# 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)**
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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 **Sneha S Bhairappa (1BM23CS333),** 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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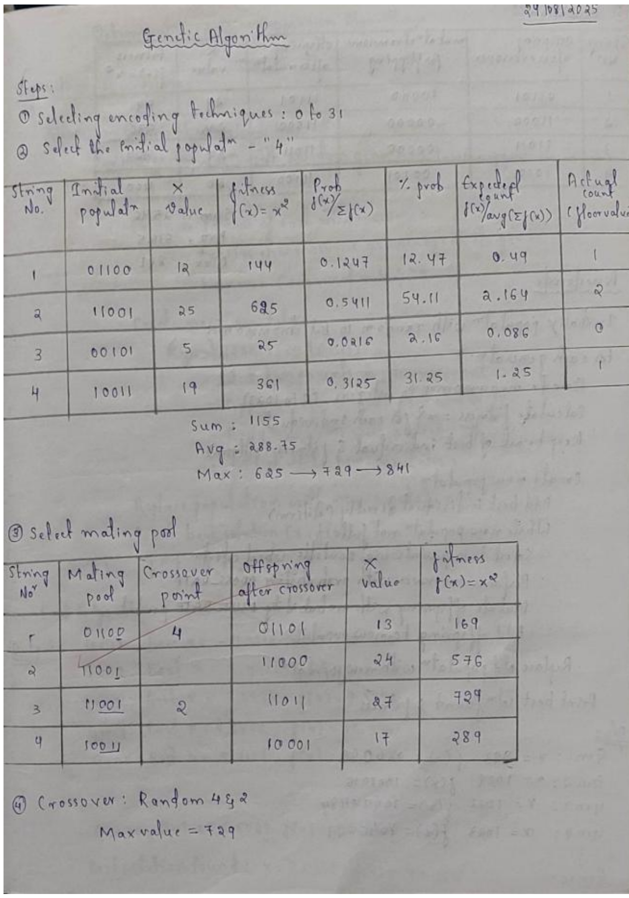
Github Link:
https://github.com/1BM23CS333/BIS-LAB.git

<u>**Program 1**</u>

## Genetic Algorithm for Optimization Problems

## Algorithm:



24/08/2025

Genetic Algorithm

Steps:

① Selecting encoding techniques : 0 to 31

② Select the initial populatn - "4"

| String No. | Initial populatn | x Value | fitness $f(x) = x^2$ | Prob $f(x)/\Sigma f(x)$ | % prob | Expected count $f(x)/avg(\Sigma f(x))$ | Actual count (floor 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 | 0.086 | 0 |
| 4 | 10011 | 19 | 361 | 0.3125 | 31.25 | 1.25 | 1 |

Sum : 1155

Avg : 288.75

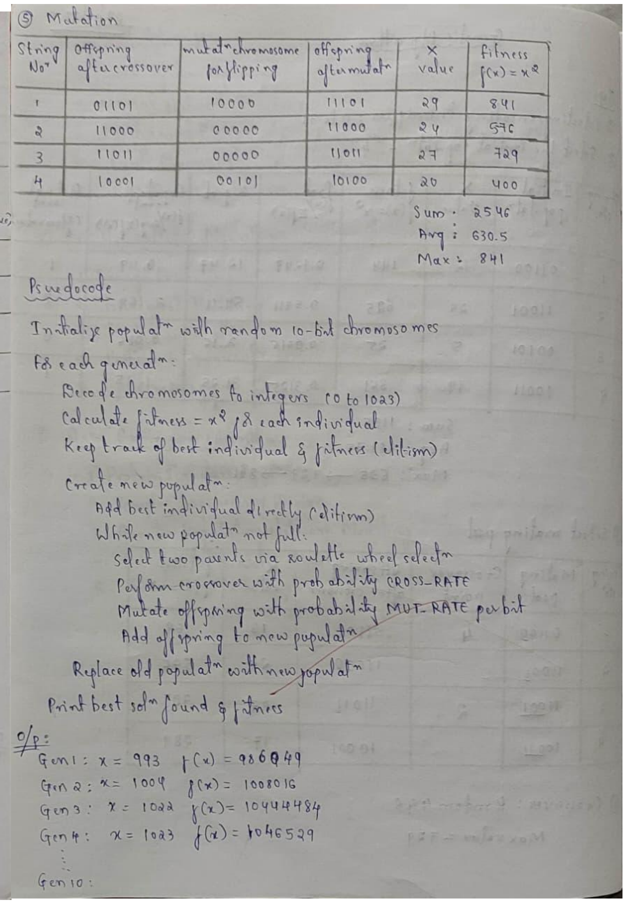
Max : 625 ⟶ 729 ⟶ 841

③ Select mating pool

| String 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

Max value = 729



⑤ Mutation

| String No | Offspring after crossover | mutatn chromosome for flipping | offspring after mutatn | 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 |

Sum : 2546

Avg : 630.5

Max : 841

Pseudocode

```
Initialize populatn with random 10-bit chromosomes
For each generatn:
    Decode chromosomes to integers (0 to 1023)
    Calculate fitness = x^2 for each individual
    Keep track of best individual & fitness (elitism)
    Create new populatn:
        Add best individual directly (elitism)
        While new populatn not full:
            Select two parents via roulette wheel selectn
            Perform crossover with probability CROSS_RATE
            Mutate offspring with probability MUT_RATE per bit
            Add offspring to new populatn
    Replace old populatn with new populatn
Print best soln found & fitness
```

O/P:

Gen 1 : x = 993  f(x) = 986049

Gen 2 : x = 1004  f(x) = 1008016

Gen 3 : x = 1022  f(x) = 10444484

Gen 4 : x = 1023  f(x) = 1046529

⋮

Gen 10 :

**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:**

Optimizatⁿ via Gene Expression Algorithms 05/09/2025

Algorithm / Psuedocode:

Algorithm GeneExpressionAlgorithm
Initialize populatⁿ with random genes in [lower, upper]
For each generatⁿ:
Evaluate fitness of each chromosome:
- Express chromosome as average of its genes
- Fitness = (expressed value)^2

Create new_populatn:
Repeat POP_SIZE times:
- select two parents by tournament
- Apply crossover with probability Pc
- Apply mutation with probability Pm
- Add child to new_population

Replace population with new_population
Track best solution (x, f(x))

Return best solution found

End Algorithm.

Output: Gen1 : Best x = −4.3850 , f(x) = 19.2279
Gen2 : Best x = 3.4352, f(x) = 11.8008
Gen3 : Best x = 3.0554, f(x) = 9.3358
Gen4 : Best x = 3.6876 , f(x) = 13.5987
Gen5 : Best x = 5.4107 , f(x) = 29.2759
⋮
Gen20 : Best x = 6.6529, f(x) = 44.2616

Best solution found : x = 6.6529 , f(x) = 44.2616

**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:

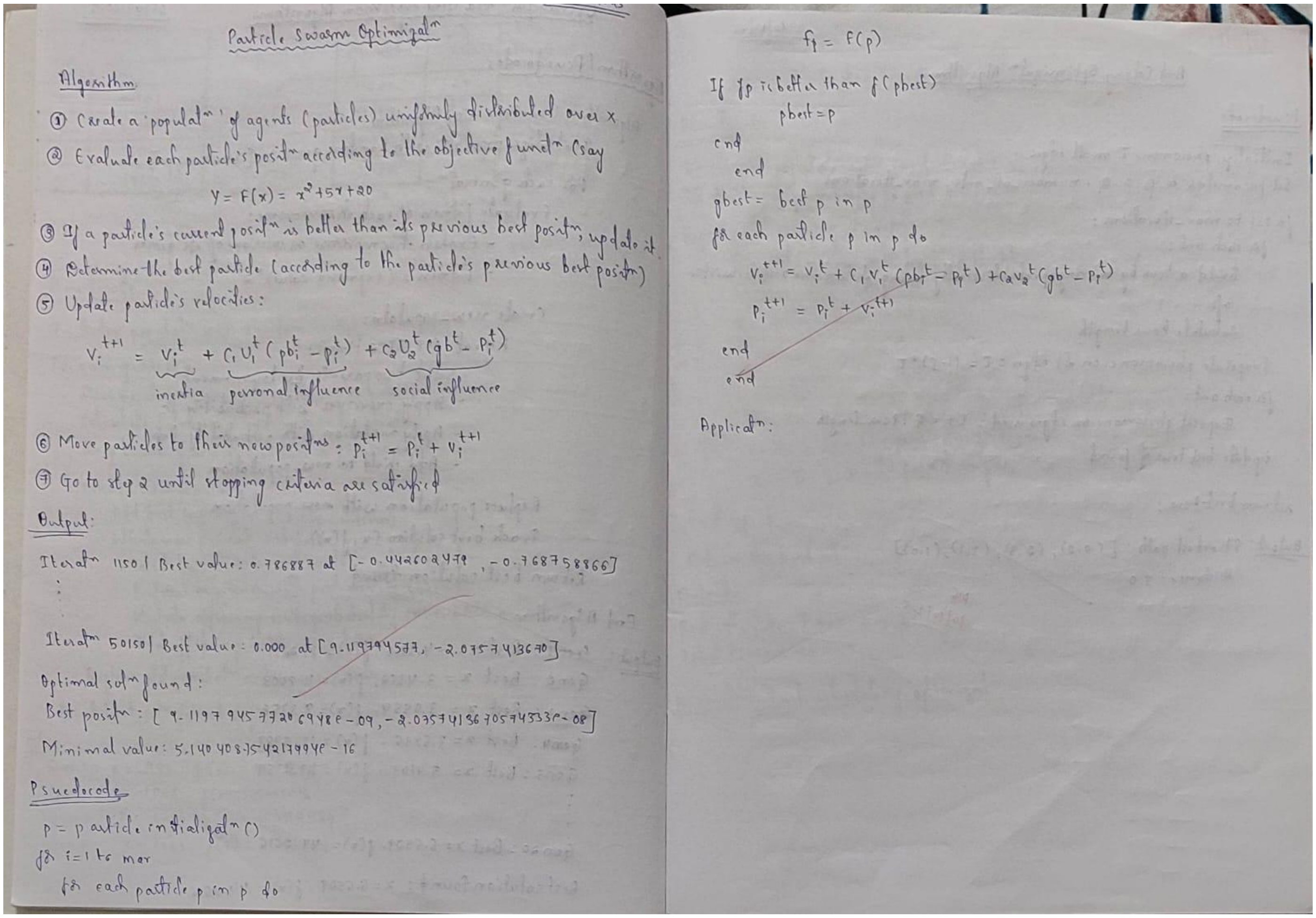
```
Generation 1: Best Fitness = 2.3125, Best x = 0.4262
Generation 2: Best Fitness = 2.3125, Best x = 0.4262
Generation 3: Best Fitness = 2.3125, Best x = 0.4262
Generation 4: Best Fitness = 2.3125, Best x = 0.4262
Generation 5: Best Fitness = 2.3125, Best x = 0.4262
Generation 6: Best Fitness = 2.3125, 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 Optimizatⁿ

Algorithm

① Create a 'populatⁿ' of agents (particles) uniformly distributed over x

② Evaluate each particle's positⁿ according to the objective functⁿ (say

$$y = F(x) = x^2 + 5x + 20$$

③ If a particle's current positⁿ is better than its previous best positⁿ, update it

④ Determine the best particle (according to the particle's previous best positⁿ)

⑤ Update particle's velocities:

$$v_i^{t+1} = \underbrace{v_i^t}_{\text{inertia}} + \underbrace{c_1 U_1^t (pb_i^t - p_i^t)}_{\text{personal influence}} + \underbrace{c_2 U_2^t (gb^t - p_i^t)}_{\text{social influence}}$$

⑥ Move particles to their new positⁿs: $p_i^{t+1} = p_i^t + v_i^{t+1}$

⑦ Go to step 2 until stopping criteria are satisfied

Output:

Iteratⁿ 1150 | Best value: 0.786887 at [-0.442602479, -0.768758866]

:

Iteratⁿ 50150 | Best value: 0.000 at [9.119794577, -2.0757413670]

Optimal solⁿ found:

Best positⁿ: [9.11979457720694 8e-09, -2.0757413670574333e-08]

Minimal value: 5.140408754217994e-16

Psuedocode

```
p = particle initializatⁿ()
for i=1 to max
    for each particle p in p do
        fp = f(p)
        If fp is better than f(pbest)
            pbest = p
        end
    end
    gbest = best p in p
    for each particle p in p do
        vi^(t+1) = vi^t + c1 v1^t (pbi^t - pi^t) + c2 v2^t (gb^t - pi^t)
        pi^(t+1) = pi^t + vi^(t+1)
    end
end
```

Applicatⁿ:

**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:**

10/10/25

Ant Colony Optimizatⁿ Algorithm

Psuedocode

```
Initialize pheromone τ on all edges
Set parameters α, β, ρ, Q, number_of_ants, max_iterations

for i=1 to max_iterations:
    for each ant:
        Build a tour by moving probablistically using pheromone and heuristic
        info
        Calculate tour length
    Evaporate pheromone on all edges : τ = (1-ρ)*τ
    for each ant:
        Deposit pheromone on edges used : τ+ = Q / tour_length
    update best tour if found

return best tour;
```

Output: Shortest path : [(0,2), (2,3), (3,1), (1,0)]
Distance: 9.0

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:**

17/10/25

Cuckoo Search Algorithm

Pseudocode

Initialize populatn of n nests (solutions)
Set discovery probability Pa and max iteratn
Repeat until stopping conditn:
    Generate a new soln by Levy flight
    Evaluate its fitness.
    Randomly choose a nest j
    if new soln is better than nest j:
        Replace nest j with new soln
    Abandon a fraction Pa of worst nests
    Create a new random solns for them
    Keep the best soln found so far

End repeat
Return the best soln.

Output:

~~Best schedule: [6,5,4,3,2]~~
~~Total time: 20~~

Applicatn: Task scheduling optimizatn

**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:

17/10/25

Grey Wolf Optimizer

Pseudocode

1. Initialize parameters: no of wolves (N), max iteration (T)
2. Initialize the positn of each wolf randomly within the search space
3. Evaluate fitness of all wolves
4. Identify alpha (best), beta (second best), delta (third best) wolves
5. while (t < T) do
   a) for each wolf i:
      update coefficient vectors A & C
      compute distances to alpha, beta, delta
      update positn using
      $x_i(t+1) = (x_\alpha + x_\beta + x_\delta)/3$
   b) Enforce search boundaries
   c) Evaluate fitness of updated positns
   d) Update $\alpha, \beta, \delta$ wolves
   e) $t = t+1$
6. Return alpha wolf positn as the best soln

Output:

BestMakespan: 21.60720720

Best Task Allocatn (task → VM)

Task1 → VM2
Task 2 → VM1
Task 3 → VM4
Task4 → VM5
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

Applicatn: Cloud Task Allocatn

**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}")
```

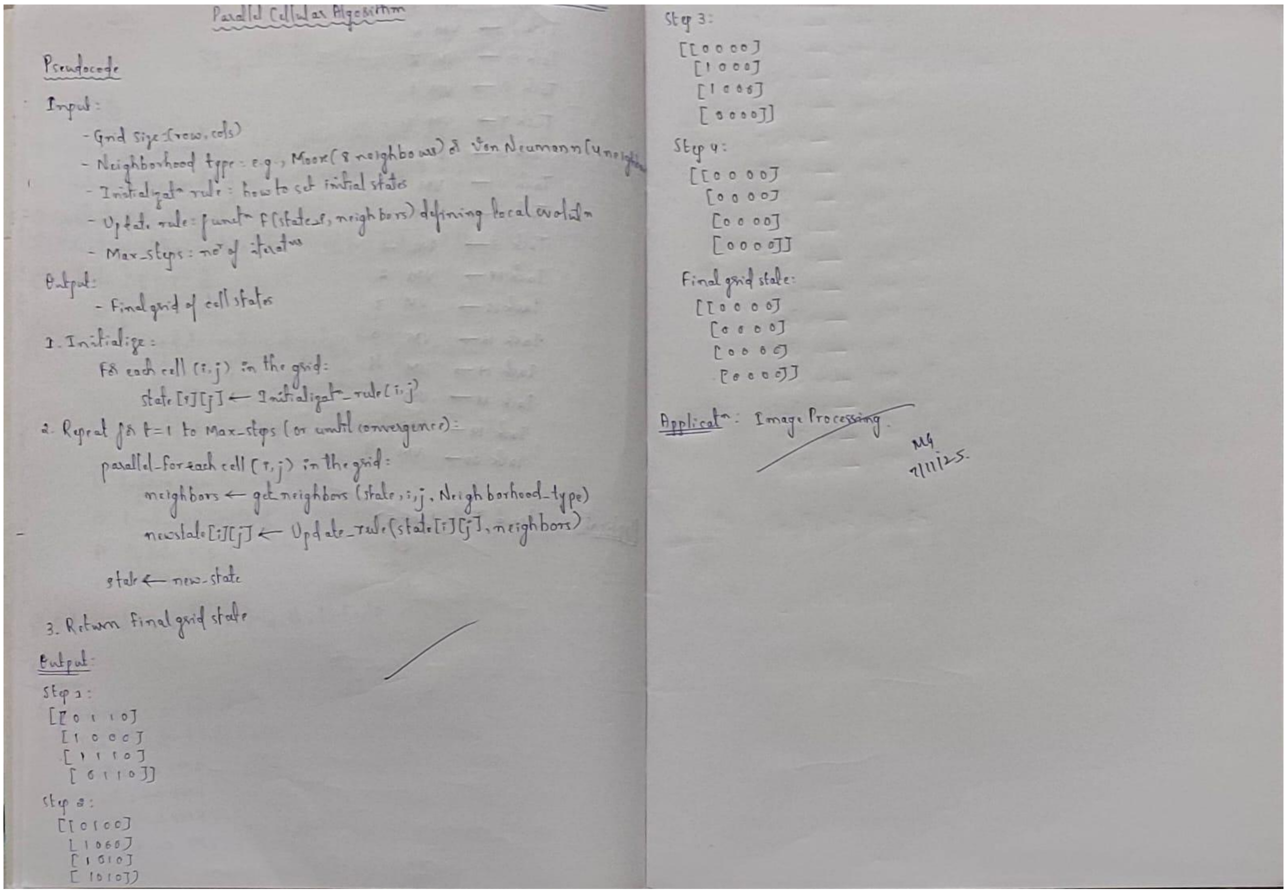
**Output:**

```
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

Pseudocode

Input:

- Grid size: (rows, cols)
- Neighborhood type: e.g., Moore (8 neighbours) or Von Neumann (4 neighbours)
- Initializatn rule: how to set initial states
- Update rule: functn f(state, neighbors) defining local evolutn
- Max_steps: no of iteratns

Output:

- Final grid of cell states

```
1. Initialize:
      For each cell (i, j) in the grid:
          state[i][j] ← Initializatn_rule(i, j)
2. Repeat for t=1 to Max_steps (or until convergence):
      parallel_for each cell (i, j) in the grid:
          neighbors ← get_neighbors(state, i, j, Neighborhood_type)
          newstate[i][j] ← Update_rule(state[i][j], neighbors)

      state ← new_state

3. Return final grid state
```

Output:

Step 1:
```
[[0 1 1 0]
 [1 0 0 0]
 [1 1 1 0]
 [0 1 1 0]]
```
Step 2:
```
[[0 1 0 0]
 [1 0 0 0]
 [1 0 1 0]
 [1 0 1 0]]
```
Step 3:
```
[[0 0 0 0]
 [1 0 0 0]
 [1 0 0 0]
 [0 0 0 0]]
```
Step 4:
```
[[0 0 0 0]
 [0 0 0 0]
 [0 0 0 0]
 [0 0 0 0]]
```
Final grid state:
```
[[0 0 0 0]
 [0 0 0 0]
 [0 0 0 0]
 [0 0 0 0]]
```

Applicatn: Image Processing.

MG
7/11/25.

**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
```