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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
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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 **Shreyas T S (1BM23CS322),** 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/Shreyes45/BIS-lab

Program 1

Genetic Algorithm for Optimization Problems

Lab - 1

Genetic Algorithm : 5 main phases
- Initialization
- Fitness Assignment
- Selection
- Crossover
- Termination

Iteration - 1

Steps

1) Selecting encoding technique
0 to 31

2) Select the initial population - '4'

Sl No	Initial population	x value	fitness $f(x)=x^2$	prob $f(x)/\Sigma f(x)$	% Prob	Expected count $f(x)/Avg(f(x))$	Actual count (After, value)
1	01100	12	144	0.1247	12.47	0.49	1
2	11001	25	625	0.5411	54.11	2.164	2
3	00101	5	25	0.0216	2.16	0.084	0
4	10011	19	361	0.3125	31.25	1.25	1

3) Select Mating pool

Sl No	mating pool	crossover point	offspring after crossover	x value	fitness $f(x)=x^2$
1	01100	4	01101	13	169
2	11001		11000	24	576
3	11001	2	11011	27	729
4	10011		10001	17	289

4) Crossover : Random 4 & 2

5) Mutation

Sl no	offspring after crossover	mutation chromosome for flipping	offspring after mutation	x value	fitness $f(x)=x^2$
1	01101	10000	11101	29	841
2	11000	00000	11000	24	576
3	11011	00000	11011	27	729
4	10001	00101	10100	20	400

Pseudo code

```
function fitness(x):
    Return x^2

Function generate_population(pop_size, lower_bound, upper_bound):
    population = []
    for i from 1 to pop_size:
        individual = RandomNumberInRange(lower_bound, upper_bound)
        Add individual to population
    return population

function select_parents(population):
    fitness_values = []
    for each individual in population:
        fitness_values.append(fitness(individual))
    total_fitness = sum(fitness_values)

    selection_probs = []
    for each fitness_value in fitness_values:
        selection_probs.append(fitness_value / total_fitness)
    parent1, parent2 = RandomlySelectTwoIndividualsBasedOnSelectionProbabilities(population, selection_probs)
    return parent1, parent2

Function crossover(parent1, parent2):
    crossover_point = RandomNumberInRange(0, 1)
    child1 = crossover_point * parent1 + (1 - crossover_point) * parent2
    child2 = crossover_point * parent2 + (1 - crossover_point) * parent1
    return child1, child2

Function mutate(individual, mutation_rate, lower_bound, upper_bound):
    if Random() < mutation_rate:
        mutation = RandomNumberInRange(lower_bound, upper_bound)
        individual = individual + mutation
        individual = clamp(individual, lower_bound, upper_bound)
    return individual

Function genetic_algorithm(pop_size, generations, lower_bound, upper_bound, mutation_rate):
    population = generate_population(pop_size, lower_bound, upper_bound)
    for generation from 1 to generations:
        new_population = []
        for i from 1 to pop_size/2:
            parent1, parent2 = select_parents(population)
            child1, child2 = crossover(parent1, parent2)
            child1 = mutate(child1, mutation_rate, lower_bound, upper_bound)
            child2 = mutate(child2, mutation_rate, lower_bound, upper_bound)
            Add child1 and child2 to new_population

        population = new_population
        best_individual = findBestIndividual(population)
        print "Generation", generation, ": Best fitness - ", fitness(best_individual), "Best Solution :", best_individual
    best_solution = findBestIndividual(population)
    return best_solution

// Main program
Define population_size = 100
Define generation = 5
Define lower_bound = 0
Define upper_bound = 31
Define mutation_rate = 0.1
best_solution = genetic_algorithm(population_size, lower_bound, upper_bound, mutation_rate)
print "Best Solution found:", best_solution, "Fitness", fitness(best_solution)
```

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Department of CSE,

output:

Generation 1 : Best fitness = 961 , Best Solution 31
Generation 2 : Best fitness = 961 , Best Solution 31
Generation 3 : Best fitness = 877.017600833, Best Solution : 29.61758040
Generation 4 : Best fitness = 877.81760833368, Best Solution = 29.6138561449
Generation 5 : Best fitness = 961 , Best Solution = 31
Best Solution found : 31 , fitness : 961

applications :
* Travelling salesman problem
* Knapsack problem
* function optimization

Code:

```
import random

def fitness_function(x):
    return x ** 2

def decode(chromosome):
    return int(chromosome, 2)

def evaluate_population(population):
    return [fitness_function(decode(individual)) for individual in population]

def select(population, fitnesses):
    total_fitness = sum(fitnesses)
    if total_fitness == 0:
        return random.choice(population)
    pick = random.uniform(0, total_fitness)
    current = 0
    for individual, fitness in zip(population, fitnesses):
        current += fitness
        if current > pick:
            return individual

def crossover(parent1, parent2):
    if random.random() < CROSSOVER_RATE:
        point = random.randint(1, CHROMOSOME_LENGTH - 1)
        return (parent1[:point] + parent2[point:], parent2[:point] + parent1[point:])
    return parent1, parent2

def mutate(chromosome):
    new_chromosome = ''
    for bit in chromosome:
        if random.random() < MUTATION_RATE:
            new_chromosome += '0' if bit == '1' else '1'
        else:
            new_chromosome += bit
    return new_chromosome

def get_initial_population(size, length):
    population = []
    print(f"Enter {size} chromosomes (each of {length} bits, e.g., '10101'):")
    while len(population) < size:
        chrom = input(f"Chromosome {len(population)+1}: ").strip()
        if len(chrom) == length and all(bit in '01' for bit in chrom):
            population.append(chrom)
        else:
            print(f"Invalid input. Please enter a {length}-bit binary string.")
    return population
```

```python
def genetic_algorithm():
    population = get_initial_population(POPULATION_SIZE, CHROMOSOME_LENGTH)
    best_solution = None
    best_fitness = float('-inf')

    for generation in range(GENERATIONS):
        fitnesses = evaluate_population(population)

        for i, individual in enumerate(population):
            if fitnesses[i] > best_fitness:
                best_fitness = fitnesses[i]
                best_solution = individual

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

        new_population = []
        while len(new_population) < POPULATION_SIZE:
            parent1 = select(population, fitnesses)
            parent2 = select(population, fitnesses)
            offspring1, offspring2 = crossover(parent1, parent2)
            offspring1 = mutate(offspring1)
            offspring2 = mutate(offspring2)
            new_population.extend([offspring1, offspring2])

        population = new_population[:POPULATION_SIZE]

    print("\nBest solution found:")
    print(f"Chromosome: {best_solution}")
    print(f"x = {decode(best_solution)}")
    print(f"f(x) = {fitness_function(decode(best_solution))}")

POPULATION_SIZE = 4
CHROMOSOME_LENGTH = 5
MUTATION_RATE = 0.01
CROSSOVER_RATE = 0.8
GENERATIONS = 20

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

Program 2

Particle Swarm Optimization for Function Optimization

Lab-2

Particle Swarm optimization

Pseudo Code

1) P = particle initialization();
2) for i = 1 to max
   3) for each particle p in P do
      $f_p = f(p)$
4) if f_p is better than f(pbest)
      pbest = p;
5) end
6) end
7) gbest = best p in P
8) for each particle p in P do

a) $v_i^{t+1} = \underbrace{v_i^t}_{\text{inertia}} + \underbrace{c_1 u_1^t (pb_i^t - p_i^t)}_{\text{personal influence}} + \underbrace{c_2 u_2^t (gb^t - \dots}_{\text{social influence}}$

10) $p_i^{t+1} = p_i^t + v_i^{t+1}$

11) end
12) end

Output:

iteration 1/20 - Best fitness = 0.081045
iteration 2/20 - Best fitness = 0.081045
iteration 3/20 - Best fitness = 0.006721
:
:
iteration 10/20 - Best fitness = 0.002056
:
iteration 20/20 - Best fitness = 0.000018
Best Solution found:
position: [0.0032145, -0.00268]
fitness: 1.75372e-05

eg: Iteration I

$f(x,y) = x^2 + y^2$

value of Cognitive & Social Constant

$c_1 = 2$ & $c_2 = 2$

initial solⁿ are set to 1000

P1 fitness value = $1^2 + 1^2 = 2$

Particle No	initial	Pos	Velocity x	Velocity y	Best	fitness
P1	1	1	0	0	1000	2
P2	-1	1	0	0	1000	2
P3	0.5	-0.5	0	0	100	0.3
P4	1	-1	0	0	100	2
P5	0.5	0.2	0	0	100	0

Iteration-2

pno	initial	Pos	Velocity x	Velocity y	Best	Best Pos x	Best Pos y	final
P1	1	1	-0.75	0.75	2	1	1	2
P2	-1	1	1.25	-0.75	2	-1	1	2
P3	0.5	-0.5	-0.75	0.75	0.5	0.5	-0.5	0.5
P4	1	-1	-0.75	1.25	2	1	-1	2
P5	0.25	0.25	0	0	0.125	0.25	0.25	0.01

Best position: 2.5 Best = 20.250

Code:

```
import numpy as np

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

num_particles = 30
num_dimensions = 5
max_iter = 15
w = 0.7
c1 = 1.5
c2 = 1.5
x_min = -10
x_max = 10

positions = np.random.uniform(x_min, x_max, (num_particles, num_dimensions))
velocities = np.random.uniform(-1, 1, (num_particles, num_dimensions))
personal_best_positions = positions.copy()
personal_best_scores = np.array([objective_function(x) for x in positions])

global_best_index = np.argmin(personal_best_scores)
global_best_position = personal_best_positions[global_best_index].copy()
global_best_score = personal_best_scores[global_best_index]

for iteration in range(max_iter):
    for i in range(num_particles):
        r1 = np.random.rand(num_dimensions)
        r2 = np.random.rand(num_dimensions)
        velocities[i] = (
            w * velocities[i]
            + c1 * r1 * (personal_best_positions[i] - positions[i])
            + c2 * r2 * (global_best_position - positions[i])
        )
        positions[i] = positions[i] + velocities[i]
        positions[i] = np.clip(positions[i], x_min, x_max)
        fitness = objective_function(positions[i])
        if fitness < personal_best_scores[i]:
            personal_best_scores[i] = fitness
            personal_best_positions[i] = positions[i].copy()
    best_particle_index = np.argmin(personal_best_scores)
    if personal_best_scores[best_particle_index] < global_best_score:
        global_best_score = personal_best_scores[best_particle_index]
        global_best_position = personal_best_positions[best_particle_index].copy()

print("Best Solution Found:", global_best_position)
print("Best Fitness Value:", global_best_score)
```

Program 3

Ant Colony Optimization for the Traveling Salesman Problem

lab-3

Ant Colony optimization for Traveling Salesman Problem

Initialize parameters:
- cities (coordinates)
- No of ants (num_ants)
- pheromone importance (alpha)
- Heuristic importance (beta)
- pheromone evaporation rate (rho)
- no of iteration (iterations)
- initial pheromone on all edges

For each iteration from 1 to iterations
- initialize an empty list to store all tours
- For each ant from 1 to num_ants:
  - start from a random city
  - initialize an empty list to store the tour & visited cities
  - while there are cities to visit:
    - select the next city based on pheromone & heuristic using the probabilities:
      - Calculate probability for each unvisited city:
        P(city) = (pheromone[i][j]^alpha)*(1/distance[i][j]^beta)
      - Normalize probabilities
      - choose next city probabilistically
  - Add the starting city to end of the tour
  - Store tour.
- update pheromones:
  - evaporate pheromones on all edges:
    pheromone[i][j] = pheromone[i][j] * (1 - rho)
  - For each tour in all_tours:
    - Calculate the tour length
    - Deposit pheromone along the edges of tour
      pheromone[i][j] += 1/tour_length

output the best tour & its length after all iterations.

output :-

Best Solution : [0, 4, 3, 1, 0]
Best length : 14

MG
10/10/25

Code:

```
import numpy as np

def ant_colony_optimization(dist_matrix, n_ants, n_iterations, alpha=1, beta=2, rho=0.5, q=100):
    n = len(dist_matrix)
    pheromone = np.ones((n, n))
    visibility = 1 / (dist_matrix + np.eye(n) * 1e10)
    best_length = np.inf
    best_path = None

    for _ in range(n_iterations):
        all_paths = []
        all_lengths = []
        for _ in range(n_ants):
            path = [np.random.randint(n)]
            while len(path) < n:
                i = path[-1]
                prob = (pheromone[i] ** alpha) * (visibility[i] ** beta)
                prob[path] = 0
                prob /= prob.sum()
                next_city = np.random.choice(range(n), p=prob)
                path.append(next_city)
            length = sum(dist_matrix[path[i], path[i+1]] for i in range(n-1)) + dist_matrix[path[-1], path[0]]
            all_paths.append(path)
            all_lengths.append(length)
            if length < best_length:
                best_length = length
                best_path = path
        pheromone *= (1 - rho)
        for path, length in zip(all_paths, all_lengths):
            for i in range(n-1):
                pheromone[path[i], path[i+1]] += q / length
            pheromone[path[-1], path[0]] += q / length
    return best_path, best_length

dist = np.array([
    [0, 2, 9, 10],
    [1, 0, 6, 4],
    [15, 7, 0, 8],
    [6, 3, 12, 0]
])

path, length = ant_colony_optimization(dist, n_ants=10, n_iterations=100)
print("Best path:", path)
print("Best length:", length)
```

Program 4

Cuckoo Search

Lab - 4

Cuckoo Search (CS):

Cuckoo_Search_for_job_scheduling():

1. Initialize n nests with random job orders
2. Define discovery rate pa and MaxIterations
3. For t = 1 to MaxIterations:
    For each nest i:
        Generate new schedule using Levy flights
        Evaluate fitness = TotalCompletionTime(schedule_i)

        if fitness_new < fitness_old:
            replace nest i with new one

    Abandon a fraction pa of worst nests
    Generate new random job order
    Keep the best schedules
4. End for
5) output the job order with the minimum total completion time.

output:

Iteration 1, Best fitness (negative total complet^n time): -152

⋮

Iteration 4, Best fitness (negative total complet^n time): -135

Iteration 5, Best fitness (negative total complet^n time): -134

⋮

Iteration 40, Best fitness (negative total complet^n time): -136

Best job sequence found: [0 6 3 5 4 1 3]

minimum total completion time: 134

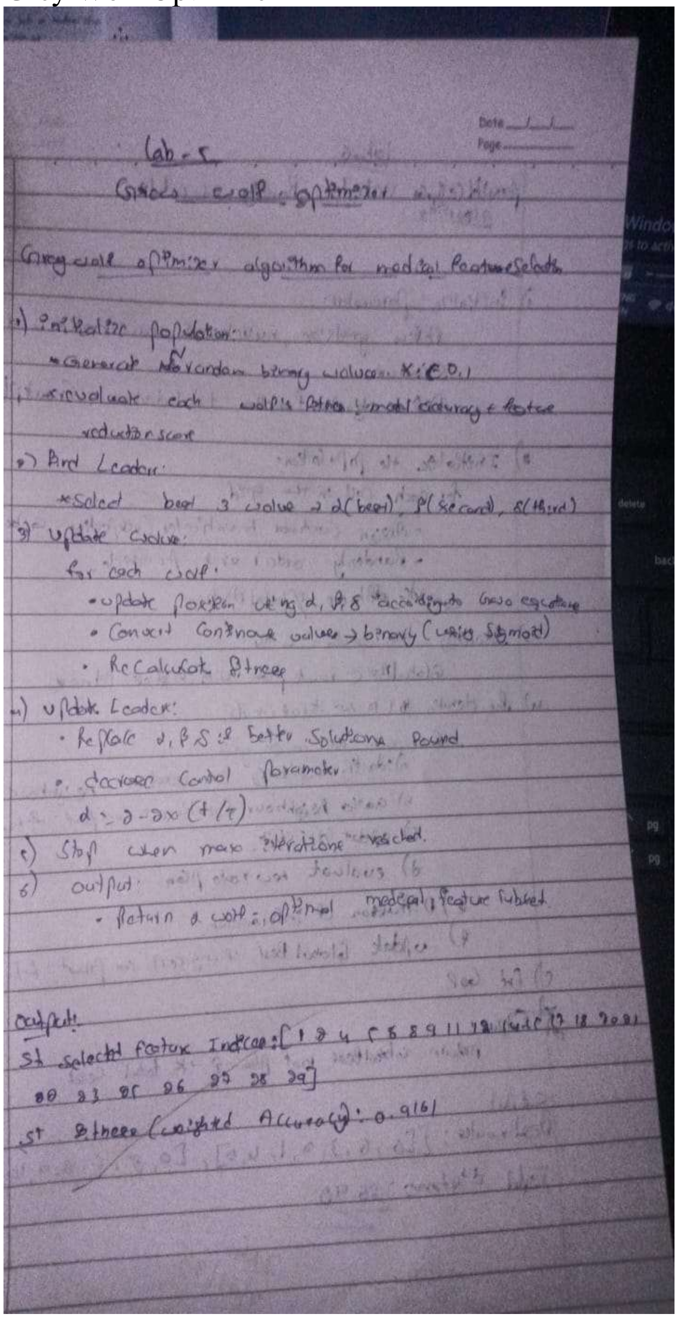
Code:

```
import numpy as np
from scipy.special import gamma  # import gamma from scipy.special

def levy_flight(dim, beta=1.5):
    sigma_u = (gamma(1 + beta) * np.sin(np.pi * beta / 2) /
            gamma((1 + beta) / 2) * beta * np.power(2, (beta - 1) / 2)) ** (1 / beta)
    u = np.random.normal(0, sigma_u, dim)
    v = np.random.normal(0, 1, dim)
```

```
    step = u / np.power(np.abs(v), 1 / beta)
    return step

def cuckoo_search(objective_function, n, dim, Pa=0.25, MaxGen=100, bounds=(-5, 5)):
    nests = np.random.uniform(bounds[0], bounds[1], (n, dim))
    fitness = np.apply_along_axis(objective_function, 1, nests)
    best_solution = nests[np.argmin(fitness)]
    best_fitness = np.min(fitness)

    for gen in range(MaxGen):
        new_nests = np.copy(nests)
        for i in range(n):
            step = levy_flight(dim)
            new_nests[i] = nests[i] + step
            new_nests[i] = np.clip(new_nests[i], bounds[0], bounds[1])
        new_fitness = np.apply_along_axis(objective_function, 1, new_nests)
        better_nests = new_fitness < fitness
        nests[better_nests] = new_nests[better_nests]
        fitness[better_nests] = new_fitness[better_nests]
        forget_idx = np.random.rand(n) < Pa
        nests[forget_idx] = np.random.uniform(bounds[0], bounds[1], (np.sum(forget_idx), dim))
        fitness = np.apply_along_axis(objective_function, 1, nests)
        current_best_fitness = np.min(fitness)
        if current_best_fitness < best_fitness:
            best_fitness = current_best_fitness
            best_solution = nests[np.argmin(fitness)]
        print(f"Generation {gen + 1}/{MaxGen}, Best Fitness: {best_fitness}")
    return best_solution, best_fitness

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

n = 30
dim = 5
MaxGen = 100
Pa = 0.25

best_solution, best_fitness = cuckoo_search(sphere_function, n, dim, Pa, MaxGen)

print("\nBest Solution Found: ", best_solution)
print("Best Fitness Value: ", best_fitness)
```

Program 5

Grey Wolf Optimizer



Date __/__/__

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Lab - 5

Grey wolf optimizer

Grey wolf optimizer algorithm for medical feature selection

1) Initialize population:
   * Generate N random binary wolves $X_i \in \{0,1\}$
   * Evaluate each wolf's fitness (model accuracy + feature reduction score)

2) Find Leader:
   * Select best 3 wolves → α (best), β (second), δ (third)

3) Update wolves:
   for each wolf:
   * update position using α, β, δ according to GWO equations
   * Convert continuous values → binary (using sigmoid)
   * Recalculate fitness

4) Update Leader:
   * Replace α, β, δ if better solutions found
   * decrease control parameter
     $a = 2 - 2 \times (t/T)$

5) Stop when max iterations reached.

6) Output:
   * Return α wolf = optimal medical feature subset

Output:

Selected feature Indices: [1 2 4 5 6 8 9 11 12 14 15 17 18 20 21 22 23 25 26 27 28 29]

Fitness (weighted Accuracy): 0.9161

Code:

```
import numpy as np

def gwo(objective_function, n, dim, max_gen, lb, ub):
    wolves = np.random.uniform(lb, ub, (n, dim))
    fitness = np.apply_along_axis(objective_function, 1, wolves)
    alpha, beta, delta = np.copy(wolves), np.copy(wolves), np.copy(wolves)
    alpha_f, beta_f, delta_f = np.copy(fitness), np.copy(fitness), np.copy(fitness)

    for gen in range(max_gen):
        sorted_idx = np.argsort(fitness)
        alpha, beta, delta = wolves[sorted_idx[0]], wolves[sorted_idx[1]], wolves[sorted_idx[2]]
        alpha_f, beta_f, delta_f = fitness[sorted_idx[0]], fitness[sorted_idx[1]], fitness[sorted_idx[2]]

        A = 2 * np.random.rand(n, dim) - 1
        C = 2 * np.random.rand(n, dim)
        for i in range(n):
            D_alpha = np.abs(C[i] * alpha - wolves[i])
            D_beta = np.abs(C[i] * beta - wolves[i])
            D_delta = np.abs(C[i] * delta - wolves[i])

            wolves[i] = wolves[i] + A[i] * (D_alpha + D_beta + D_delta) / 3
            wolves[i] = np.clip(wolves[i], lb, ub)

        fitness = np.apply_along_axis(objective_function, 1, wolves)
        print(f"Gen {gen+1}/{max_gen}, Best Fitness: {min(fitness)}")

    return alpha, alpha_f

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

n = 30
dim = 5
max_gen = 50
lb, ub = -5, 5

best_solution, best_fitness = gwo(sphere_function, n, dim, max_gen, lb, ub)
print("\nBest Solution Found: ", best_solution)
print("Best Fitness: ", best_fitness)
```

Program 6

Parallel Cellular Algorithm

lab-6

Parallel Cellular Algorithm Vehicle Routing Scheduling

1) Initialize Parameters:

Define gridsize, numvehicle, maxIteration and neighbour structure.

Define objective function: total distance (routeplan).

2) Initialize the population:

for each cell in the grid:

- Assign customers to vehicles (respecting capacity)
- Randomly order visit for vehicle.

Compute fitness = 1/total Distance.

3) identify best solution so far:

GlobalBest ← route plan with highest fitness

4) for iterate = 1 to max iteration do:

for each cell in the grid

a) identify neighbouring cell based on neighbouring structure

b) Gather neighbour solution & compare fitness.

c) update cell state.

d) evaluate new route plan

e) Diffusion of information:

f) update GlobalBest if any cell improved fitness.

5) End loop

6) Output:

return GlobalBest route plan & its total cost.

Output

Best route: [[0, 6, 3, 9, 1, 4, 0], [0, 8, 5, 2, 9, 10, 0]]

Total distance: 86.99

Code: import numpy as np

```
def total_distance(routes, dist_matrix):
    dist = 0
    for route in routes:
        for i in range(len(route)-1):
            dist += dist_matrix[route[i], route[i+1]]
    return dist

def generate_random_routes(num_customers, num_vehicles):
    customers = np.arange(1, num_customers + 1)
    np.random.shuffle(customers)
    splits = np.array_split(customers, num_vehicles)
    return [[0] + list(s) + [0] for s in splits if len(s) > 0]

def crossover(r1, r2):
    flat1 = np.concatenate([x[1:-1] for x in r1 if len(x)>2]) if r1 else []
    flat2 = np.concatenate([x[1:-1] for x in r2 if len(x)>2]) if r2 else []
    if len(flat1)==0 or len(flat2)==0:
        return r1 if len(flat1)>0 else r2
    point = np.random.randint(1, len(flat1))
    child_seq = list(flat1[:point]) + [x for x in flat2 if x not in flat1[:point]]
    splits = np.array_split(child_seq, 2)
    return [[0]+list(s)+[0] for s in splits if len(s)>0]

def mutate(routes, rate=0.2):
    for route in routes:
        if np.random.rand() < rate and len(route) > 3:
            i, j = np.random.choice(range(1, len(route)-1), 2, replace=False)
            route[i], route[j] = route[j], route[i]
    return routes

def local_optimize(routes, dist_matrix):
    for route in routes:
        improved = True
        while improved:
            improved = False
            for i in range(1, len(route)-2):
                for j in range(i+1, len(route)-1):
                    a, b, c, d = route[i-1], route[i], route[j], route[j+1]
                    before = dist_matrix[a,b]+dist_matrix[c,d]
                    after = dist_matrix[a,c]+dist_matrix[b,d]
                    if after < before:
                        route[i:j+1] = route[i:j+1][::-1]
                        improved = True
    return routes

def create_distance_matrix(num_customers):
    coords = np.random.rand(num_customers + 1, 2) * 20
```

```
    return np.sqrt(((coords[:, None, :] - coords[None, :, :]) ** 2).sum(-1))

def parallel_cellular_vrp(num_customers=10, num_vehicles=2, grid_size=(3,3), iterations=50):
    dist_matrix = create_distance_matrix(num_customers)
    grid = np.empty(grid_size, dtype=object)
    fit = np.zeros(grid_size)

    for i in range(grid_size[0]):
        for j in range(grid_size[1]):
            routes = generate_random_routes(num_customers, num_vehicles)
            grid[i,j] = routes
            fit[i,j] = 1 / (1 + total_distance(routes, dist_matrix))

    best = grid[np.unravel_index(np.argmax(fit), fit.shape)]

    for _ in range(iterations):
        new_grid = np.empty_like(grid)
        for i in range(grid_size[0]):
            for j in range(grid_size[1]):
                neighbors = []
                for di in [-1,0,1]:
                    for dj in [-1,0,1]:
                        if di==0 and dj==0: continue
                        ni, nj = (i+di)%grid_size[0], (j+dj)%grid_size[1]
                        neighbors.append(grid[ni,nj])
                best_neighbor = max(neighbors, key=lambda r: 1/(1+total_distance(r, dist_matrix)))
                child = crossover(grid[i,j], best_neighbor)
                child = mutate(child)
                child = local_optimize(child, dist_matrix)
                new_fit = 1 / (1 + total_distance(child, dist_matrix))
                if new_fit > fit[i,j]:
                    new_grid[i,j] = child
                    fit[i,j] = new_fit
                else:
                    new_grid[i,j] = grid[i,j]
        grid = new_grid
        current_best = grid[np.unravel_index(np.argmax(fit), fit.shape)]
        if (1/(1+total_distance(current_best, dist_matrix))) > (1/(1+total_distance(best, dist_matrix))):
            best = current_best

    return best, total_distance(best, dist_matrix)

best_routes, best_cost = parallel_cellular_vrp()
print("Best Routes:", best_routes)
print("Total Distance:", round(best_cost, 2))
```

Program 7

Optimization via Gene Expression Algorithm

Lab-7

Optimization via Gene expression algo

Total 6 phase

- → initialization
- → fitness assignment
- → Selection
- → Cross over
- → mutation
- → Gene expression
- → Termination

Step 1:- fitness $(x) = x^2$

1) select encoding technique 0 to 31, use chromosome of fixed length with (variable, constraints, function)

2) Initial population:-

	Initial Chromosome	Phenotype	value	fitness	probability
1	+x x	x	12	144	0.1247
2	+x x	2x	25	625	0.541
3	-x	x	5	25	0.0216
4	-x2	x-2	19	361	0.3125

$\Sigma f(x) = 1155$

Avg = 288.75

actual	expected
[illegible]	0.5
2	2.1
0	0.08
1	1.25

3) Selection of mating pool

	Selected Chromosome	Crossover pool	offspring	phenotype	value
1	+x x	2	+x x	x(x+1)	13
2	+x x	1	+x x	2x	24
3	+x x	3	+x -	x(x-)	27
4	-x2	1	+x2	x+2	17

fitness

169

576

729

289

4) Crossover:- perform crossover randomly choose gene position max fitness after crossover = 729.

5) Mutation:-

	offspring after mutation	mutation applied	offspring after mutation	Phenotype	x value
1	+x x	+x -	+x -	x^2(x-)	29
2	+x x	None	+x x	2x	24
3	+x -	-x	+x x	x-	27
4	+x2	none	+x2	x+2	20

fitness

841

576

729

400

6) Gene expression & evolution

Decode each genotype → phenotype

Calculate fitness

$\Sigma f(x) = 2546$

Avg = 636.5

max = 841

7) Iterate until convergence repeat steps 3-6 until fitness improvement is negligible/generation limit has reached.

Pseudo code:-

- Define fitness evolution func,
- create population
- Define parameters
- Select mating pool
- mutation after mating
- Gene expression and evolution
- iterate
- output Best value

output:-

Genes = [29.53, 29.82, 29.34, 28.54, 15.81, 21.08, 23.13, 30.81, 22.51, 26.22]

x = 26.37

f(x) = 695.45.

Code:

```
import random
import math

def fitness_function(x):
    return x * math.sin(10 * math.pi * x) + 2

POPULATION_SIZE = 6
GENE_LENGTH = 10
MUTATION_RATE = 0.05
CROSSOVER_RATE = 0.8
GENERATIONS = 20
DOMAIN = (-1, 2)

def random_gene():
    return random.uniform(DOMAIN[0], DOMAIN[1])

def create_chromosome():
    return [random_gene() for _ in range(GENE_LENGTH)]

def initialize_population(size):
    return [create_chromosome() for _ in range(size)]

def evaluate_population(population):
    return [fitness_function(express_gene(chrom)) for chrom in population]

def express_gene(chromosome):
    return sum(chromosome) / len(chromosome)

def select(population, fitnesses):
    total_fitness = sum(fitnesses)
    pick = random.uniform(0, total_fitness)
    current = 0
    for individual, fitness in zip(population, fitnesses):
        current += fitness
        if current > pick:
            return individual
    return random.choice(population)

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

def mutate(chromosome):
    new_chromosome = []
```

```
    for gene in chromosome:
        if random.random() < MUTATION_RATE:
            new_chromosome.append(random_gene())
        else:
            new_chromosome.append(gene)
    return new_chromosome

def gene_expression_algorithm():
    population = initialize_population(POPULATION_SIZE)
    best_solution = None
    best_fitness = float("-inf")

    for generation in range(GENERATIONS):
        fitnesses = evaluate_population(population)

        for i, chrom in enumerate(population):
            if fitnesses[i] > best_fitness:
                best_fitness = fitnesses[i]
                best_solution = chrom[:]

        print(f"Generation {generation+1}: Best Fitness = {best_fitness:.4f}, Best x =
{express_gene(best_solution):.4f}")

        new_population = []
        while len(new_population) < POPULATION_SIZE:
            parent1 = select(population, fitnesses)
            parent2 = select(population, fitnesses)
            offspring1, offspring2 = crossover(parent1, parent2)
            offspring1 = mutate(offspring1)
            offspring2 = mutate(offspring2)
            new_population.extend([offspring1, offspring2])

        population = new_population[:POPULATION_SIZE]

    print("\nBest solution found:")
    print(f"Genes: {best_solution}")
    x_value = express_gene(best_solution)
    print(f"x = {x_value:.4f}")
    print(f"f(x) = {fitness_function(x_value):.4f}")

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