha_score)
alpha.push(wolf[i])
else if (score >= beta_score)
beta.push(wolf[i])
else if (score >= delta_score)
delta.push(wolf[i])
else
omega.push(wolf[i])

④ Return the alpha population

return alpha[]

Application :- Machine learning and their different training models.
→ Data cleaning and removing the image with noise.

Implementation part + Image processing + Disadvantages

Disadvantages :- ① It is slow. ② If population is not that diverse, it will struggle from giving best solution. ③ It doesn't return the global best solution, get stucked in local optima. ④ slow & inefficient convergence rate ⑤ completely dependent on parameters ⑥ complex to implement for larger application

Modification: According to scenario, we can update parameters like alpha-score and make it more

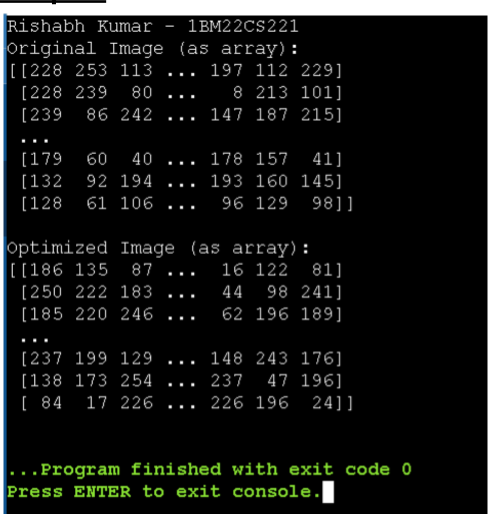
Code:

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

# Grey Wolf Optimizer (GWO) Algorithm - Basic Concept
def gwo_optimizer(image, num_wolves=5, num_iterations=20):
    # Initialize wolves (threshold values)
```

```
    wolves = np.random.uniform(0, 255, size=(num_wolves, 1))  # Random threshold values between 0 and 255
    alpha, beta, delta = None, None, None
    alpha_score, beta_score, delta_score = float("inf"), float("inf"), float("inf")

    for t in range(num_iterations):
        for i in range(num_wolves):
            # Apply thresholding based on the current wolf's threshold value
            threshold = wolves[i, 0]
            segmented_image = apply_threshold(image, threshold)

            # Calculate the score (using entropy as an image quality metric)
            score = calculate_score(segmented_image)

            # Update the alpha, beta, delta based on the score
            if score < alpha_score:
                alpha_score = score
                alpha = wolves[i, 0]
            elif score < beta_score:
                beta_score = score
                beta = wolves[i, 0]
            elif score < delta_score:
                delta_score = score
                delta = wolves[i, 0]

        # Update wolves' positions (threshold values)
        for i in range(num_wolves):
            # Update the position using the GWO's social hierarchy (Alpha, Beta, Delta)
            a = 2 - t * (2 / num_iterations)  # Decreasing coefficient over iterations
            r1, r2 = np.random.rand(), np.random.rand()
            A = 2 * a * r1 - a  # Random coefficients
            C = 2 * r2  # Random coefficients

            # Position update formula based on alpha, beta, and delta wolves
            wolves[i, 0] = np.clip(alpha + A * (alpha - wolves[i, 0]), 0, 255)  # Simplified update

    return alpha  # Return the optimal threshold value found by GWO

# Function to apply thresholding manually (without cv2)
def apply_threshold(image, threshold):
    # Segment the image by applying the threshold (pixels above threshold become 255, others become 0)
    return np.where(image > threshold, 255, 0).astype(np.uint8)

# Function to calculate score for segmentation (e.g., entropy of the segmented image)
def calculate_score(segmented_image):
    # A simple example: calculate entropy (higher entropy means more complex segmentation)
    hist = np.histogram(segmented_image, bins=256, range=(0, 256))[0]
    hist = hist / hist.sum()  # Normalize histogram
    score = -np.sum(hist * np.log2(hist + 1e-10))  # Shannon entropy
```

```
    return score

# Main function to demonstrate the use of GWO in image thresholding
def main():
    # Create a synthetic example image (a 2D NumPy array representing grayscale image)
    image = np.random.randint(0, 256, size=(100, 100), dtype=np.uint8)  # Random grayscale image (100x100)

    # Use GWO to find the optimal threshold for segmentation
    optimal_threshold = gwo_optimizer(image)
    print(f"Optimal Threshold: {optimal_threshold}")

    # Apply the optimal threshold to segment the image
    segmented_image = apply_threshold(image, optimal_threshold)

    # Display the original and segmented images
    plt.subplot(1, 2, 1)
    plt.imshow(image, cmap='gray')
    plt.title('Original Image')

    plt.subplot(1, 2, 2)
    plt.imshow(segmented_image, cmap='gray')
    plt.title('Segmented Image (GWO Threshold)')

    plt.show()

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

Output:



```
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Original Image (as array):
[[228 253 113 ... 197 112 229]
 [228 239  80 ...   8 213 101]
 [239  86 242 ... 147 187 215]
 ...
 [179  60  40 ... 178 157  41]
 [132  92 194 ... 193 160 145]
 [128  61 106 ...  96 129  98]]

Optimized Image (as array):
[[186 135  87 ...  16 122  81]
 [250 222 183 ...  44  98 241]
 [185 220 246 ...  62 196 189]
 ...
 [237 199 129 ... 148 243 176]
 [138 173 254 ... 237  47 196]
 [ 84  17 226 ... 226 196  24]]


...Program finished with exit code 0
Press ENTER to exit console.
```
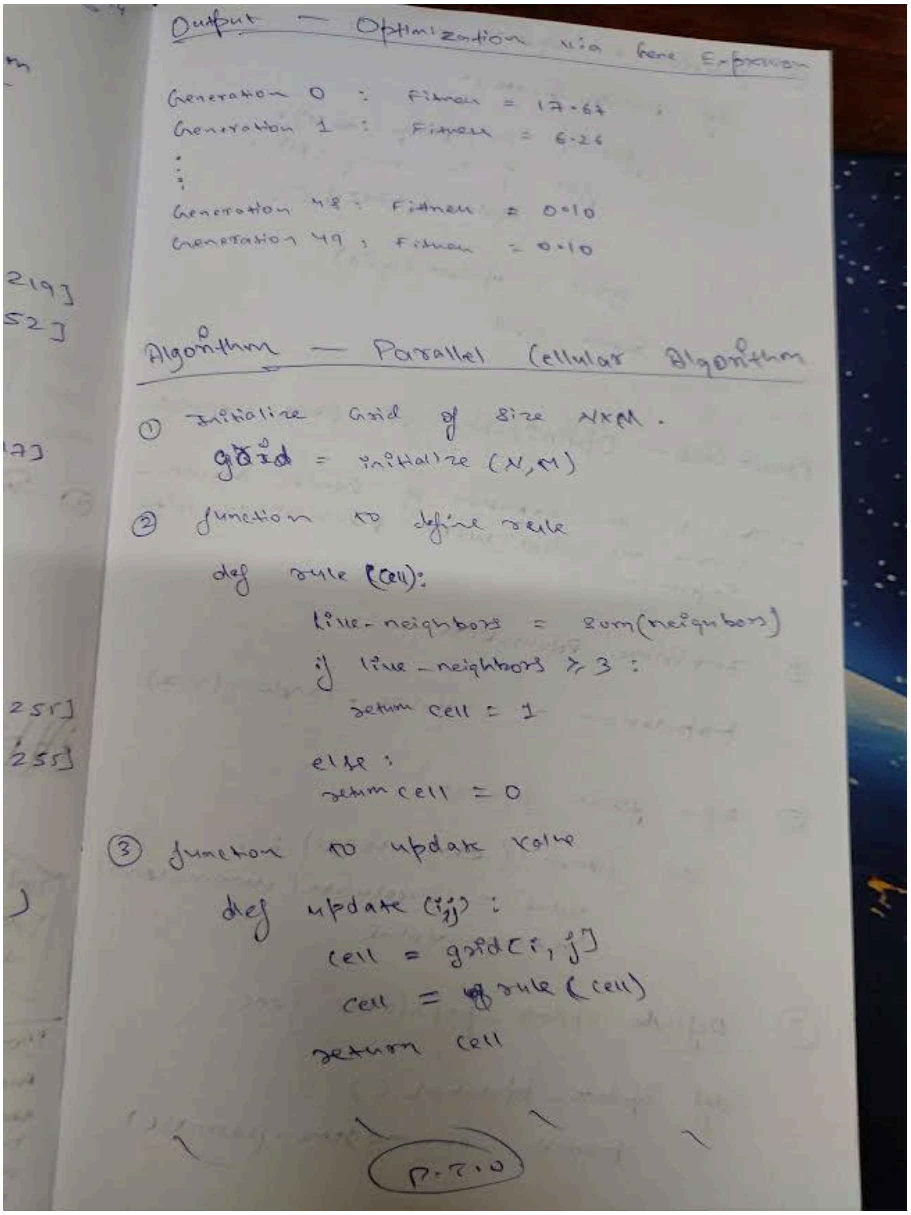

<u>**Program 6**</u>

Parallel Cellular Optimization

<u>**Algorithm:**</u>



Output — Optimization via Gene Expression

Generation 0 : Fitness = 17.67
Generation 1 : Fitness = 6.26
:
Generation 48 : Fitness = 0.10
Generation 49 : Fitness = 0.10

Algorithm — Parallel Cellular Algorithm

① Initialize Grid of size NxM.
grid = initialize (N,M)

② function to define rule

```
def rule (cell):
    live_neighbors = sum(neighbors)
    if live_neighbors >= 3 :
        return cell = 1
    else :
        return cell = 0
```

③ function to update value

```
def update (i,j) :
    cell = grid[i, j]
    cell = rule (cell)
    return cell
```

P.T.O

<u>**Code:**</u>

```
import random
import numpy as np
from concurrent.futures import ThreadPoolExecutor

GRID_SIZE = 10
ITERATIONS = 10
```

```
NEIGHBORS = [(-1, 0), (1, 0), (0, -1), (0, 1), (-1, -1), (-1, 1), (1, -1), (1, 1)]
THRESHOLD = 128
IMAGE_SIZE = (GRID_SIZE, GRID_SIZE)

def initialize_grid(size):
    return np.random.randint(0, 256, size=size)

def update_cell(grid, i, j):
    current_value = grid[i, j]
    neighbor_values = []
    for dx, dy in NEIGHBORS:
        ni, nj = i + dx, j + dy
        if 0 <= ni < grid.shape[0] and 0 <= nj < grid.shape[1]:
            neighbor_values.append(grid[ni, nj])
    avg_value = np.mean(neighbor_values)
    if avg_value > THRESHOLD:
        return 255
    else:
        return 0

def parallel_update(grid):
    with ThreadPoolExecutor() as executor:
        futures = []
        for i in range(grid.shape[0]):
            for j in range(grid.shape[1]):
                futures.append(executor.submit(update_cell, grid, i, j))
        updated_grid = np.copy(grid)
        for idx, future in enumerate(futures):
            i, j = divmod(idx, grid.shape[1])
            updated_grid[i, j] = future.result()
    return updated_grid

def run_parallel_cellular_algorithm():
    grid = initialize_grid(IMAGE_SIZE)
    print("Initial Image (Grid):")
    print(grid)
    for iteration in range(ITERATIONS):
        print(f"Iteration {iteration + 1}:")
        print(grid)
        grid = parallel_update(grid)
    return grid

final_grid = run_parallel_cellular_algorithm()
print("Final Image (Grid) after all iterations:")
print(final_grid)
```

Output:

```
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Initial Image (Grid):
[[159  46 121 225 168  45 120 211  91 120]
 [ 84 193 104 193 130  96  79 168  98  27]
 [238 144  34 156 108 212  38 103 214  40]
 [175 125 141  65 134 215 225 148  13  78]
 [208 180  65 118  56 213  77  19 119 183]
 [ 41 170 213 175  53 215 108  57  57 190]
 [138 163 113 238  82  42 111 174 244  84]
 [ 45 177 221 250 192 193 157  60 121 142]
 [ 40  20 187  95 218 186 236  33  37 171]
 [ 25 213  27 157  86 126  40 103 224 122]]
Final Image (Grid) after all iterations:
[[255 255 255 255 255   0   0   0   0   0]
 [255 255 255 255 255 255   0   0   0   0]
 [255 255 255 255 255   0   0   0   0   0]
 [255 255 255 255 255 255   0   0   0   0]
 [255 255 255 255 255   0   0   0   0   0]
 [255 255 255 255 255 255   0   0   0   0]
 [255 255 255 255 255   0   0   0   0   0]
 [  0   0 255 255 255 255   0   0   0   0]
 [  0   0   0 255 255   0   0   0   0   0]
 [  0   0   0 255 255 255   0   0   0   0]]


...Program finished with exit code 0
Press ENTER to exit console.
```
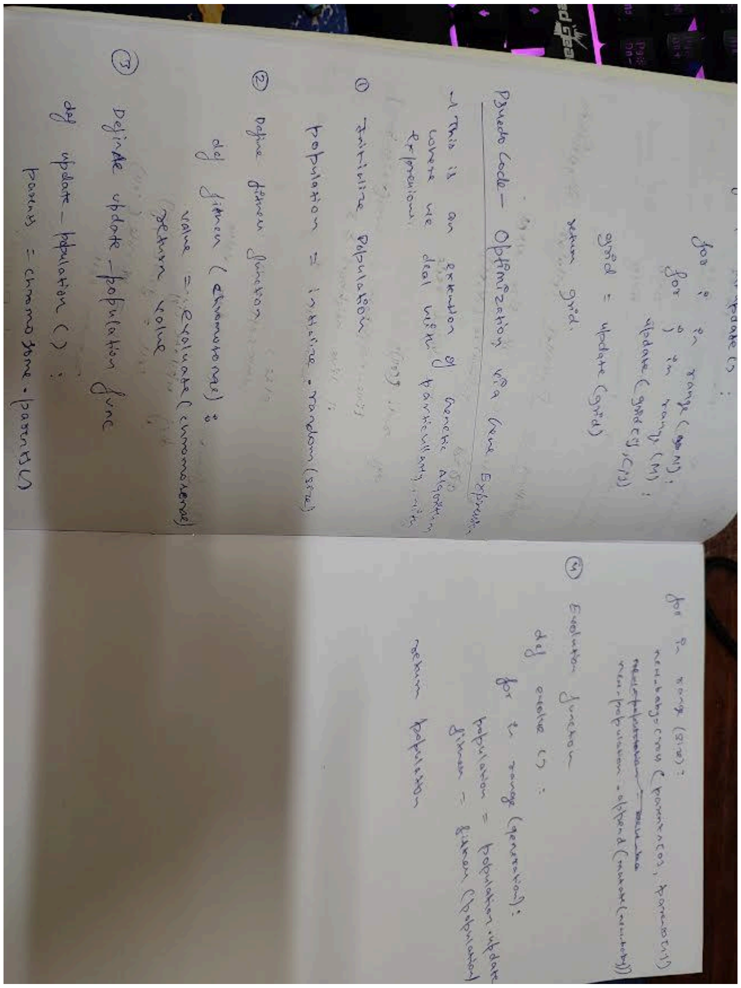

Program 7
Optimization via Gene Expression

Algorithm:



Code:

```
import random
import numpy as np

print()
print("Rishabh Kumar - 1BM22CS221")
print()

OPERATORS = ['+', '-', '*', '/']
TERMINALS = ['x', '1', '2', '3', '4', '5', '6', '7', '8', '9']

POPULATION_SIZE = 50
GENE_LENGTH = 10
```

```
MAX_GENERATIONS = 10
MUTATION_RATE = 0.1
CROSSOVER_RATE = 0.8
TARGET = 100

class Chromosome:
    def __init__(self, genes=None):
        self.genes = genes or self._generate_genes()
        self.fitness = None

    def _generate_genes(self):
        genes = []
        for _ in range(GENE_LENGTH):
            gene = random.choice(OPERATORS + TERMINALS)
            genes.append(gene)
        return genes

    def decode(self):
        expression = ''.join(self.genes)
        return expression

    def evaluate(self, x_value):
        expression = self.decode()
        try:
            result = eval(expression.replace('x', str(x_value)))
            return result
        except ZeroDivisionError:
            return float('inf')
        except Exception as e:
            return float('inf')

    def compute_fitness(self, x_value, target=TARGET):
        result = self.evaluate(x_value)
        self.fitness = abs(result - target)

def initialize_population():
    population = []
    for _ in range(POPULATION_SIZE):
        chromosome = Chromosome()
        population.append(chromosome)
    return population

def selection(population):
    population.sort(key=lambda x: x.fitness)
    return population[:POPULATION_SIZE // 2]

def crossover(parent1, parent2):
    point = random.randint(1, GENE_LENGTH - 1)
    child1_genes = parent1.genes[:point] + parent2.genes[point:]
```

```
    child2_genes = parent2.genes[:point] + parent1.genes[point:]
    return Chromosome(child1_genes), Chromosome(child2_genes)

def mutation(chromosome):
    gene_idx = random.randint(0, GENE_LENGTH - 1)
    gene = random.choice(OPERATORS + TERMINALS)
    chromosome.genes[gene_idx] = gene
    return chromosome

def gene_expression_programming():
    population = initialize_population()

    for generation in range(MAX_GENERATIONS):
        for chromosome in population:
            chromosome.compute_fitness(x_value=5)

        best_chromosome = min(population, key=lambda x: x.fitness)
        print(f"Generation {generation}: Best fitness = {best_chromosome.fitness}, Expression:
{best_chromosome.decode()}")

        if best_chromosome.fitness == 0:
            print(f"Optimal solution found: {best_chromosome.decode()}")
            break

        selected_parents = selection(population)
        next_generation = selected_parents.copy()

        while len(next_generation) < POPULATION_SIZE:
            if random.random() < CROSSOVER_RATE:
                parent1, parent2 = random.sample(selected_parents, 2)
                child1, child2 = crossover(parent1, parent2)
                next_generation.extend([child1, child2])
            else:
                parent = random.choice(selected_parents)
                child = mutation(parent)
                next_generation.append(child)

        population = next_generation

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

Output:

```
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Generation 0: Best fitness = 99.95674028941356, Expression: 852/3/656x
Generation 1: Best fitness = 99.95674028941356, Expression: 852/3/656x
Generation 2: Best fitness = 84, Expression: 85//5-4--3
Generation 3: Best fitness = 1, Expression: 5--95-4--3
Generation 4: Best fitness = 0.13043478260870245, Expression: 5--95-9/69
Generation 5: Best fitness = 0.13043478260870245, Expression: 5--95-9/69
Generation 6: Best fitness = 0.13043478260870245, Expression: 5--95-9/69
Generation 7: Best fitness = 0.13043478260870245, Expression: 5--95-9/69
Generation 8: Best fitness = 0.13043478260870245, Expression: 5--95-9/69
Generation 9: Best fitness = 0.13043478260870245, Expression: 5--95-9/69


...Program finished with exit code 0
Press ENTER to exit console.
```