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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B.M.S. College of Engineering,
Bull Temple Road, Bangalore 560019
(Affiliated To Visvesvaraya Technological University, Belgaum)
Department of Computer Science and Engineering

CERTIFICATE

This is to certify that the Lab work entitled " Bio Inspired Systems (23CS5BSBIS)" carried out by **Shreyas Sinha (1BM23CS321),** who is a 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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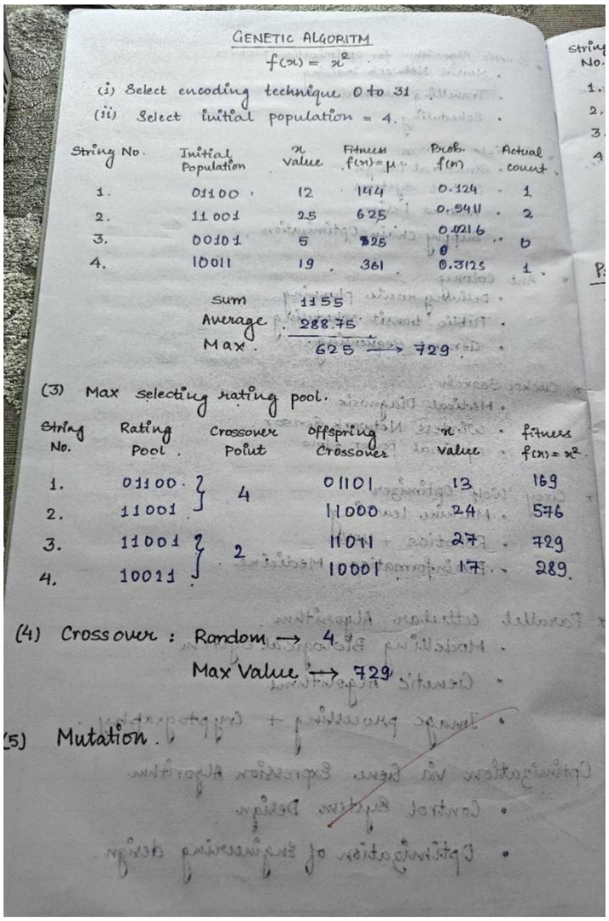
GitHub Link: https://github.com/Shreyas-2607/BIS_LAB

Program 1

Genetic Algorithm for Optimization Problems

Algorithm:



GENETIC ALGORITM

$f(x) = x^2$

(i) Select encoding technique 0 to 31

(ii) Select initial population = 4.

String No.	Initial Population	x value	Fitness $f(x) = \mu$	Prob. $f(x)$	Actual count
1.	01100	12	144	0.124	1
2.	11001	25	625	0.5411	2
3.	00101	5	25	0.0216	0
4.	10011	19	361	0.3125	1

Sum 1155

Average 288.75

Max 625 → 729

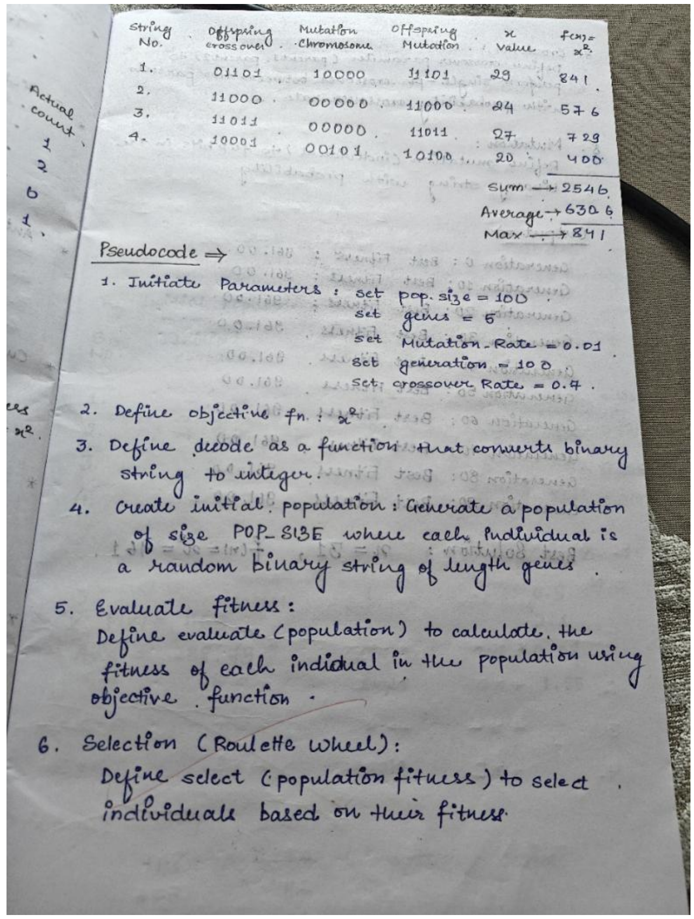
(3) Max selecting rating pool.

String No.	Rating Pool	Crossover Point	Offspring 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

Max Value → 729

(5) Mutation.



String No.	Offspring crossover	Mutation Chromosome	Offspring Mutation	x Value	$f(x) = x^2$
1.	01101	10000	11101	29	841
2.	11000	00000	11000	24	576
3.	11011	00000	11011	27	729
4.	10001	00101	10100	20	400

Sum → 2546

Average → 630.6

Max → 841

Pseudocode ⇒

1. Initiate Parameters : set pop. size = 100
   set genes = 5
   set Mutation_Rate = 0.01
   set generation = 100
   set crossover Rate = 0.7
2. Define objective fn. : x^2
3. Define decode as a function that converts binary string to integer.
4. Create initial population : Generate a population of size POP_SIZE where each individual is a random binary string of length genes.
5. Evaluate fitness :
   Define evaluate (population) to calculate the fitness of each indidual in the population using objective function.
6. Selection (Roulette wheel):
   Define select (population fitness) to select individuals based on their fitness.

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

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()
```

Output:

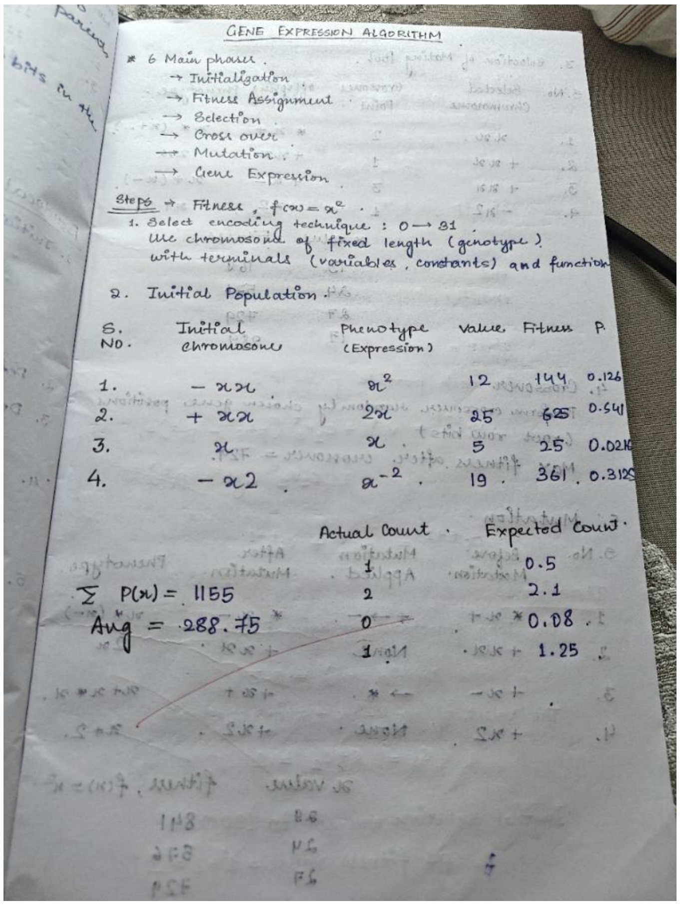
```
Enter 4 chromosomes (each of 5 bits, e.g., '10101'):
Chromosome 1: 01100
Chromosome 2: 11001
Chromosome 3: 00101
Chromosome 4: 10011
Generation 1: Best Fitness = 625, Best x = 25
Generation 2: Best Fitness = 625, Best x = 25
Generation 3: Best Fitness = 625, Best x = 25
Generation 4: Best Fitness = 625, Best x = 25
Generation 5: Best Fitness = 625, Best x = 25
Generation 6: Best Fitness = 625, Best x = 25
Generation 7: Best Fitness = 625, Best x = 25
Generation 8: Best Fitness = 625, Best x = 25
Generation 9: Best Fitness = 625, Best x = 25
Generation 10: Best Fitness = 625, Best x = 25
Generation 11: Best Fitness = 625, Best x = 25
Generation 12: Best Fitness = 625, Best x = 25
Generation 13: Best Fitness = 625, Best x = 25
Generation 14: Best Fitness = 625, Best x = 25
Generation 15: Best Fitness = 625, Best x = 25
Generation 16: Best Fitness = 625, Best x = 25
Generation 17: Best Fitness = 625, Best x = 25
Generation 18: Best Fitness = 625, Best x = 25
Generation 19: Best Fitness = 625, Best x = 25
Generation 20: Best Fitness = 625, Best x = 25

Best solution found:
Chromosome: 11001
x = 25
f(x) = 625
```

Program 2

Optimization via Gene Expression Algorithms:

Algorithm:



GENE EXPRESSION ALGORITHM

* 6 Main phases.
  - → Initialization
  - → Fitness Assignment
  - → Selection
  - → Cross over
  - → Mutation
  - → Gene Expression

Steps → Fitness, $f(x) = x^2$.

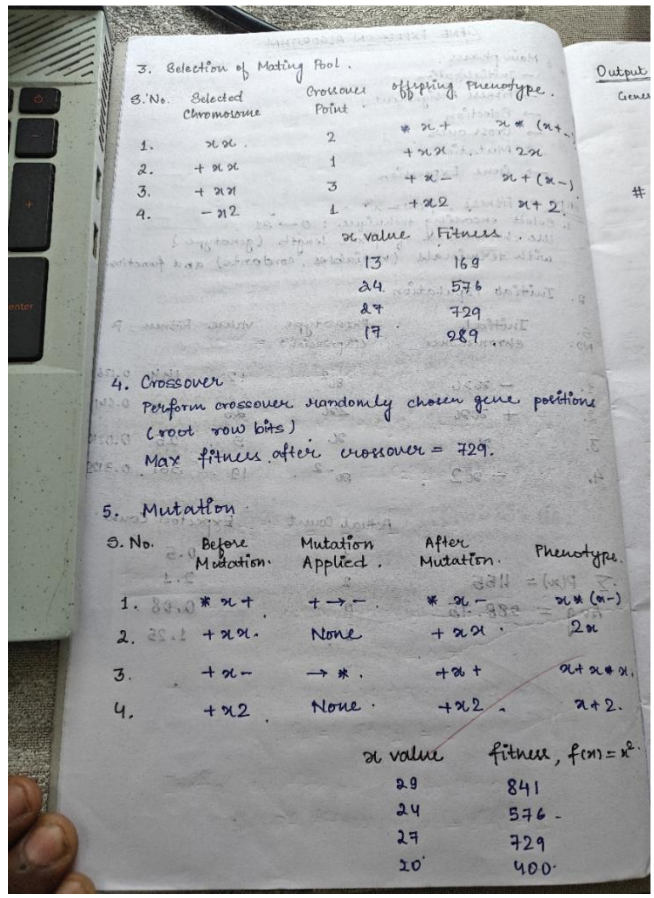
1. Select encoding technique : 0 → 31
   We chromosome of fixed length (genotype) with terminals (variables, constants) and function
2. Initial Population

S. No.	Initial chromosome	Phenotype (Expression)	Value	Fitness	P
1.	$-xx$	x^2	12	144	0.126
2.	$+xx$	$2x$	25	625	0.541
3.	x	x	5	25	0.0216
4.	$-x2$	x^{-2}	19	361	0.3125

Actual Count	Expected Count
1	0.5
2	2.1
0	0.08
1	1.25

$\Sigma P(x) = 1155$

Avg = 288.75



3. Selection of Mating Pool.

S. No.	Selected Chromosome	Crossover Point	offspring	Phenotype
1.	xx	2	$*x+$	$x*(x+)$
2.	$+xx$	1	$+xx$	$2x$
3.	$+xx$	3	$+x-$	$x+(x-)$
4.	$-x2$	1	$+x2$	$x+2$

x value	Fitness
13	169
24	576
27	729
17	289

4. Crossover

Perform crossover randomly chosen gene positions (root row bits).

Max fitness after crossover = 729.

5. Mutation

S. No.	Before Mutation	Mutation Applied	After Mutation	Phenotype
1.	$*x+$	$+ \to -$	$*x-$	$x*(x-)$
2.	$+xx$	None	$+xx$	$2x$
3.	$+x-$	$\to *$	$+x+$	$x+x*x$
4.	$+x2$	None	$+x2$	$x+2$

x value	fitness, $f(x) = x^2$
29	841
24	576
27	729
20	400

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()
```

Output:

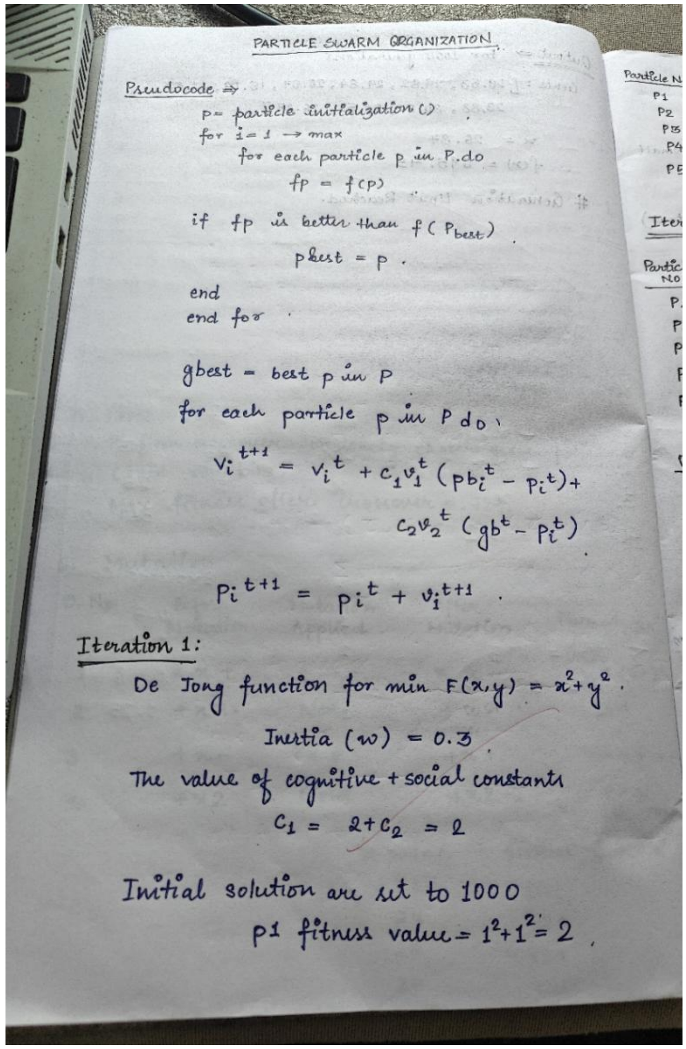
```
Generation 1: Best Fitness = 2.3125, Best x = 0.4262
Generation 2: Best Fitness = 2.3125, Best x = 0.4262
Generation 3: Best Fitness = 2.3125, Best x = 0.4262
Generation 4: Best Fitness = 2.3125, Best x = 0.4262
Generation 5: Best Fitness = 2.3125, Best x = 0.4262
Generation 6: Best Fitness = 2.3125, Best x = 0.4262
Generation 7: Best Fitness = 2.3125, Best x = 0.4262
Generation 8: Best Fitness = 2.4233, Best x = 0.6237
Generation 9: Best Fitness = 2.4233, Best x = 0.6237
Generation 10: Best Fitness = 2.4233, Best x = 0.6237
Generation 11: Best Fitness = 2.4233, Best x = 0.6237
Generation 12: Best Fitness = 2.4233, Best x = 0.6237
Generation 13: Best Fitness = 2.4233, Best x = 0.6237
Generation 14: Best Fitness = 2.4233, Best x = 0.6237
Generation 15: Best Fitness = 2.4233, Best x = 0.6237
Generation 16: Best Fitness = 2.4233, Best x = 0.6237
Generation 17: Best Fitness = 2.4395, Best x = 0.4594
Generation 18: Best Fitness = 2.4395, Best x = 0.4594
Generation 19: Best Fitness = 2.4395, Best x = 0.4594
Generation 20: Best Fitness = 2.4395, Best x = 0.4594

Best solution found:
Genes: [0.6948405045559576, -0.647173288232043, -0.3013499383055478, 1.631627548910124, 0.9271637073163099, 0.0324867196364278, -0.3565755055362756, 1.5226396608397925, 1.0654293190513275
x = 0.4594
f(x) = 2.4395
```

Program 3

Particle Swarm Optimization

Algorithm:



PARTICLE SWARM ORGANIZATION

Pseudocode ⇒

```
p = particle initialization ()
for i = 1 → max
    for each particle p in P.do
        fp = f(p)
if fp is better than f(P_best)
        pbest = p.
end
end for

gbest = best p in P
for each particle p in P do
```

$$v_i^{t+1} = v_i^t + c_1 v_1^t (pb_i^t - p_i^t) + c_2 v_2^t (gb^t - p_i^t)$$

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

Iteration 1:

De Jong function for min $F(x,y) = x^2 + y^2$.

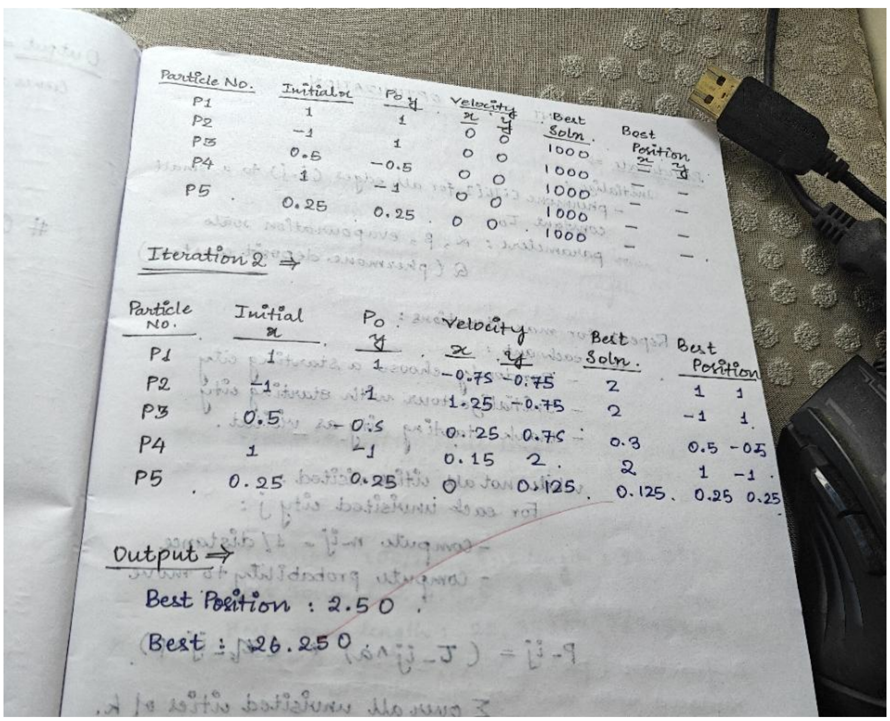
Inertia (w) = 0.3

The value of cognitive + social constants

$c_1 = 2 + c_2 = 2$

Initial solution are set to 1000

p1 fitness value = $1^2 + 1^2 = 2$.



Particle No.	Initial x	Po y	Velocity x	Velocity y	Best Soln.	Best Position x	Best Position y
P1	1	1	0	0	1000	—	—
P2	−1	1	0	0	1000	—	—
P3	0.5	−0.5	0	0	1000	—	—
P4	1	−1	0	0	1000	—	—
P5	0.25	0.25	0	0	1000	—	—

Iteration 2 ⇒

Particle No.	Initial x	Po y	Velocity x	Velocity y	Best Soln.	Best Position x	Best Position y
P1	1	1	−0.75	−0.75	2	1	1
P2	−1	1	1.25	−0.75	2	−1	1
P3	0.5	−0.5	0.25	0.75	0.3	0.5	−0.5
P4	1	−1	0.15	2	2	1	−1
P5	0.25	0.25	0	0.125	0.125	0.25	0.25

Output ⇒

Best Position : 2.50.

Best : 26.250

Code:

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


def objective_function(x):
    return x**2 - 4*x + 4

class Particle:
    def __init__(self, lower_bound, upper_bound):
        self.position = np.random.uniform(lower_bound, upper_bound)
        self.velocity = np.random.uniform(-1, 1)
        self.best_position = self.position
        self.best_value = objective_function(self.position)

    def update(self, global_best_position, w, c1, c2):
        r1 = np.random.rand()
        r2 = np.random.rand()


        self.velocity = w * self.velocity + c1 * r1 * (self.best_position - self.position) + c2 * r2 *
(global_best_position - self.position)
        self.position += self.velocity


        current_value = objective_function(self.position)


        if current_value < self.best_value:
            self.best_value = current_value
            self.best_position = self.position

# PSO parameters
num_particles = 30
num_iterations = 100
w = 0.7
c1 = 1.5
c2 = 1.5
lower_bound = -10
upper_bound = 10


particles = [Particle(lower_bound, upper_bound) for _ in range(num_particles)]


global_best_position = particles[0].best_position
global_best_value = particles[0].best_value
```

```
# PSO loop
for iteration in range(num_iterations):
    for particle in particles:
        particle.update(global_best_position, w, c1, c2)


        if particle.best_value < global_best_value:
            global_best_value = particle.best_value
            global_best_position = particle.best_position


    if iteration % 10 == 0:
        print(f"Iteration {iteration}: Global Best Position = {global_best_position}, Value =
{global_best_value}")


print(f"\nOptimal Position: {global_best_position}")
print(f"Optimal Value: {global_best_value}")


x_values = np.linspace(lower_bound, upper_bound, 100)
y_values = objective_function(x_values)

plt.plot(x_values, y_values, label="Objective Function f(x)")
plt.scatter(global_best_position, global_best_value, color='red', label='Optimal Solution (PSO)', zorder=5)
plt.title("Particle Swarm Optimization for Minimizing f(x) = x^2 - 4x + 4")
plt.xlabel("x")
plt.ylabel("f(x)")
plt.legend()
plt.show()
```

Output:

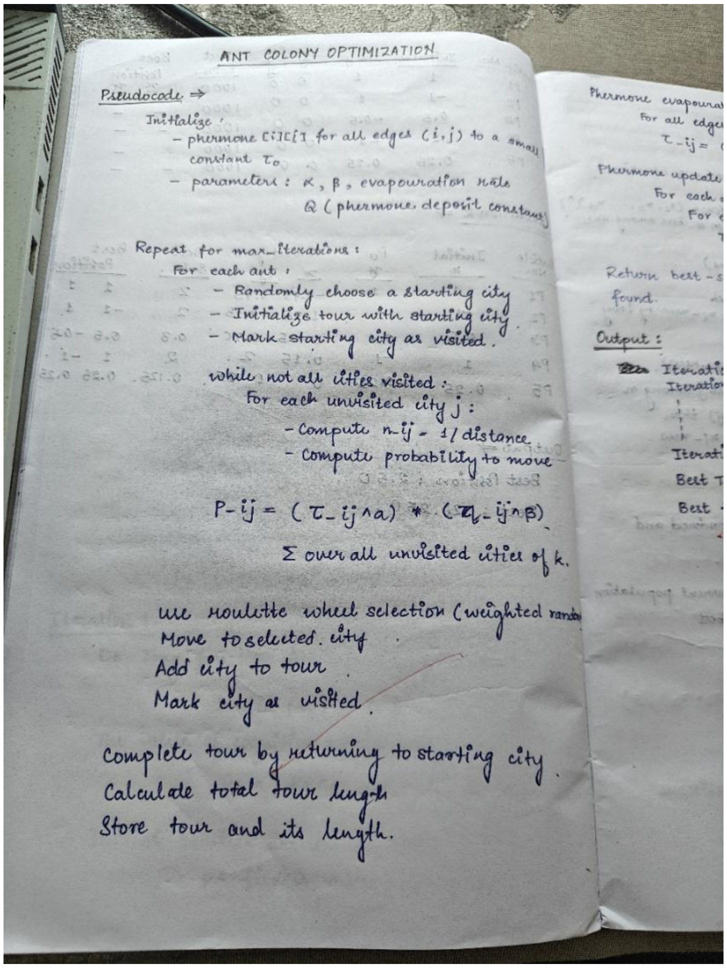
```
••• Iteration 2:
        x     y    vx     vy  pbest_x  pbest_y  pbest_val
    0  1.00  1.00 -0.75 -0.750    1.00     1.00     27.000
    1 -1.00  1.00  1.25 -0.750   -1.00     1.00     27.000
    2  0.50 -0.50  0.25  0.750    0.50    -0.50     25.500
    3  1.00 -1.00  0.15  2.000    1.00    -1.00     27.000
    4  0.85  0.25  0.00  0.125    0.85     0.25     25.785

    Output:
    Best position: (0.5, -0.5)
    Best value: 25.500
```

Program 4

Ant Colony Optimization for Vehicle Routing Problem:

Algorithm:



ANT COLONY OPTIMIZATION

Pseudocode ⇒

Initialize :

- phermone [i][j] for all edges (i, j) to a small constant τ_0
- parameters : α, β, evapouration rate
  Q (phermone deposit constant)

Repeat for max_iterations :

For each ant :

- Randomly choose a starting city
- Initialize tour with starting city .
- Mark starting city as visited .

while not all cities visited :

For each unvisited city j :

- Compute n_ij = 1/ distance
- Compute probability to move

P_ij = (τ_ij ^a) * (η_ij ^ β)

Σ over all unvisited cities of k.

use roulette wheel selection (weighted random)

Move to selected city .

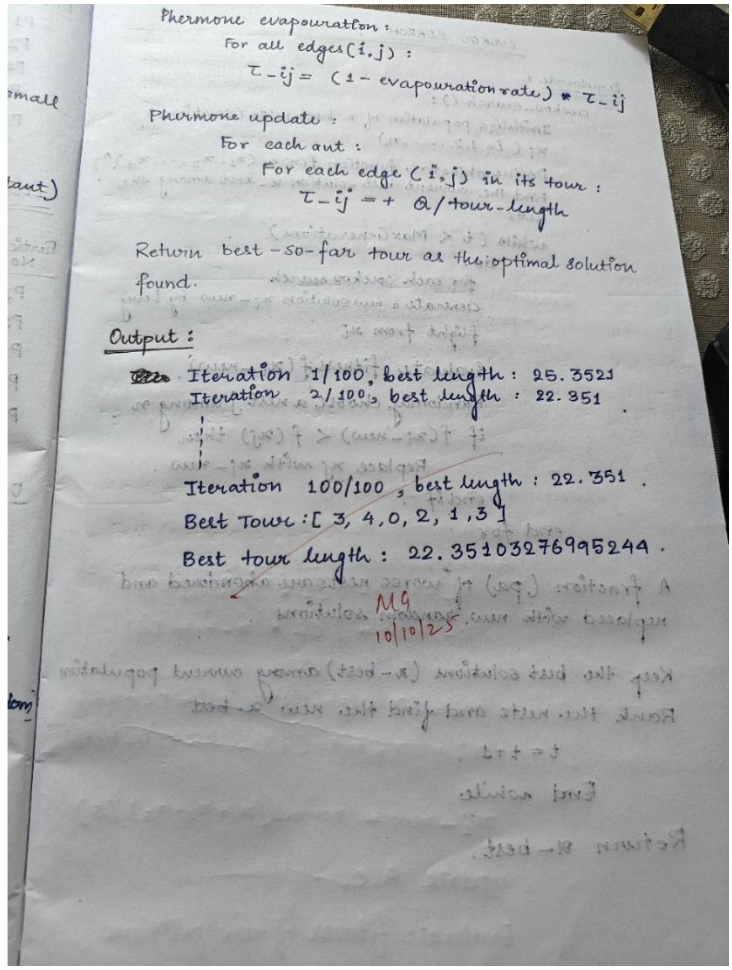
Add city to tour .

Mark city as visited .

Complete tour by returning to starting city .

Calculate total tour length

Store tour and its length.



Phermone evapouration :

For all edges(i, j) :

τ_ij = (1 - evapouration rate) * τ_ij

Phermone update :

For each ant :

For each edge (i, j) in its tour :

τ_ij =+ Q/tour_length

Return best-so-far tour as the optimal solution found.

Output :

Iteration 1/100, best length : 25.3521

Iteration 2/100, best length : 22.351 .

Iteration 100/100 , best length : 22.351 .

Best Tour :[3, 4, 0, 2, 1, 3]

Best tour length : 22.35103276995244 .

MG
10/10/25

Code:

```
import random
import numpy as np

class VRP:
    def __init__(self, depot, customers, capacities):
        self.depot = depot
        self.customers = customers
        self.capacities = capacities
        self.num_customers = len(customers)
        self.num_vehicles = len(capacities)
        self.distance_matrix = self.create_distance_matrix()

    def create_distance_matrix(self):
        dist_matrix = np.zeros((self.num_customers + 1, self.num_customers + 1))  # +1 for depot
        for i in range(self.num_customers + 1):
            for j in range(i + 1, self.num_customers + 1):
                if i == 0:
                    dist = np.linalg.norm(np.array(self.depot) - np.array(self.customers[j-1]))
                elif j == 0:
                    dist = np.linalg.norm(np.array(self.depot) - np.array(self.customers[i-1]))
                else:
                    dist = np.linalg.norm(np.array(self.customers[i-1]) - np.array(self.customers[j-1]))
                dist_matrix[i][j] = dist_matrix[j][i] = dist
        return dist_matrix

class AntColony:
    def __init__(self, vrp, num_ants, alpha=1, beta=5, rho=0.5, q0=0.9, iterations=100):
        self.vrp = vrp
        self.num_ants = num_ants
        self.alpha = alpha
        self.beta = beta
        self.rho = rho
        self.q0 = q0
        self.iterations = iterations
        self.pheromone = np.ones((vrp.num_customers + 1, vrp.num_customers + 1))
        self.best_solution = None
        self.best_solution_length = float('inf')

    def construct_solution(self, ant_idx):
        unvisited = set(range(1, self.vrp.num_customers + 1))
        routes = {vehicle: [] for vehicle in range(self.vrp.num_vehicles)}
        demands = {vehicle: 0 for vehicle in range(self.vrp.num_vehicles)}
        current_city = 0

        while unvisited:
            vehicle = random.choice(range(self.vrp.num_vehicles))
            if demands[vehicle] < self.vrp.capacities[vehicle]:
                next_city = self.select_next_city(current_city, unvisited)
                routes[vehicle].append(next_city)
                unvisited.remove(next_city)
```

```
            demands[vehicle] += 1
            current_city = next_city
        else:
            continue

    for vehicle in range(self.vrp.num_vehicles):
        routes[vehicle].append(0)

    return routes

def calculate_probabilities(self, current_city, unvisited):
    probabilities = []
    for city in unvisited:
        pheromone = self.pheromone[current_city][city] ** self.alpha
        distance = self.vrp.distance_matrix[current_city][city]
        heuristic = (1 / distance) ** self.beta
        probabilities.append(pheromone * heuristic)

    total_prob = sum(probabilities)
    if total_prob == 0:
        return [1 / len(unvisited)] * len(unvisited)

    probabilities = [p / total_prob for p in probabilities]
    return probabilities

def select_next_city(self, current_city, unvisited):
    probabilities = self.calculate_probabilities(current_city, unvisited)
    return random.choices(list(unvisited), probabilities)[0]

def update_pheromones(self, solutions, lengths):
    self.pheromone *= (1 - self.rho)

    for idx, solution in enumerate(solutions):
        length = lengths[idx]
        for route in solution.values():
            for i in range(len(route) - 1):
                self.pheromone[route[i]][route[i + 1]] += 1 / length

def run(self):
    for iteration in range(self.iterations):
        all_solutions = []
        all_lengths = []

        for ant_idx in range(self.num_ants):
            solution = self.construct_solution(ant_idx)
            length = self.calculate_solution_length(solution)
            all_solutions.append(solution)
            all_lengths.append(length)

            if length < self.best_solution_length:
                self.best_solution = solution
                self.best_solution_length = length
```

```
            self.update_pheromones(all_solutions, all_lengths)

            print(f"Iteration {iteration + 1}/{self.iterations}: Best Length = {self.best_solution_length}")

        return self.best_solution, self.best_solution_length

    def calculate_solution_length(self, solution):
        length = 0
        for vehicle in solution.values():
            for i in range(len(vehicle) - 1):
                length += self.vrp.distance_matrix[vehicle[i]][vehicle[i + 1]]
        return length

if __name__ == "__main__":
    depot = (0, 0)
    customers = [(2, 4), (3, 2), (6, 5), (8, 3), (7, 8), (5, 7)]
    capacities = [3, 3]

    vrp = VRP(depot, customers, capacities)
    aco = AntColony(vrp, num_ants=10, alpha=1, beta=2, rho=0.5, q0=0.9, iterations=50)

    best_solution, best_solution_length = aco.run()

    print("Best Solution (Routes):")
    for vehicle, route in best_solution.items():
        print(f"Vehicle {vehicle + 1}: {route}")

    print(f"\nBest Solution Length (Total Distance): {best_solution_length}")
```

Output:

```
Iteration 1/50: Best Length = 30.704096057970965
Iteration 2/50: Best Length = 25.85324233796014
Iteration 3/50: Best Length = 25.85324233796014
Iteration 4/50: Best Length = 25.85324233796014
Iteration 5/50: Best Length = 25.85324233796014
Iteration 6/50: Best Length = 25.85324233796014
Iteration 7/50: Best Length = 25.80789435080295
Iteration 8/50: Best Length = 25.80789435080295
Iteration 9/50: Best Length = 25.80789435080295
Iteration 10/50: Best Length = 25.80789435080295
Iteration 11/50: Best Length = 25.738177938973646
Iteration 12/50: Best Length = 25.738177938973646
Iteration 13/50: Best Length = 25.738177938973646
Iteration 14/50: Best Length = 22.65045276546171
Iteration 15/50: Best Length = 22.65045276546171
Iteration 16/50: Best Length = 22.65045276546171
Iteration 17/50: Best Length = 22.65045276546171
Iteration 18/50: Best Length = 22.65045276546171
Iteration 19/50: Best Length = 22.65045276546171
Iteration 20/50: Best Length = 22.65045276546171
Iteration 21/50: Best Length = 22.65045276546171
Iteration 22/50: Best Length = 22.65045276546171
Iteration 23/50: Best Length = 22.483842533421615
Iteration 24/50: Best Length = 22.483842533421615
Iteration 25/50: Best Length = 22.483842533421615
Iteration 26/50: Best Length = 22.483842533421615
Iteration 27/50: Best Length = 22.483842533421615
Iteration 28/50: Best Length = 22.483842533421615
Iteration 29/50: Best Length = 22.483842533421615
Iteration 30/50: Best Length = 22.483842533421615
Iteration 31/50: Best Length = 22.483842533421615
Iteration 32/50: Best Length = 22.483842533421615
Iteration 33/50: Best Length = 22.483842533421615
Iteration 34/50: Best Length = 22.483842533421615
Iteration 35/50: Best Length = 22.483842533421615
```

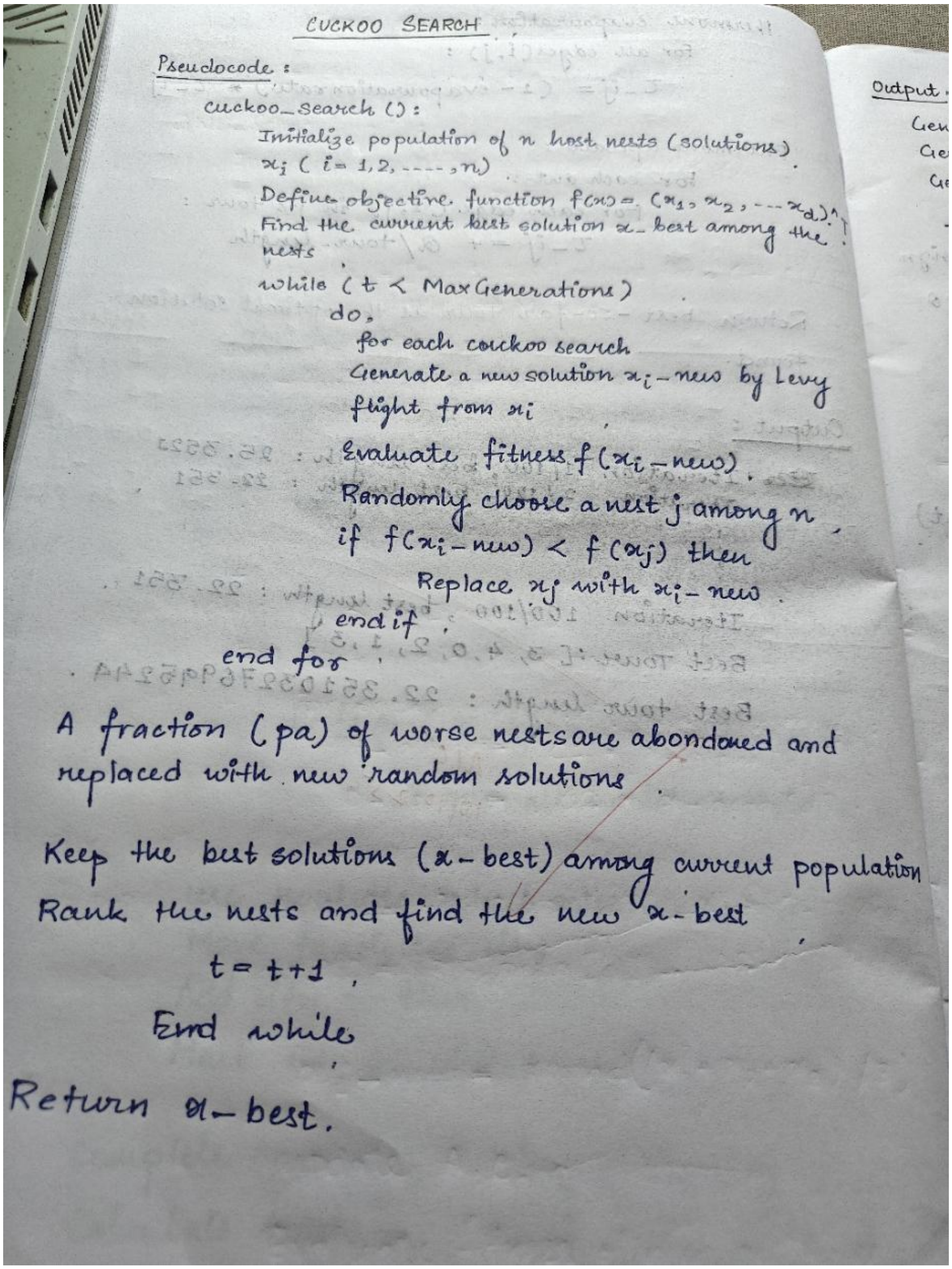
```
Iteration 36/50: Best Length = 22.483842533421615
Iteration 37/50: Best Length = 22.483842533421615
Iteration 38/50: Best Length = 22.483842533421615
Iteration 39/50: Best Length = 22.483842533421615
Iteration 40/50: Best Length = 22.483842533421615
Iteration 41/50: Best Length = 22.483842533421615
Iteration 42/50: Best Length = 22.483842533421615
Iteration 43/50: Best Length = 22.483842533421615
Iteration 44/50: Best Length = 22.483842533421615
Iteration 45/50: Best Length = 22.483842533421615
Iteration 46/50: Best Length = 22.483842533421615
Iteration 47/50: Best Length = 22.483842533421615
Iteration 48/50: Best Length = 22.483842533421615
Iteration 49/50: Best Length = 22.483842533421615
Iteration 50/50: Best Length = 22.483842533421615
Best Solution (Routes):
Vehicle 1: [5, 6, 1, 0]
Vehicle 2: [3, 4, 2, 0]

Best Solution Length (Total Distance): 22.483842533421615
```

Program 5

Cuckoo Search Algorithm for Task Scheduling Optimization:

Algorithm:



CUCKOO SEARCH

Pseudocode :

```
cuckoo_search ():
    Initialize population of n host nests (solutions)
    xi ( i= 1,2, ---- ,n)
    Define objective function f(x) = (x1, x2, --- xd)^T
    Find the current best solution x_best among the nests
    while ( t < MaxGenerations )
        do,
            for each cuckoo search
            Generate a new solution xi-new by Levy
            flight from xi
            Evaluate fitness f(xi-new)
            Randomly choose a nest j among n
            if f(xi-new) < f(xj) then
                Replace xj with xi-new
            end if
        end for
A fraction (pa) of worse nests are abondoned and
replaced with new random solutions

Keep the best solutions (x-best) among current population
Rank the nests and find the new x-best
        t = t+1
    End while
Return x-best.
```

Code:

```
import random

tasks = [2, 3, 4, 5, 6]
num_tasks = len(tasks)
num_nests = 5
Pa = 0.25
MaxGen = 50

def fitness(schedule):
    """Lower total duration = better fitness."""
    total_time = 0
    for t in schedule:
        total_time += t
    return -total_time

def random_schedule():
    """Create a random schedule (random order of tasks)."""
    s = tasks[:]
    random.shuffle(s)
    return s

def levy_flight(schedule):
    """Generate new schedule by small random changes."""
    new_s = schedule[:]
    i, j = random.sample(range(num_tasks), 2)
    new_s[i], new_s[j] = new_s[j], new_s[i]
    return new_s

nests = [random_schedule() for _ in range(num_nests)]
fitness_values = [fitness(s) for s in nests]

for gen in range(MaxGen):
    for i in range(num_nests):
        new_solution = levy_flight(nests[i])
        new_fitness = fitness(new_solution)

        j = random.randint(0, num_nests - 1)
        if new_fitness > fitness_values[j]:
            nests[j] = new_solution
            fitness_values[j] = new_fitness

    sorted_nests = sorted(zip(fitness_values, nests), reverse=True)
    num_abandon = int(Pa * num_nests)
    for k in range(num_abandon):
        sorted_nests[-(k+1)] = (fitness(random_schedule()), random_schedule())

    fitness_values, nests = zip(*sorted_nests)
```

```
        fitness_values, nests = list(fitness_values), list(nests)

    best_index = fitness_values.index(max(fitness_values))
    print("Best Schedule:", nests[best_index])
    print("Total Time:", -fitness_values[best_index])
```

Output:

```
Best Schedule: [6, 5, 4, 3, 2]
Total Time: 20
```

Program 6

Grey Wolf Optimizer (GWO):

Algorithm:

GREY WOLF OPTIMIZER

Application ⇒ Scheduling and Resource Allocation.

GWO_Scheduling () :

Initialize population of wolves (solutions).

x_i for $i = 1, \ldots, n$.

Each x_i represents a task-to-machine assignment.

Ex: $x_i = [0, 1, 2, 1, 0]$ means task 0 → M0, task 1 ⇒ M1 etc.

Evaluate fitness for each x_i

- for each solution, complete makespan (maximum machine time).

Identify Alpha (best), Beta (second best), Delta wolves (third best).

while (t < MaxIterations)

For each wolf x_i in population :

For each dimension d (task assignment) :

D-alpha = | C1 * x-alpha [d] |

D-beta = | C2 * x-beta [d] .

x1 = x-alpha [d] - A1 * D-alpha

x2 = x-beta [d] - A2 * D-beta

x_i-new = round(($x_1 + x_2 + x_3$) / 3)

update A, C, a.

Evaluate fitness of new positions.

t = t+1

Return Alpha.

Code:

```
import numpy as np

num_tasks = 20
num_vms = 5
num_wolves = 15
max_iter = 50

task_load = np.random.randint(1000, 10000, num_tasks)

vm_speed = np.random.randint(500, 2000, num_vms)

def fitness(position):
    """
    position[i] = VM index assigned to task i
    Fitness = total makespan (time to finish all tasks)
    """
    loads = np.zeros(num_vms)
    for i, vm in enumerate(position.astype(int)):
        loads[vm] += task_load[i] / vm_speed[vm]
    return np.max(loads)

wolves = np.random.randint(0, num_vms, (num_wolves, num_tasks))
alpha, beta, delta = None, None, None
alpha_score, beta_score, delta_score = np.inf, np.inf, np.inf

for t in range(max_iter):
    a = 2 - 2 * t / max_iter

    for i in range(num_wolves):
        score = fitness(wolves[i])

        if score < alpha_score:
            alpha_score, alpha = score, wolves[i].copy()
        elif score < beta_score:
            beta_score, beta = score, wolves[i].copy()
        elif score < delta_score:
            delta_score, delta = score, wolves[i].copy()

    for i in range(num_wolves):
        for j in range(num_tasks):
            r1, r2 = np.random.rand(), np.random.rand()
            A1, C1 = 2*a*r1 - a, 2*r2
            D_alpha = abs(C1 * alpha[j] - wolves[i][j])
            X1 = alpha[j] - A1 * D_alpha

            r1, r2 = np.random.rand(), np.random.rand()
```

```
            A2, C2 = 2*a*r1 - a, 2*r2
            D_beta = abs(C2 * beta[j] - wolves[i][j])
            X2 = beta[j] - A2 * D_beta

            r1, r2 = np.random.rand(), np.random.rand()
            A3, C3 = 2*a*r1 - a, 2*r2
            D_delta = abs(C3 * delta[j] - wolves[i][j])
            X3 = delta[j] - A3 * D_delta

            new_pos = (X1 + X2 + X3) / 3
            wolves[i][j] = np.clip(round(new_pos), 0, num_vms - 1)

best_allocation = alpha.astype(int)
best_makespan = alpha_score

print("Best Makespan:", best_makespan)
print("Best Task Allocation (task → VM):")
for i, vm in enumerate(best_allocation):
    print(f"  Task {i+1} → VM {vm+1}")
```

Output:

```
Best Makespan: 21.60720720720721
Best Task Allocation (task → VM):
  Task 1 → VM 2
  Task 2 → VM 1
  Task 3 → VM 4
  Task 4 → VM 5
  Task 5 → VM 3
  Task 6 → VM 5
  Task 7 → VM 4
  Task 8 → VM 1
  Task 9 → VM 1
  Task 10 → VM 5
  Task 11 → VM 4
  Task 12 → VM 3
  Task 13 → VM 4
  Task 14 → VM 2
  Task 15 → VM 3
  Task 16 → VM 5
  Task 17 → VM 4
  Task 18 → VM 2
  Task 19 → VM 1
  Task 20 → VM 4
```

Program 7

Parallel Cellular Algorithm :

Algorithm:

PARALLEL CELLULAR ALGORITHM

(i) Define objective function f(x) to be minimized or maximized.

(ii) Set algorithm parameters :
- grit size.
- num iterations.
- neighbourhood_type.
- alpha (diffusion coefficient).
- mutation_rate.

(iii) Initialize each cell with a random position, x_i in the search space.

(iv) Evaluate fitness (x_i) for each cell.

(v) For each iteration t = 1 to num_iterations :

for each cell i in the grid :
- Get neighbour cells based on neighbourhood type.
- Find best neighbour solution x_best.
- Update cell's solution :

x_to_new = x_i + alpha * (x_best - x_i) + mutation_rate * random_noise

(vi) Evaluate f(x_i_new) for all cells.

Replace x_i with x_i_new if it improves ~~or~~ fitness

vii) Output best solution found

Output ⇒

Iteration

Code:

```
import numpy as np

N = 20
infection_prob = 0.25
infection_duration = 5
steps = 10

grid = np.zeros((N, N), dtype=int)
infection_time = np.zeros((N, N), dtype=int)

for _ in range(5):
    x, y = np.random.randint(0, N, 2)
    grid[x, y] = 1

print("Step | Healthy | Infected | Recovered")
print("--------------------------------------")

for step in range(steps):
    new_grid = grid.copy()

    for i in range(N):
        for j in range(N):
            if grid[i, j] == 0:
                for dx in [-1, 0, 1]:
                    for dy in [-1, 0, 1]:
                        if dx == 0 and dy == 0:
                            continue
                        ni, nj = (i + dx) % N, (j + dy) %
N
                        if grid[ni, nj] == 1 and
np.random.rand() < infection_prob:
                            new_grid[i, j] = 1
                            break
            elif grid[i, j] == 1:
                infection_time[i, j] += 1
                if infection_time[i, j] >
infection_duration:
                    new_grid[i, j] = 2

    grid = new_grid

    healthy = np.count_nonzero(grid == 0)
    infected = np.count_nonzero(grid == 1)
    recovered = np.count_nonzero(grid == 2)
```

    print(f"{step:>4} | {healthy:>7} |
{infected:>8} | {recovered:>9}")

Output:

```
•••  Step | Healthy | Infected | Recovered
     --------------------------------------
        0 |     388 |       12 |         0
        1 |     371 |       29 |         0
        2 |     338 |       62 |         0
        3 |     301 |       99 |         0
        4 |     244 |      156 |         0
        5 |     200 |      195 |         5
        6 |     162 |      226 |        12
        7 |     106 |      265 |        29
        8 |      64 |      274 |        62
        9 |      30 |      271 |        99
```