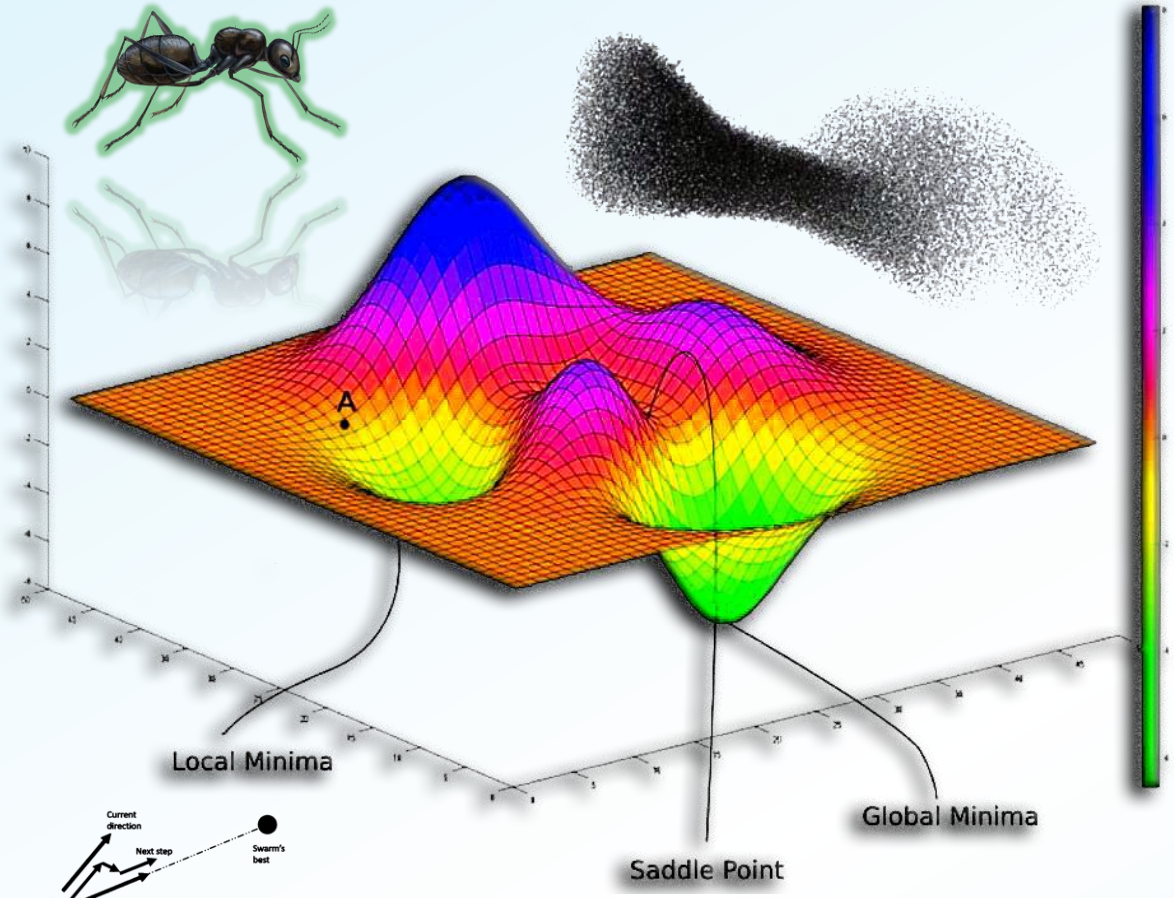
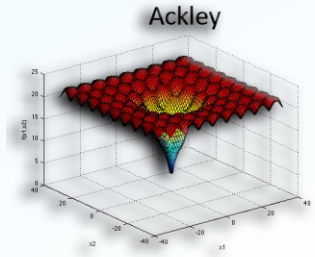
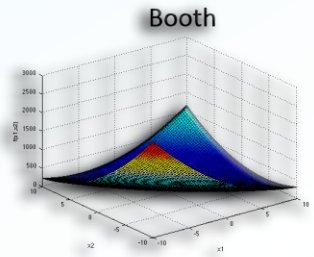
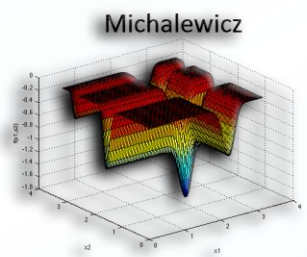
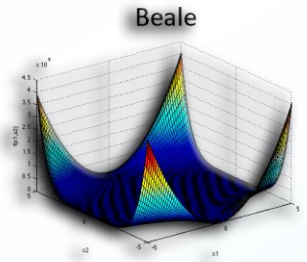
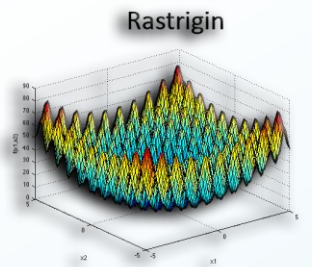


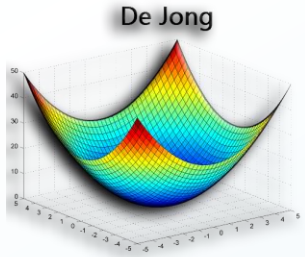


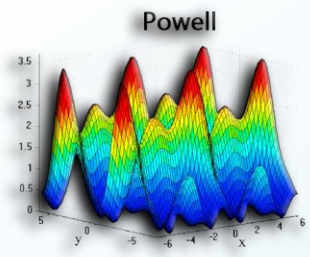


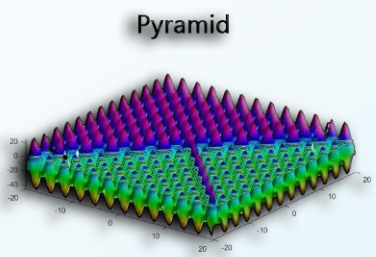


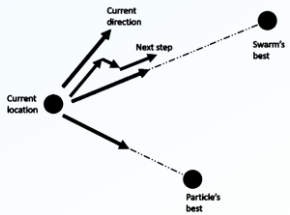


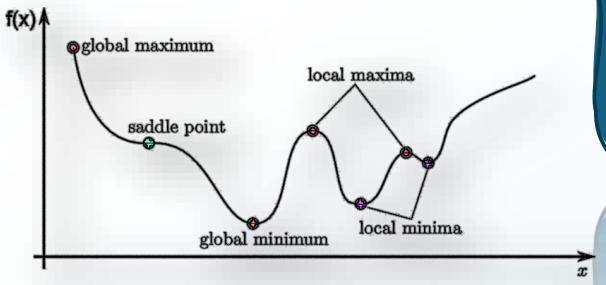










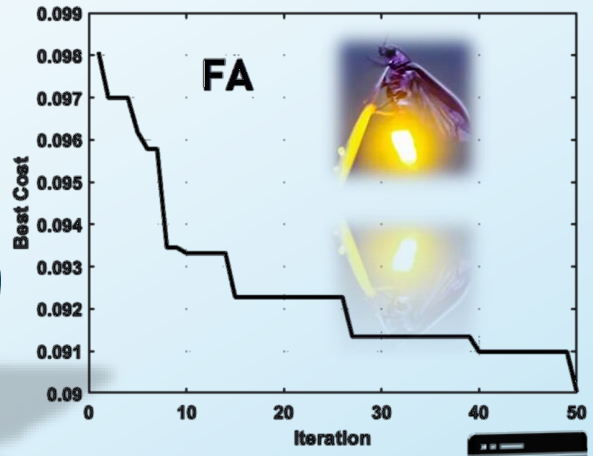


Metaheuristic Optimization: 4 Cutting-Edge Applications

Evolved Antenna Design by Particle Swarm Optimization algorithm (PSO)

By: Seyed Muhammad Hossein Mousavi

2025



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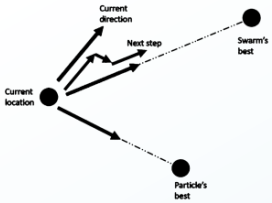
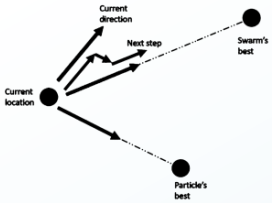


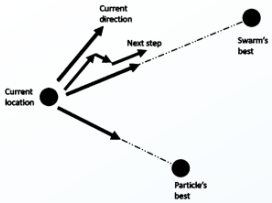
- **Optimization**
  - ❖ **Optimization Problems**
    - ➢ **Protein Folding by Differential Evolution algorithm (DE)**
    - ➢ **Space-Time Warping by Firefly Algorithm (FA)**
    - ➢ **Exoplanetary Adaptation Simulation by Genetic Algorithm (GA)**
    - ➢ **Evolved Antenna Design by Particle Swarm Optimization (PSO) algorithm**

• Optimization Problems

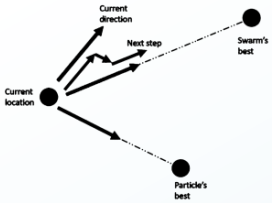


❖ Evolved Antenna Design by Particle Swarm Optimization algorithm (PSO)

- **Antenna**: A device that transmits or receives electromagnetic waves by converting electrical signals into radio waves and vice versa.
- **Evolved Antenna**: An antenna whose shape or geometry is automatically optimized using evolutionary algorithms instead of manual design.
- **Optimization**: The process of **adjusting design variables** to achieve the best possible performance under given constraints.
- **Objective Function**: A mathematical formula that measures **how good or bad the antenna design is**. Here, lower values mean better performance.
- **Particle Swarm Optimization (PSO)**: A nature-inspired algorithm that simulates the collective behavior of birds or fish to find optimal solutions.
- **Particle**: A single candidate solution in PSO representing **one possible antenna geometry**.

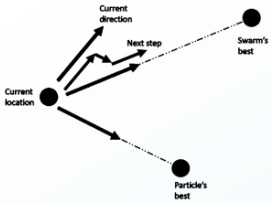


- **Optimization Problems**
  - ❖ **Evolved Antenna Design by Particle Swarm Optimization algorithm (PSO)**
    - **Swarm**: A group of particles exploring the search space together, sharing information to find the best solution.
    - **Fitness / Cost**: A numerical score computed by the objective function that determines how good each antenna design is.
    - **Iteration**: One full update cycle where all particles adjust their positions and velocities based on personal and global bests.
    - **Global Best (gbest)**: The best solution (antenna design) found by the entire swarm up to the current iteration.
    - **Personal Best (pbest)**: the best antenna design found by one specific particle so far.
    - **Inertia Weight (w)**: A coefficient controlling how much of the previous velocity a particle keeps in the next iteration (balances exploration/exploitation).



- # Optimization Problems
  - ## ❖ Evolved Antenna Design by Particle Swarm Optimization algorithm (PSO)
    - **Cognitive Component (c1)**: A PSO parameter that makes each particle move toward **its own best-known position**.
    - **Social Component (c2)**: A PSO parameter that makes each particle move **toward the swarm's best-known position.**
    - **Velocity**: The rate of change of a particle's position determines how fast and in which direction it moves through the search space.
    - **Search Space**: The multidimensional region containing all possible antenna designs that PSO explores.
    - **Convergence**: The stage when all particles gradually move toward the same best solution.
    - **Bending Penalty**: A penalty term that discourages sharp bends or irregularities in the antenna's 3D path.
    - **Euclidean Distance**: The straight-line distance between two points in 3D space, used to measure antenna segment lengths.

• Optimization Problems

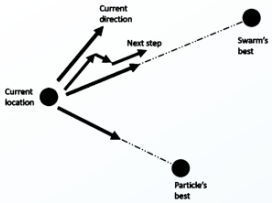


❖ Evolved Antenna Design by Particle Swarm Optimization algorithm (PSO)

○ The objective function:

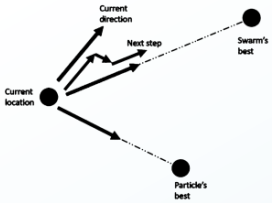
- It tells the PSO which antenna design is better; **shorter and smoother antennas get lower cost values and are considered better**.
- It **calculates the total length of the antenna** by summing all the distances between consecutive joints.
- Shorter antennas are better because they use **less material**.
- **Adds a penalty for sharp vertical bends** by checking how much the z-coordinate changes between points; **smoother antennas get a lower penalty**.

• Optimization Problems



❖ Evolved Antenna Design by Particle Swarm Optimization algorithm (PSO)

- **Why antenna design matters?**
  - Antennas directly control how efficiently wireless systems transmit and receive signals, affecting everything from communication range to power use.
- **Why use metaheuristics like PSO?**
  - Traditional formula-based or manual designs struggle with complex, nonlinear 3-D geometries where analytical optimization is impossible.
- **Why is PSO better in this context?**
  - PSO efficiently **searches vast design spaces** without requiring gradients, **balancing exploration and exploitation** to discover high-performance antenna shapes automatically.



• Optimization Problems

❖ Evolved Antenna Design by Particle Swarm Optimization algorithm (PSO)

Input: Antenna Representation

- An antenna is represented as a series of **3D joints** connected by straight segments: Like A.

$$A = \{P_0, P_1, P_2, \dots, P_n\}$$

where each point

$$P_i = (x_i, y_i, z_i)$$

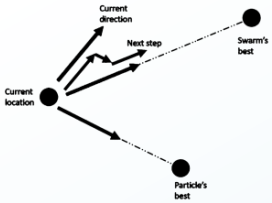
- Denotes the 3D coordinates of the i-th joint of the antenna.
  - n : number of joints (for example, 8 joints)
  - A : represents the entire antenna geometry
  - The full antenna is therefore a matrix of shape $(n + 1) \times 3$
- **Each antenna design (one candidate solution)** can be written as a flattened vector:

$$\boldsymbol{A \text{ or } \mathbf{x}} = [x_0, y_0, z_0, x_1, y_1, z_1, \dots, x_n, y_n, z_n]$$

- This vector is what PSO optimizes.

• Optimization Problems

❖ Evolved Antenna Design by Particle Swarm Optimization algorithm (PSO)



Mathematical Formulation

- The optimization problem is defined as:

$$\min_{\mathbf{x}} f(\mathbf{x})$$

- where $f(\mathbf{x})$ is the objective (cost) function measuring how good the antenna geometry is. The antenna is evaluated according to two main criteria:

1. Total Length (Efficiency Term):

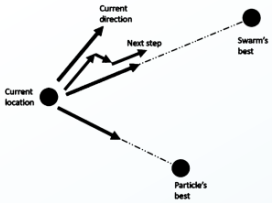
Shorter antennas are often more efficient and lighter.

$$L = \sum_{i=0}^{n-1} \|P_{i+1} - P_i\|_2$$

- where $\|\cdot\|_2$ denotes the Euclidean distance between consecutive joints.

• Optimization Problems

❖ Evolved Antenna Design by Particle Swarm Optimization algorithm (PSO)



2. Bending Smoothness (Penalty Term):

- Antennas with sharp vertical bends (large jumps in z) are penalized.

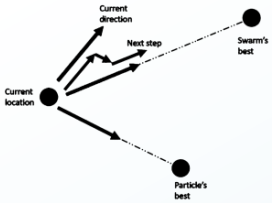
$$B = \sum_{i=0}^{n-1} |z_{i+1} - z_i|$$

- Thus, the **final objective function becomes**:

$$f(\mathbf{x}) = L + \lambda B$$

where

- L : total antenna length
- B : bending penalty
- λ : weighting factor controlling the influence of bending (Like, $\lambda = 0.3$)



• Optimization Problems

❖ Evolved Antenna Design by Particle Swarm Optimization algorithm (PSO)

Optimization Process (PSO Core)

- We now minimize $f(\mathbf{x})$ using Particle Swarm Optimization.
  Each particle p maintains:
  - A current position $\mathbf{x}_p$
  - A velocity $\mathbf{v}_p$
  - Its best-known position pbest $_p$
  - The swarm's best-known position gbest
- Each iteration updates as:

$$\mathbf{v}_p(t+1) = w\mathbf{v}_p(t) + c_1 r_1\left(\mathbf{pbest}_p - \mathbf{x}_p(t)\right) + c_2 r_2\left(\text{ gbest } - \mathbf{x}_p(t)\right)$$

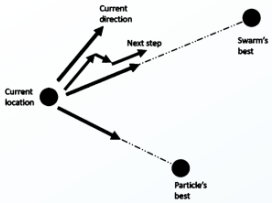
$$\mathbf{x}_p(t+1) = \mathbf{x}_p(t) + \mathbf{v}_p(t+1)$$

where:

- w : inertia weight (balances exploration vs. exploitation)
- c_1, c_2 : learning coefficients (cognitive and social terms)
- r_1, r_2 : random numbers in [0,1]

- The process repeats for the defined number of iterations (like 200), and the global best solution gradually converges toward the most optimal antenna shape.

- **Optimization Problems**



❖ **Evolved Antenna Design by Particle Swarm Optimization algorithm (PSO)**

Output: Optimized Geometry and Convergence

- After convergence, we obtain:

1. Optimized Antenna Geometry:

- The 3D coordinates $A^* = \{P_0^*, P_1^*, \ldots, P_n^*\}$ corresponding to the lowest cost found.

2. Convergence Curve:

- The cost $f(\mathbf{x})$ over iterations, showing the swarm's progress:

$$f_{\text{best}}(t) = \min_p f\left(\mathbf{x}_p(t)\right)$$

- **Optimization Problems**
  - ❖ **Evolved Antenna Design by Particle Swarm Optimization algorithm (PSO)**