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

BACHELOR OF ENGINEERING
in
COMPUTER SCIENCE AND ENGINEERING

B.M.S. COLLEGE OF ENGINEERING
(Autonomous Institution under VTU)
BENGALURU-560019
Sep-2024 to Jan-2025

B.M.S. College of Engineering,
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CERTIFICATE

This is to certify that the Lab work entitled " Bio Inspired Systems (23CS5BSBIS)" carried out by **Shreyansh Sethiya (1BM22CS269)** 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/Shreyanshsethiya/BISLAB

Program 1

Genetic Algorithm for Optimization Problems

Algorithm:

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Genetic Algorithm

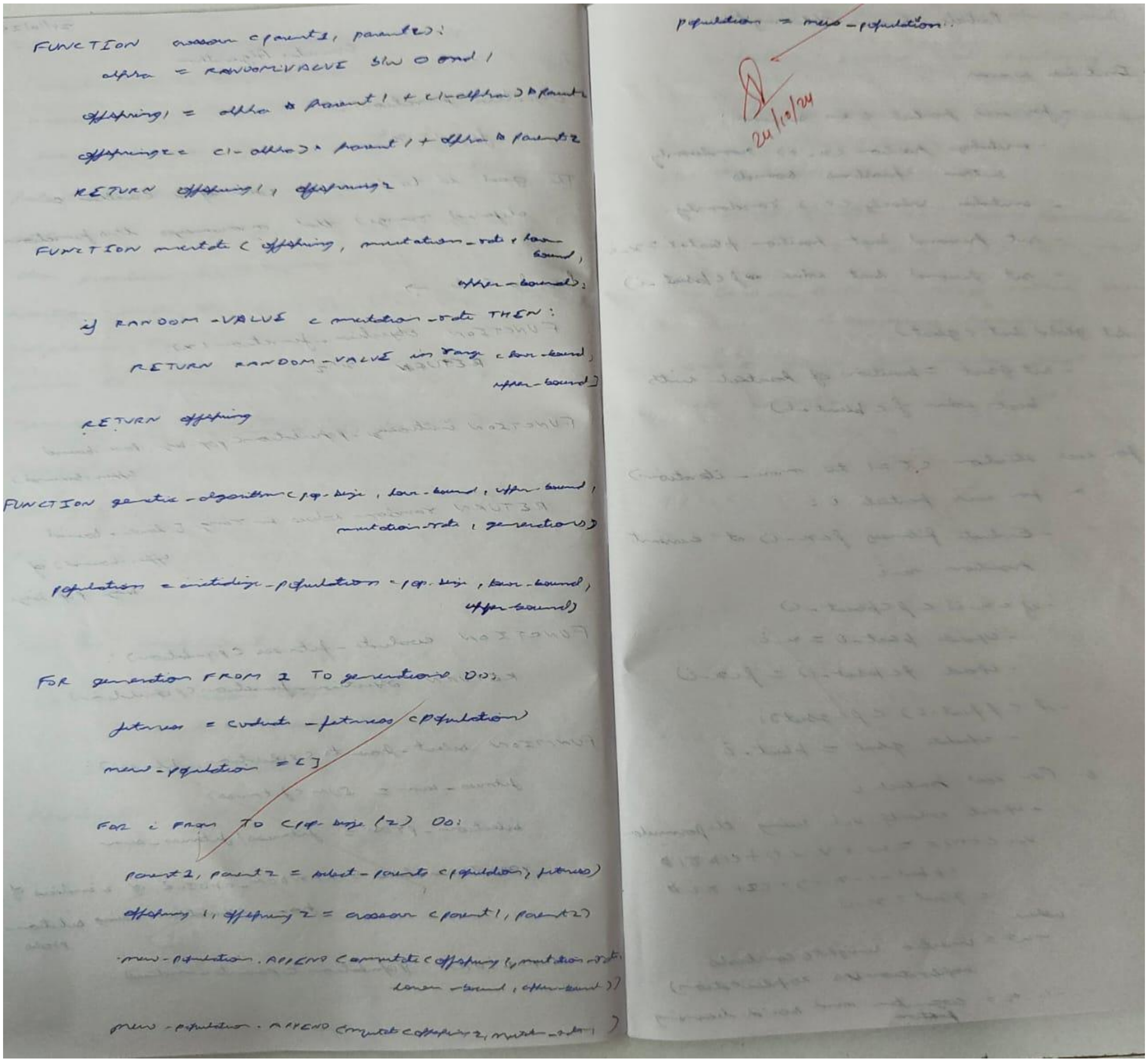
Objective function:

$f(x) = x^2$

The goal is to find the value of x (within a defined range) that maximizes this function

Pseudo code →

```
FUNCTION objective_function (x):
    RETURN x^2

FUNCTION initialize_population(pop_size, lower_bound,
                                upper_bound):

    RETURN random values in range [lower_bound,
                                   upper_bound] of
                                   size pop_size

FUNCTION evaluate_fitness (population):
    RETURN objective_function(population)

FUNCTION select_parents (population, fitness):
    fitness_sum = SUM (fitness)
    selection_probs = fitness / fitness_sum
    parents_indices = RANDOM_CHOICE of 2 indices of
                      from population using selection_
                      probs

    RETURN population (parents_indices)
```


FUNCTION crossover(parent1, parent2):
alpha = RANDOM_VALUE b/w 0 and 1
offspring1 = alpha * parent1 + (1-alpha) * parent2
offspring2 = (1-alpha) * parent1 + alpha * parent2
RETURN offspring1, offspring2

FUNCTION mutate(offspring, mutation_rate, lower_bound, upper_bound):
if RANDOM_VALUE < mutation_rate THEN:
RETURN RANDOM_VALUE in range (lower_bound, upper_bound)
RETURN offspring

FUNCTION genetic_algorithm(pop_size, lower_bound, upper_bound, mutation_rate, generations)
population = initialize_population(pop_size, lower_bound, upper_bound)
FOR generation FROM 1 TO generations DO:
fitness = evaluate_fitness(population)
new_population = []
FOR i FROM 1 TO (pop_size / 2) DO:
parent1, parent2 = select_parents(population, fitness)
offspring1, offspring2 = crossover(parent1, parent2)
new_population.APPEND(mutate(offspring1, mutation_rate, lower_bound, upper_bound))
new_population.APPEND(mutate(offspring2, mutation_rate,)
population = new_population
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Code:

```
import random

# Set a random seed for reproducibility
random.seed(42)

def fitness(chromosome):
    x = int(''.join(map(str, chromosome)), 2)
    return x ** 2

def binary_string_to_chromosome(binary_string):
```

```
    return [int(bit) for bit in binary_string]

def generate_population_from_input():
    population = []
    for _ in range(population_size):
        while True:
            binary_string = input("Enter a binary string of size 5 (e.g., '11001'): ")
            if len(binary_string) == 5 and all(bit in '01' for bit in binary_string):
                population.append(binary_string_to_chromosome(binary_string))
                break
            else:
                print("Invalid input. Please enter a binary string of size 5.")
    return population

def select_pair(population, fitnesses):
    total_fitness = sum(fitnesses)
    selection_probs = [f / total_fitness for f in fitnesses]
    parent1 = population[random.choices(range(len(population)), selection_probs)[0]]
    parent2 = population[random.choices(range(len(population)), selection_probs)[0]]
    return parent1, parent2

def crossover(parent1, parent2):
    point = random.randint(1, len(parent1) - 1)
    offspring1 = parent1[:point] + parent2[point:]
    offspring2 = parent2[:point] + parent1[point:]
    return offspring1, offspring2

def mutate(chromosome, mutation_rate):
    return [gene if random.random() > mutation_rate else 1 - gene for gene in chromosome]

# Parameters
population_size = 4
generations = 20
mutation_rate = 0.01

# Initialize population from user input
population = generate_population_from_input()

for generation in range(generations):
    fitnesses = [fitness(chromosome) for chromosome in population]

    new_population = []
```

```
    # Create new population
    while len(new_population) < population_size:
        parent1, parent2 = select_pair(population, fitnesses)
        offspring1, offspring2 = crossover(parent1, parent2)
        new_population.append(mutate(offspring1, mutation_rate))
        new_population.append(mutate(offspring2, mutation_rate))

    # Ensure the new population has the right size
    population = new_population[:population_size]

# Get the maximum fitness
fitnesses = [fitness(chromosome) for chromosome in population]
max_fitness = max(fitnesses)

print(f"Maximum Possible Fitness: {max_fitness}")
```

Output:

```
Enter a binary string of size 5 (e.g., '11001'): 11011
Enter a binary string of size 5 (e.g., '11001'): 01011
Enter a binary string of size 5 (e.g., '11001'): 11100
Enter a binary string of size 5 (e.g., '11001'): 01101
Maximum Possible Fitness: 841
```

Program 2

Ant Colony Optimization

Algorithm:

Ant Colony Optimization for Travelling Salesman

Objective → To find the shortest possible route of salesman that visits a list of cities and returns to the origin city using ant colony

1) Initialization →

- Number of Ants → A fixed number of ants are used to explore the solution space. Each ant is treated as an individual agent to construct a solution.
- Number of iterations → Runs for a fixed number of iterations.

Pheromone Parameters:

- alpha : ~~weight~~ concentration of the pheromone in the decision-making process
- beta : weight of the heuristic (inverse distance) in the decision-making process.
- rho : Evaporation rate of the pheromone, which simulates how old pheromones dissipate over time.

Distance Matrix : Euclidean distance btw each pair of cities is pre-computed

2) Construction of Ant Tours :→

- For each ant a tour is constructed:

Each ant starts at a random city

From the starting city, it repeatedly choses the next city to visit based on the following factors →

Pheromone concentration → The stronger the pheromone on an edge

Heuristic information → The inverse of the distance b/w cities. The shorter the distance, the more likely an ant to choose that edge.

Probability calculation → (Alpha) α and (heuristic information) β to calculate the probability

Ant select the ants with greater probability. and a degree of randomness is also include to encourage exploration.

This process continues until all cities are visited.

write pseudocode

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3) Pheromone Update:

- After all ants have completed their tours, the pheromone matrix is updated →

Pheromone Evaporation: All pheromone values are reduced by a factor (1 - rho), simulating the natural evaporation of pheromone over time

Code:

```
import random
import numpy as np
import operator

FUNCTIONS = {'+': operator.add, '-': operator.sub, '*': operator.mul, '/': operator.truediv}
TERMINALS = ['x', 1, 2, 3, 4]  # x and constants

def random_gene(length=10):
    return [random.choice(list(FUNCTIONS.keys()) + TERMINALS) for _ in range(length)]

def decode_chromosome(chromosome, x):
    stack = []
    for gene in chromosome:
        if gene in FUNCTIONS:  # If it's a function, pop arguments and apply
            if len(stack) < 2:  # Avoid errors if stack has fewer than 2 elements
                stack.append(0)
                continue
            b = stack.pop()
            a = stack.pop()
            try:
                result = FUNCTIONS[gene](a, b)
            except ZeroDivisionError:
                result = 1  # Avoid division by zero
            stack.append(result)
        elif gene == 'x':
            stack.append(x)
        else:
            stack.append(gene)
    return stack[0] if stack else 0  # Return top of stack as output

def fitness_function(chromosome, target_function, x_values):
    predictions = [decode_chromosome(chromosome, x) for x in x_values]
    targets = [target_function(x) for x in x_values]
    mse = np.mean([(p - t) ** 2 for p, t in zip(predictions, targets)])
    return mse
```

```
def selection(population, fitnesses):
    total_fitness = sum(1 / (f + 1e-6) for f in fitnesses)  # Avoid division by zero
    probabilities = [(1 / (f + 1e-6)) / total_fitness for f in fitnesses]
    return population[np.random.choice(len(population), p=probabilities)]

def mutate(chromosome, mutation_rate=0.1):
    new_chromosome = chromosome[:]
    for i in range(len(new_chromosome)):
        if random.random() < mutation_rate:
            new_chromosome[i] = random.choice(list(FUNCTIONS.keys()) + TERMINALS)
    return new_chromosome

def crossover(parent1, parent2):
    point = random.randint(1, len(parent1) - 1)
    child1 = parent1[:point] + parent2[point:]
    child2 = parent2[:point] + parent1[point:]
    return child1, child2

def ant_colony_optimization(cost_matrix, n_ants=10, n_iterations=100, evaporation_rate=0.5,
alpha=1, beta=2):
    n_nodes = len(cost_matrix)
    pheromones = np.ones((n_nodes, n_nodes))  # Initialize pheromones

    def calculate_probability(i, j, visited):
        if j in visited:
            return 0
        return (pheromones[i][j] ** alpha) * ((1 / cost_matrix[i][j]) ** beta)

    def construct_solution():
        path = [random.randint(0, n_nodes - 1)]
        while len(path) < n_nodes:
            i = path[-1]
            probabilities = [calculate_probability(i, j, path) for j in range(n_nodes)]
            total = sum(probabilities)
            probabilities = [p / total if total > 0 else 0 for p in probabilities]
            next_node = np.random.choice(range(n_nodes), p=probabilities)
            path.append(next_node)
        path.append(path[0])  # Return to start
        return path

    def path_cost(path):
        return sum(cost_matrix[path[i]][path[i + 1]] for i in range(len(path) - 1))
```

```
    best_path = None
    best_cost = float('inf')

    for iteration in range(n_iterations):
        solutions = [construct_solution() for _ in range(n_ants)]
        costs = [path_cost(solution) for solution in solutions]
        for i, cost in enumerate(costs):
            if cost < best_cost:
                best_cost = cost
                best_path = solutions[i]

        pheromones *= (1 - evaporation_rate)  # Evaporation
        for i, solution in enumerate(solutions):
            for j in range(len(solution) - 1):
                pheromones[solution[j]][solution[j + 1]] += 1 / costs[i]

        print(f"Iteration {iteration + 1}: Best Cost = {best_cost}")

    print("Best Path:", best_path)
    print("Best Cost:", best_cost)

cost_matrix = [
    [0, 2, 2, 5, 7],
    [2, 0, 4, 8, 2],
    [2, 4, 0, 1, 3],
    [5, 8, 1, 0, 2],
    [7, 2, 3, 2, 0]
]
ant_colony_optimization(cost_matrix, n_ants=5, n_iterations=20)
```

Output:

```
Iteration 15: Best Cost = 9
Iteration 16: Best Cost = 9
Iteration 17: Best Cost = 9
Iteration 18: Best Cost = 9
Iteration 19: Best Cost = 9
Iteration 20: Best Cost = 9
Best Path: [1, 0, 2, 3, 4, 1]
Best Cost: 9
```

Program 3

Particle Swarm Optimization

Algorithm:

Particle Swarm Optimization

1) Initialize swarm

- for each particle i in swarm:
  - initialize position (x_i) randomly within problems bounds
  - initialize velocity (v_i) randomly.
  - set personal best position pbest_i = x_i
  - set personal best value f(pbest_i)

2) Set global best (gbest)

- set gbest = position of particle with best value f(pbest_i)

3) for each iteration (t=1 to max_iteration)

a. for each particle i:

- Evaluate fitness f(x_i) at current position x_i
- if (x_i) < f(pbest_i)
  - update pbest_i = x_i
  - update f(pbest_i) = f(x_i)
- if (f(pbest_i) < f(gbest)):
  - update gbest = pbest_i

b. For each particle i

- update velocity v_i using the formula

$v_i(t+1) = w + v_i(t) + c_1 * r_1 *$
$(pbest_i - x_i) + c_2 * r_2 *$
$(gbest - x_i)$

where:

- w = inertia weight (controls exploration vs exploitation)
- c_1, c_2 = cognitive and social learning factors

- r1, r2 = random value b/w 0 and 1

- pbest_i = personal best position of particle i

- gbest = global best position of the swarm

c. For each particle i

- update position x_i using formula

$$x\_i(t+1) = x\_i(t) + v\_i(t+1)$$

- Ensure that x_i stays within bounds (boundary handling)

4) Output global best position gbest and its corresponding value f(gbest)

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Code:

```
import random
import numpy as np
from matplotlib import pyplot as plt
from matplotlib import animation

def fitness_function(x1, x2):
    f1 = x1 + 2 * -x2 + 3
    f2 = 2 * x1 + x2 - 8
    z = f1**2 + f2**2
    return z

def update_velocity(particle, velocity, pbest, gbest, w_min=0.5, max=1.0, c=0.1):
    new_velocity = np.zeros_like(particle)
    r1 = random.uniform(0, max)
    r2 = random.uniform(0, max)
    w = random.uniform(w_min, max)

    for i in range(len(particle)):
        new_velocity[i] = (w * velocity[i] +
                           c * r1 * (pbest[i] - particle[i]) +
                           c * r2 * (gbest[i] - particle[i]))
    return new_velocity

def update_position(particle, velocity):
    new_particle = particle + velocity
    return new_particle

def pso_2d(population, dimension, position_min, position_max, generation, fitness_criterion):
    # Initialization
    particles = np.array([[random.uniform(position_min, position_max) for _ in range(dimension)] for
_ in range(population)])
    pbest_position = particles.copy()
```

```
pbest_fitness = np.array([fitness_function(p[0], p[1]) for p in particles])

gbest_index = np.argmin(pbest_fitness)
gbest_position = pbest_position[gbest_index]

velocity = np.zeros((population, dimension))

images = []  # For animation

for t in range(generation):
    if np.average(pbest_fitness) <= fitness_criterion:
        break

    for n in range(population):
        velocity[n] = update_velocity(particles[n], velocity[n], pbest_position[n], gbest_position)
        particles[n] = update_position(particles[n], velocity[n])

    pbest_fitness = np.array([fitness_function(p[0], p[1]) for p in particles])
    for n in range(population):
        if pbest_fitness[n] < fitness_function(pbest_position[n][0], pbest_position[n][1]):
            pbest_position[n] = particles[n]

    gbest_index = np.argmin(pbest_fitness)
    gbest_position = pbest_position[gbest_index]

    # Plotting the current positions of the particles
    fig = plt.figure(figsize=(10, 10))
    ax = fig.add_subplot(111, projection='3d')
    ax.set_xlabel('x')
    ax.set_ylabel('y')
    ax.set_zlabel('z')

    x = np.linspace(position_min, position_max, 80)
    y = np.linspace(position_min, position_max, 80)
    X, Y = np.meshgrid(x, y)
    Z = fitness_function(X, Y)
    ax.plot_wireframe(X, Y, Z, color='r', linewidth=0.2)

    ax.scatter3D(
        particles[:, 0],
        particles[:, 1],
        [fitness_function(p[0], p[1]) for p in particles],
```

```
        c='b'
    )

    # Capture the frame for animation
    plt.title(f'Generation: {t + 1}')
    plt.tight_layout()
    plt.savefig(f'frame_{t}.png')
    plt.close(fig)

  # Create animation
  frames = [plt.imread(f'frame_{i}.png') for i in range(t)]
  fig, ax = plt.subplots(figsize=(10, 10))
  ax.axis('off')
  image = ax.imshow(frames[0])

  def update(frame):
    image.set_array(frames[frame])
    return image,

  ani = animation.FuncAnimation(fig, update, frames=len(frames), interval=100)
  ani.save('./pso_simple.gif', writer='pillow')

  # Print the results
  print('Global Best Position: ', gbest_position)
  print('Best Fitness Value: ', min(pbest_fitness))
  print('Average Particle Best Fitness Value: ', np.average(pbest_fitness))
  print('Number of Generations: ', t)

# Run the PSO algorithm
pso_2d(population=30, dimension=2, position_min=-10, position_max=10, generation=100,
fitness_criterion=1e-3)
```

Output:

```
Global Best Position:  [2.59992843 2.79914636]
Best Fitness Value:  3.6691186243893878e-06
Average Particle Best Fitness Value:  0.0007223322365523365
Number of Generations:  45
```

Program 4

Cuckoo Search Algorithm

Algorithm:

Cuckoo Search Algorithm

Pseudo code ⇒

```
#1) Define the objective function to be optimized
    def objective_function(x):

#2) Initialize Parameters
    N = 20            # Number of Nests
    pa = 0.25         # Probability of discovery
    Max Iter = 100    # Maximum number of iterations
    dimensions = 2    # Dimensionality of the problem
    Lower Bound = -5  # Lower bound of search space
    Upper Bound = 5   # Upper bound of search space

#3) Initialize population (nests)
    def initialize_population(N, dimensions, lower bound,
                                              upper bound):
        # random position within the bounds

#4) Evaluate Fitness (Calculate for each nest :)
    def evaluate_fitness(nests):
            return np.apply_along_axis(objective_function, 1,
                                                      nests)

#5) Generate New solutions using Levy flights ⇒
    def levy_flight(dimension, beta=1.5):
        # Returns random step size using levy distribution
        step = u/np.abs(v) ** (1/beta)
        return step
```

Generate new positions using levy flight for each nest.

```
def generate_new_solution(nest, alpha = 0.01):
    # Apply levy flight to generate new position
    return nest + alpha * levy_flight(dimension)
```

#6 Bound the solution within the allowed limit

```
def bound_solution(solution, LowerBound, UpperBound):
    return np.clip(solution, LowerBound, UpperBound)
```

#7 Main loop for iterations →

```
for iter in range(MaxIter):
    for i in range(N):
        # Generate new solution for nest i
        new_nest = generate_new_solution(nests[i])

        # Bound the new solution
        new_nest = bound_solution(new_nest,
                                  LowerBound, UpperBound)

        # Evaluate the fitness of the new solution
        new_fitness = objective_function
                                  (new_nest)

        # If the new solution is better, replace
            the old one
        if new_fitness < fitness[i]:
            nests[i] = new_nest
            fitness[i] = new_fitness
```

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Code:

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

# Objective function: Rastrigin Function
def rastrigin(x):
    A = 10
    return A * len(x) + sum(xi**2 - A * np.cos(2 * np.pi * xi) for xi in x)

# Lévy flight function for generating random steps
def levy_flight(beta=1.5, dim=2):
    sigma_u = np.power(np.math.gamma(1 + beta) * np.sin(np.pi * beta / 2) / np.math.gamma((1 +
beta) / 2) / np.power(2, (beta - 1) / 2), 1 / beta)
    sigma_v = 1
    u = np.random.normal(0, sigma_u, dim)
    v = np.random.normal(0, sigma_v, dim)
    return u / np.power(np.abs(v), 1 / beta)

# Cuckoo Search Algorithm
class CuckooSearch:
    def __init__(self, func, dim, population_size, max_generations, pa=0.25, beta=1.5, lower_bound=-
5, upper_bound=5):
        self.func = func                # Objective function
        self.dim = dim                  # Dimension of the problem
        self.population_size = population_size  # Number of nests (solutions)
        self.max_generations = max_generations  # Maximum number of generations
        self.pa = pa                    # Probability of alien eggs (nest replacement)
        self.beta = beta                # Lévy flight exponent
        self.lower_bound = lower_bound  # Lower bound of the search space
        self.upper_bound = upper_bound  # Upper bound of the search space

        # Initialize population (nests)
        self.nests = np.random.uniform(self.lower_bound, self.upper_bound, (self.population_size,
self.dim))
        self.fitness = np.array([self.func(nest) for nest in self.nests])  # Fitness of each nest
        self.best_nest = self.nests[np.argmin(self.fitness)]  # Best solution found
        self.best_fitness = np.min(self.fitness)  # Best fitness value

    # Update nests using Lévy flights and objective function evaluations
    def generate_new_nests(self):
```

```
        new_nests = []
        for i in range(self.population_size):
            step = levy_flight(self.beta, self.dim)
            new_nest = self.nests[i] + step
            # Apply boundary check
            new_nest = np.clip(new_nest, self.lower_bound, self.upper_bound)
            new_nests.append(new_nest)
        return np.array(new_nests)

    # Main cuckoo search algorithm
    def search(self):
        history = []  # To record the best fitness values over generations

        for generation in range(self.max_generations):
            # Generate new nests based on Lévy flight
            new_nests = self.generate_new_nests()
            new_fitness = np.array([self.func(nest) for nest in new_nests])

            # Replace nests with new ones if they are better
            for i in range(self.population_size):
                if new_fitness[i] < self.fitness[i] or np.random.rand() < self.pa:
                    self.nests[i] = new_nests[i]
                    self.fitness[i] = new_fitness[i]

            # Find the best nest in the current population
            current_best_fitness = np.min(self.fitness)
            current_best_nest = self.nests[np.argmin(self.fitness)]

            # Update the global best solution
            if current_best_fitness < self.best_fitness:
                self.best_fitness = current_best_fitness
                self.best_nest = current_best_nest

            # Record the best fitness for the current generation
            history.append(self.best_fitness)
            print(f"Generation {generation+1}: Best fitness = {self.best_fitness}")

        return self.best_nest, self.best_fitness, history

# Analyze the Cuckoo Search Algorithm
def analyze_cuckoo_search():
    # Set up parameters for Cuckoo Search
```

```
    dim = 2
    population_size = 50
    max_generations = 100
    cuckoo_search = CuckooSearch(func=rastrigin, dim=dim, population_size=population_size, max_generations=max_generations)

    # Run the Cuckoo Search algorithm
    best_nest, best_fitness, history = cuckoo_search.search()

    # Plot the convergence curve
    plt.plot(history)
    plt.title("Convergence Curve of Cuckoo Search Algorithm")
    plt.xlabel("Generation")
    plt.ylabel("Best Fitness")
    plt.show()

    print(f"Best solution found: {best_nest}")
    print(f"Best fitness: {best_fitness}")

# Run the analysis
analyze_cuckoo_search()
```

Output:

```
Best solution found: [1.30548027 2.02026344]
Best fitness: 0.16306139523513963
```

Program 5

Grey Wolf Optimizer

Algorithm:

Gray Wolf Optimizer

Pseudo Code →

// Step 1: Define the Problem

objective_Function(x) // Define the objective function
// to be optimized

// Step 2: Initialize Parameters

N = Number of wolves

max_iter = Maximum number of iterations.

Dim = Number of dimensions (variables of the problems)

lower_bound = lower bound of the search space

upper_bound = Upper bound of the search space

// Step 3: Initialize Problem

for i=1 to N:

Wolf [i].Position = Random (lower_bound, upper_bound)
// Initialize position of wolves

Wolf [i].Fitness = objective_Function (Wolf [i].Position)
// Evaluate fitness of each wolf

// Step 4: Sort the wolves by fitness

Sort wolves based on fitness in ascending order

Alpha wolf = Wolf [1] // Best fitness
Beta wolf = Wolf [2] // Second-best fitness
Delta wolf = Wolf [3] // Third-best fitness

// Step 5: Main optimization loop

for iteration = 1 to max_iter:

for i = 1 to N:

// Step 5.1: Update Position of each wolf

a = 2 * Random (0, 1) - 1 // Random vector for exploration

c = 2 * Random (0, 1)

// Calculate Distance b/w current wolf and alpha, beta, delta wolves →

D_alpha = abs (C * Alpha_Wolf.Position - Wolf[i].Position)

D_beta = abs (C * Beta_Wolf.Position - Wolf[i].Position)

D_delta = abs (C * Delta_Wolf.Position - Wolf[i].Position

// Update Position of current wolf

Wolf [i].Position = Wolf [i].Position + a * (D_alpha + D_beta + D_delta)

// Ensure the new position is within bound

for j = 1 to Dim:

If Wolf[i].Position[j] < Lower_bound [j];

Wolf [i].Position [j] = Lower_bound [j]

Else if Wolf [i].Position [j] > Upper_bound [j];

Wolf[i].Position [j] = Upper_bound [j]

// Step 5.2 Evaluate fitness of the updated position

Wolf [i].Fitness = objective_function (Wolf [i].Position)

// Step 5.3 : Sort the wolves again based on fitness

Sort wolves based on fitness in ascending order

AlphaWolf = Wolf [1]

BetaWolf = Wolf [2]

Delta Wolf = Wolf [3]

// Step 6 : Output the Best solution

Bestsolution = AlphaWolf. Position

Best fitness = AlphaWolf. fitness

Return Bestsolution, Best fitness.

o/p?

18/12/24

Code:

```
import numpy as np

def objective_function(x):
    return np.sum(x**2)

class GreyWolfOptimizer:
    def __init__(self, objective_function, n_wolves, n_variables, max_iter, lb, ub):
        self.obj_func = objective_function  # Objective function
        self.n_wolves = n_wolves  # Number of wolves
        self.n_variables = n_variables  # Number of variables in the problem
        self.max_iter = max_iter  # Maximum number of iterations
        self.lb = lb  # Lower bound for the search space
        self.ub = ub  # Upper bound for the search space

        self.wolves = np.random.uniform(self.lb, self.ub, (self.n_wolves, self.n_variables))

        self.alpha = np.zeros(self.n_variables)
        self.beta = np.zeros(self.n_variables)
        self.delta = np.zeros(self.n_variables)
        self.alpha_score = float("inf")
        self.beta_score = float("inf")
        self.delta_score = float("inf")

    def update_wolves(self):
        fitness = np.apply_along_axis(self.obj_func, 1, self.wolves)

        sorted_indices = np.argsort(fitness)
        self.wolves = self.wolves[sorted_indices]
        fitness = fitness[sorted_indices]

        # Update alpha, beta, and delta wolves
        self.alpha = self.wolves[0]
        self.beta = self.wolves[1]
        self.delta = self.wolves[2]
        self.alpha_score = fitness[0]
        self.beta_score = fitness[1]
        self.delta_score = fitness[2]
```

```
    def optimize(self):
        for t in range(self.max_iter):
            A = 2 * np.random.random((self.n_wolves, self.n_variables)) - 1  # Random values for exploration
            C = 2 * np.random.random((self.n_wolves, self.n_variables))  # Random values for exploitation
            for i in range(self.n_wolves):
                D_alpha = np.abs(C[i] * self.alpha - self.wolves[i])  # Distance to alpha wolf
                D_beta = np.abs(C[i] * self.beta - self.wolves[i])  # Distance to beta wolf
                D_delta = np.abs(C[i] * self.delta - self.wolves[i])  # Distance to delta wolf

                self.wolves[i] = self.alpha - A[i] * D_alpha

                self.wolves[i] = np.clip(self.wolves[i], self.lb, self.ub)

            self.update_wolves()

            print(f"Iteration {t+1}/{self.max_iter}, Best Score: {self.alpha_score}")

        return self.alpha, self.alpha_score  # Return the best solution found

n_wolves = 30  # Number of wolves
n_variables = 5  # Number of decision variables
max_iter = 100  # Maximum number of iterations
lb = -10  # Lower bound of the search space
ub = 10  # Upper bound of the search space

gwo = GreyWolfOptimizer(objective_function, n_wolves, n_variables, max_iter, lb, ub)
best_solution, best_score = gwo.optimize()
print("Best Solution Found:", best_solution)
print("Best Score:", best_score)
```

Output:

```
Iteration 100/100, Best Score: 1.985808550535119e-30
Best Solution Found: [-4.38373504e-17 -4.54363691e-16 -1.31663573e-15 -2.05502414e-16
  4.09828696e-17]
Best Score: 1.985808550535119e-30
```

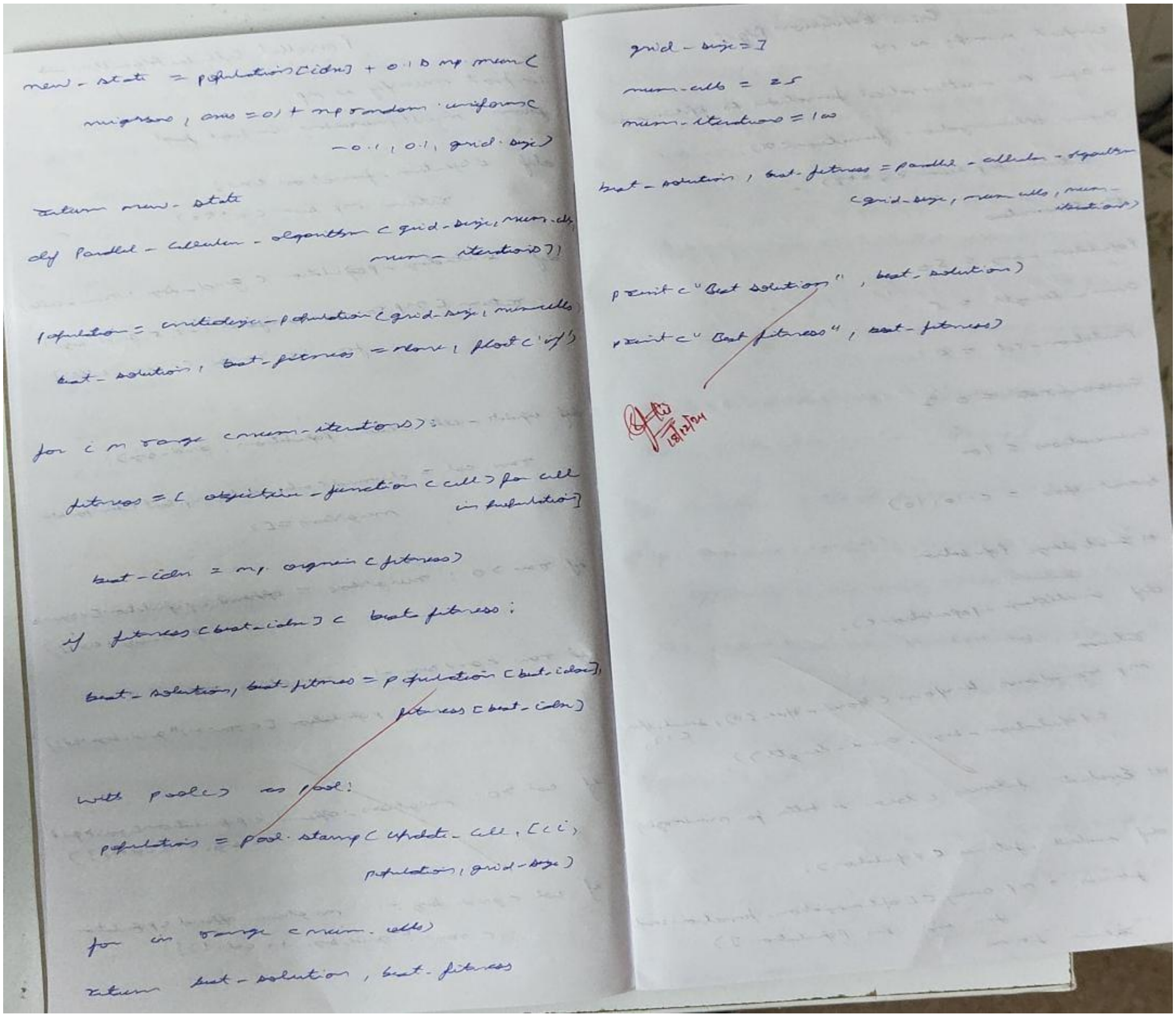
Program 6

Parallel Cellular Algorithm

Algorithm:

Parallel Cellular Algorithms →

```
import numpy as np
from multiprocessing import pool

def objective_function (x):
        return np.sum(x**2)

def initialize_population (grid_size, num_cells):
    return [np.random.uniform (-5, 5, grid_size)
                for in range (num_cells)]

def update_cell (idx, population, grid_size):
    row, col = divmod (idx, int(np.sqrt (len(population
                neighbors = []

if row > 0 : neighbors = append (population[(row-1)*
                        grid_size + col])

if row < grid_size - 1 : neighbors . append (
            population [(row+1)* grid_size + col])

if col > 0 : neighbors . append (population [row*grid
                    _size + (col-1)])

if col < grid_size - 1 : neighbors . append (population
        (row * grid_size + (col+1)])
```



new_state = population[idx] + 0.1 * np.mean(
    neighbors, axis=0) + np.random.uniform(
                    -0.1, 0.1, grid_size)

return new_state

def parallel_cellular_algorithm(grid_size, num_cells,
                    num_iterations):

population = initialize_population(grid_size, num_cells)
best_solution, best_fitness = None, float('inf')

for i in range(num_iterations):

fitness = [objective_function(cell) for cell
                    in population]

best_idx = np.argmin(fitness)

if fitness[best_idx] < best_fitness:

best_solution, best_fitness = population[best_idx],
                    fitness[best_idx]

with Pool() as pool:

population = pool.starmap(update_cell, [(i,
                    population, grid_size)

for in range(num_cells)

return best_solution, best_fitness

grid_size = 7

num_cells = 25

num_iterations = 100

best_solution, best_fitness = parallel_cellular_algorithm
                    (grid_size, num_cells, num_
                    iterations)

print("Best solution:", best_solution)

print("Best fitness:", best_fitness)

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Code:

```
import numpy as np
from multiprocessing import Pool
def update_cell(cell_index, grid, size):
    x, y = cell_index
    neighbors = [
        ((x-1) % size, y), ((x+1) % size, y),
        (x, (y-1) % size), (x, (y+1) % size)
    ]
    new_state = sum(grid[n[0], n[1]] for n in neighbors) % 2  # example: majority rule
    return (x, y, new_state)
def parallel_update(grid, size, num_iterations):
    pool = Pool(processes=4)
    for iteration in range(num_iterations):
```

```
        print(f"Iteration {iteration + 1}:")
        indices = [(x, y) for x in range(size) for y in range(size)]
        result = pool.starmap(update_cell, [(i, grid, size) for i in indices])

        for x, y, new_state in result:
            grid[x, y] = new_state
        print(grid)
    return grid
grid_size = 10
grid = np.random.randint(2, size=(grid_size, grid_size))
print("Initial state:")
print(grid)
num_iterations = 2
updated_grid = parallel_update(grid, grid_size, num_iterations)
```

Output:

```
Iteration 1:
[[1 0 0 1]
 [1 0 1 0]
 [1 0 0 1]
 [0 1 0 1]]
Iteration 2:
[[0 0 0 0]
 [0 0 0 0]
 [0 0 0 0]
 [0 0 0 0]]
```

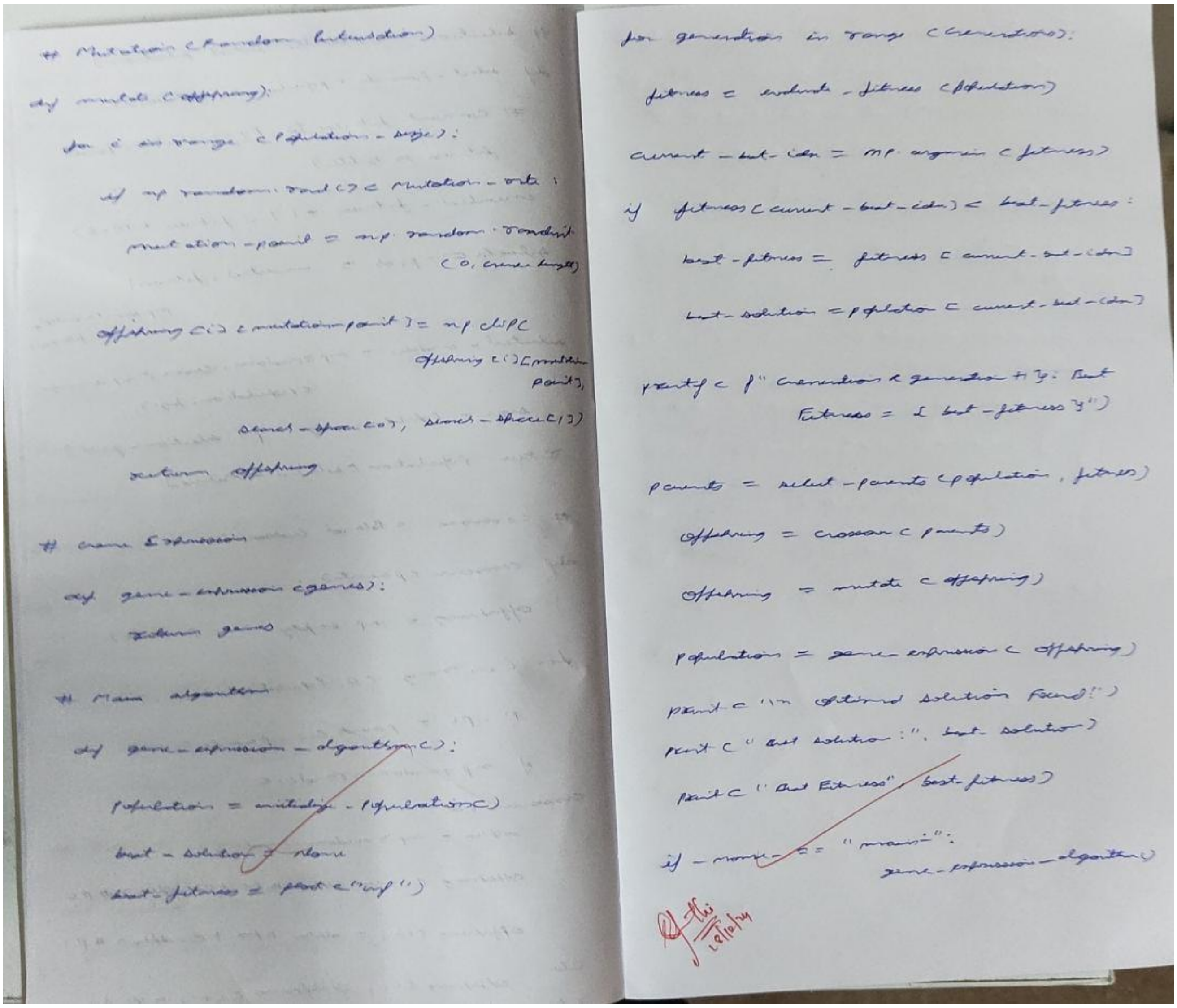
Program 7

Gene Expression Algorithm

Algorithm:

Gene Expression Algo:

```
import numpy as np
# define a mathematical function to optimize
def optimization_function(x):
    return np.sum(x**2)

# Parameters
population_size = 50
gene_length = 5
mutation_rate = 0.1
crossover_rate = 0.7
generations = 100
search_space = (-10, 10)

# Initialize Population
def initialize_population():
    return
    np.random.uniform(search_space[0], search_space[1],
        (population_size, gene_length))

# Evaluate fitness (lower is better for minimizing)
def evaluate_fitness(population):
    fitness = np.array([optimization_function(ind)
        for ind in population])
    return fitness

# Selection (Roulette wheel selection)
def select_parents(population, fitness):
    # convert fitness to probabilities (lower
      fitness is better)
    inverted_fitness = 1 / (fitness + 1e-6)
    selection_probs = inverted_fitness /
                      np.sum(inverted_fitness)

    selected_indices = np.random.choice(np.arange
                       (population_size),
        size = population_size, p = selection_probs)
    return population[selected_indices]

# Crossover (Blend Crossover)
def crossover(parents):
    offspring = np.empty_like(parents)
    for i in range(0, population_size, 2):
        p1, p2 = parents[i], parents[i+1]
        if np.random.rand() <
crossover_rate:
            alpha = np.random.rand()
            offspring[i] = alpha * p1 + (1-alpha) * p2
            offspring[i+1] = alpha * p2 + (1-alpha) * p1
        else offspring[i], offspring[i+1] = p1, p2
    return offspring
```



```
# Mutation (Random Substitution)
def mutate (offspring):
    for i in range (Population_size):
        if np.random.rand() < Mutation_rate:
            mutation_point = np.random.randint
                                    (0, Gene_length)
            offspring[i][mutation_point] = np.clip(
                                    offspring[i][mutation
                                    point],
                        Search_space[0], Search_space[1])
        return offspring

# Gene Expression
def gene_expression (genes):
    return genes

# Main algorithm
def gene_expression_algorithm():
    population = initialize_Population()
    best_solution = None
    best_fitness = float("inf")
for generation in range (Generations):
    fitness = evaluate_fitness (population)
    current_best_idx = np.argmin (fitness)
    if fitness[current_best_idx] < best_fitness:
        best_fitness = fitness[current_best_idx]
        best_solution = population[current_best_idx]

    print(f"Generation {generation+1}: Best
                Fitness = {best_fitness}")

    parents = select_parents (population, fitness)
    offspring = crossover (parents)
    offspring = mutate (offspring)

    population = gene_expression (offspring)
    print ("\n Optimized Solution Found!")
    print ("Best Solution:", best_solution)
    print ("Best Fitness", best_fitness)

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

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Code:

```
import random
import numpy as np
import operator

# Function set and terminal set
FUNCTIONS = {'+': operator.add, '-': operator.sub, '*': operator.mul, '/': operator.truediv}
TERMINALS = ['x', 1, 2, 3, 4]  # x and constants

def random_gene(length=10):
    """Generate a random chromosome (gene)."""
    return [random.choice(list(FUNCTIONS.keys()) + TERMINALS) for _ in range(length)]
```

```python
def decode_chromosome(chromosome, x):
    """Decode chromosome into a functional expression tree (phenotype)."""
    stack = []
    for gene in chromosome:
        if gene in FUNCTIONS:  # If it's a function, pop arguments and apply
            if len(stack) < 2:  # Avoid errors if stack has fewer than 2 elements
                stack.append(0)
                continue
            b = stack.pop()
            a = stack.pop()
            try:
                result = FUNCTIONS[gene](a, b)
            except ZeroDivisionError:
                result = 1  # Avoid division by zero
            stack.append(result)
        elif gene == 'x':
            stack.append(x)
        else:
            stack.append(gene)
    return stack[0] if stack else 0  # Return top of stack as output


def fitness_function(chromosome, target_function, x_values):
    """Calculate fitness based on Mean Squared Error."""
    predictions = [decode_chromosome(chromosome, x) for x in x_values]
    targets = [target_function(x) for x in x_values]
    mse = np.mean([(p - t) ** 2 for p, t in zip(predictions, targets)])
    return mse


def selection(population, fitnesses):
    """Select individuals based on fitness (roulette wheel selection)."""
    total_fitness = sum(1 / (f + 1e-6) for f in fitnesses)  # Avoid division by zero
    probabilities = [(1 / (f + 1e-6)) / total_fitness for f in fitnesses]
    return population[np.random.choice(len(population), p=probabilities)]


def mutate(chromosome, mutation_rate=0.1):
    """Apply mutation to a chromosome."""
    new_chromosome = chromosome[:]
    for i in range(len(new_chromosome)):
        if random.random() < mutation_rate:
```

```
            new_chromosome[i] = random.choice(list(FUNCTIONS.keys()) + TERMINALS)
    return new_chromosome


def crossover(parent1, parent2):
    """Perform one-point crossover between two parents."""
    point = random.randint(1, len(parent1) - 1)
    child1 = parent1[:point] + parent2[point:]
    child2 = parent2[:point] + parent1[point:]
    return child1, child2


def gene_expression_algorithm(target_function, x_values, population_size=10, generations=20):
    """Main Gene Expression Algorithm."""
    # Initialize random population
    population = [random_gene() for _ in range(population_size)]

    print("Initial Population:")
    for i, chrom in enumerate(population):
        print(f"Chromosome {i}: {chrom}")

    for generation in range(generations):
        print(f"\nGeneration {generation + 1}:")
        # Calculate fitness for each individual
        fitnesses = [fitness_function(chrom, target_function, x_values) for chrom in population]
        for i, (chrom, fit) in enumerate(zip(population, fitnesses)):
            print(f"Chromosome {i}: {chrom}, Fitness: {fit:.4f}")

        # Select the next generation
        new_population = []
        for _ in range(population_size // 2):
            parent1 = selection(population, fitnesses)
            parent2 = selection(population, fitnesses)
            child1, child2 = crossover(parent1, parent2)
            child1 = mutate(child1)
            child2 = mutate(child2)
            new_population.extend([child1, child2])
        population = new_population

    # Final results
    print("\nFinal Population and Fitness:")
    fitnesses = [fitness_function(chrom, target_function, x_values) for chrom in population]
```

```
    for i, (chrom, fit) in enumerate(zip(population, fitnesses)):
        print(f"Chromosome {i}: {chrom}, Fitness: {fit:.4f}")

    best_index = np.argmin(fitnesses)
    print("\nBest Solution:")
    print(f"Chromosome: {population[best_index]}, Fitness: {fitnesses[best_index]:.4f}")

# Target function for regression
def target_function(x):
    return x**2 + 2*x + 1  # Example: f(x) = x^2 + 2x + 1

# Input values
x_values = np.linspace(-10, 10, 20)

# Run the algorithm
gene_expression_algorithm(target_function, x_values, population_size=10, generations=10)
```

Output:

```
Best Solution:
Chromosome: [1, 3, '+', 2, 1, 4, '*', '*', '*', 3], Fitness: 1259.2067
<ipython-input-3-6df17022c257>:25: RuntimeWarning: divide by zero encountered in scalar divide
  result = FUNCTIONS[gene](a, b)
```