

Social Inspired Algorithms

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Introduction

Characteristics

- Inspired in social systems
- Borrows ideas from the organization of swarms, flocks, social psychology

Examples

- Particle Swarm Optimization
- Ant Colony Optimization
- Jaya Algorithm
- Grey Wolf Optimization
- Ant Colony Optimization

Concepts

- Optimization based on social interactions
- Uses population of individuals
- Most algorithms are using for real optimization
- They borrow ideas from the behavior of living systems

Particle Swarm Optimization

- Created in 1995 by James Kennedy and Russell Eberhart
[@blum2008swarm]
- Inspired in social psychology and bird flock simulation
- Uses a population of individuals
- Each individual has a position and a velocity
- Velocity is updated by:
 - ▶ Attraction to the best position it found in the past
 - ▶ Attraction to the best position found by the group

PSO General scheme

- ① Initialize population
- ② Evaluate individuals
- ③ For each individual
 - ① Choose individuals from neighborhood
 - ② Imitate these individuals
 - ③ Update best performance if a better position was found
- ④ Iterate to 3 until stopping criterion is found

PSO Algorithm

Individuals' state

Position Current position \vec{x}_i

Velocity Current velocity \vec{v}_i

Individualism Previously best found position \vec{p}_i

Conformism Previously best found position by the group \vec{p}_g

Algorithm

$$\begin{cases} \vec{v}_i = \chi (\vec{v}_i + \vec{U}[0, \varphi_1] (\vec{p}_i - \vec{x}_i) + \vec{U}[0, \varphi_2] (\vec{p}_g - \vec{x}_i)) \\ \vec{x}_i = \vec{x}_i + \vec{v}_i \end{cases}$$

Initial version

- Initially, the algorithm was proposed with these equations:

$$\begin{cases} \vec{v}_i = \vec{v}_i + \vec{U}[0, \varphi_1] (\vec{p}_i - \vec{x}_i) + \vec{U}[0, \varphi_2] (\vec{p}_g - \vec{x}_i) \\ \vec{x}_i = \vec{x}_i + \vec{v}_i \end{cases}$$

Maximum velocity

- The velocity often becomes very large
- To counter this effect, a new parameter was introduced: V_{max}
- This parameter prevents the velocity from becoming too large
- This parameter is usually coordinate-wise
- If it is too large, individuals fly past good solutions
- If it is too small, individuals explore too slowly and may become trapped in local optima
- Early experience showed that φ_1 and φ_2 could be set to 2 for almost all applications and only V_{max} needed to be adjusted

Innertial Weight

$$\begin{cases} \vec{v}_i = \alpha (\vec{v}_i + \vec{U}[0, \varphi_1] (\vec{p}_i - \vec{x}_i) + \vec{U}[0, \varphi_2] (\vec{p}_g - \vec{x}_i)) \\ \vec{x}_i = \vec{x}_i + \vec{v}_i \end{cases}$$

- φ_1 and φ_2 were usually set to 2.1
- The *alpha* parameter was uniformly varied between 0.9 and 0.4.

Constriction Coefficient

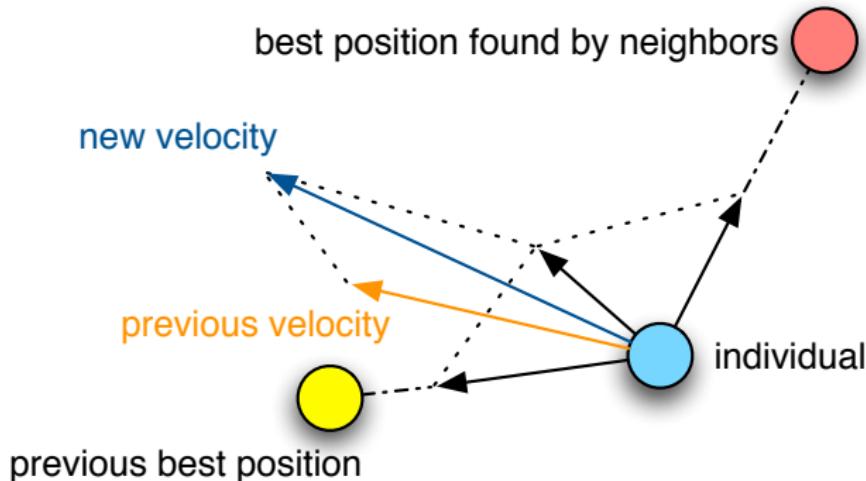
- Clerc proposed a version similar to the inertia weight
- The coefficient has a fixed value instead of a varying one
- The theoretical study seemed to indicate that a setting of all the parameters was enough to guarantee convergence without explosion or oscillation behaviors

Parameters $\varphi_1 = \varphi_2 = 2.05$, $\chi = 0.729$

Algorithm

$$\begin{cases} \vec{v}_i = \chi (\vec{v}_i + \vec{U}[0, \varphi_1] (\vec{p}_i - \vec{x}_i) + \vec{U}[0, \varphi_2] (\vec{p}_g - \vec{x}_i)) \\ \vec{x}_i = \vec{x}_i + \vec{v}_i \end{cases}$$

Solution Generation in PSO



Premature Convergence in PSO

- The global best individual in the population often degrades PSO performance
- Convergence is fast
- Diversity is lost fast
- This leads to premature convergence
- It is better to use strategies to decrease the information flow

What are the causes of premature convergence?

Optimization is a balance between two factors:

- exploration The ability to explore the search space to find promising areas
- exploitation The ability to concentrate on the promising areas of the search space

- An algorithm with too much exploration isn't *efficient*
- An algorithm with too much exploitation loses *diversity* fast
- If an algorithm doesn't have enough diversity, it will quickly stagnate

Neighborhood concept

- Individuals imitate their (most successful) neighbors
- His neighbors will only influence their neighbors once they become sufficiently successful
- This favours clustering: different social neighborhoods may explore different areas of the search space
- Immediacy may be based on:

Proximity Proximity in Cartesian space

Social To share social bonds

Example of Good Topologies

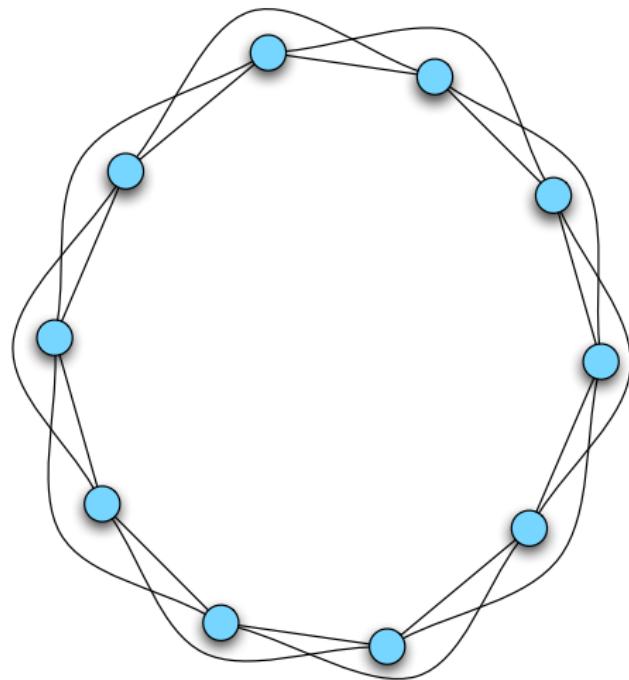


Figure 1: LBest 2

Example of Good Topologies

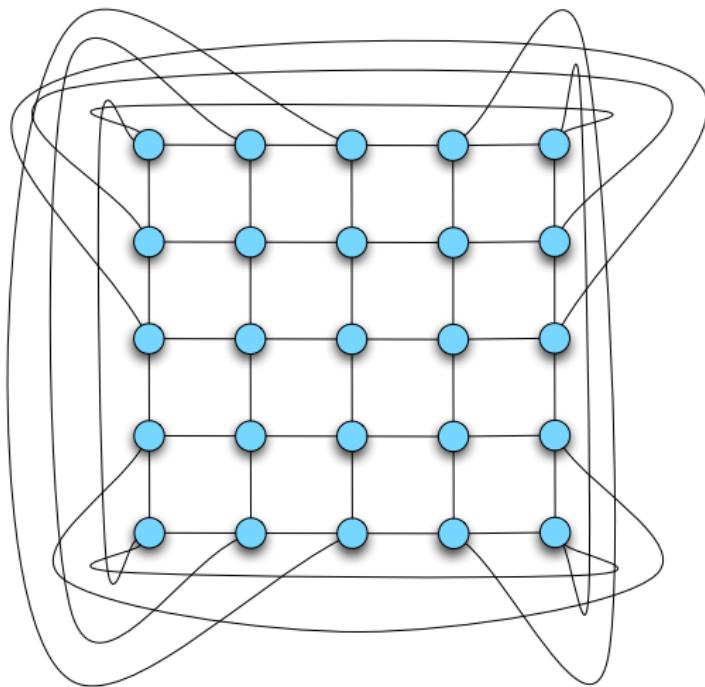


Figure 2: von Neumann or Square

Discussion

- PSO is easy to implement
- The canonical version has a setting for both φ_1 and φ_2 and chi
- Thus, the only parameters that need to be changed are the population size and the number of function evaluations
- Any of the population topologies given above works well

Fully Informed Particle Swarm

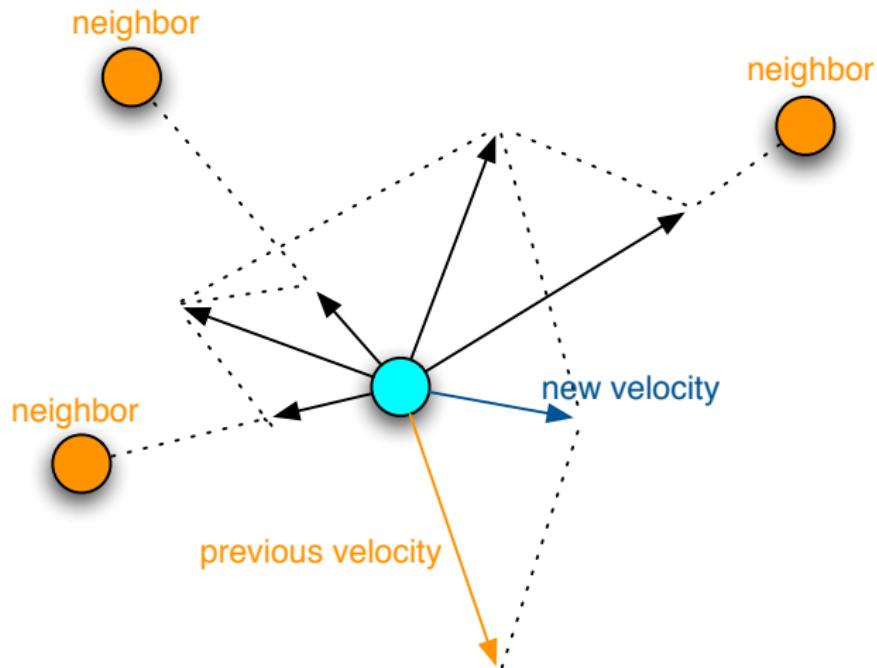
Characteristics

- All contributions of the neighborhood are used
- Individual imitates the social norm
- The social norm is the center of gravity
- \vec{p}_k is the best position of neighbor k
- \mathcal{N} is the set of neighbors

Algorithm

$$\begin{cases} \vec{v}_{t+1} = \chi \left(\vec{v}_t + \frac{\sum_{k \in \mathcal{N}} \vec{U}[0, \varphi_{max}] (\vec{p}_k - \vec{x}_t)}{|\mathcal{N}|} \right) \\ \vec{x}_{t+1} = \vec{x}_t + \vec{v}_{t+1} \end{cases}$$

Solution Generation in FIPS



Differences between Canonical PSO and FIPS

- There is no self contribution
- All individuals in the neighborhood contribute to the influence
- The number of individuals used is very important: A few contributions, typically between 2 and 4 are best
- Given a well chosen population topology, it outperforms the canonical model

Discussion

- FIPS is easy to implement
- It often has better performance than the canonical PSO
- Parameter settings are the same as for PSO, and thus are fixed
- Thus, the only parameters that need to be changed are the population size and the number of function evaluations
- Any of the population topologies given above works well

Jaya Optimization

Characteristics

- Similar to PSO
- Fewer control parameters
- Has a component towards the best point found
- Has a component away from the worst point found
- Update is elitist (i.e., new position is only used if it is better than the current one)

Algorithm

$$x_i = x_i + U[0, 1] (x_{best} - |x_i|) - U[0, 1] (x_{worst} - |x_i|)$$

Discussion

- Jaya is similar to PSO
- The best and worst performers influence the search
- The only parameters that need to be changed are the population size and the number of function evaluations
- It needs further study to ascertain its performance and if the formulas can be simplified

Grey Wolf Optimization

Characteristics

- Idea is quite similar to FIPS
- Best three solutions (α, β, δ) found guide the search
- New positions are generated by a random combination of the three positions
- The parameter a is linearly decreased from 2 to 0

Algorithm

$$\vec{A}_k = \vec{U}[-a, a] \quad \text{where } k \in \{\alpha, \beta, \delta\}$$

$$\vec{C}_k = \vec{U}[0, 2] \quad \text{where } k \in \{\alpha, \beta, \delta\}$$

$$\vec{D}_k = |\vec{C}_k \otimes \vec{X}_k - \vec{X}| \quad \text{where } k \in \{\alpha, \beta, \delta\}$$

$$\vec{P}_k = \vec{X}_k - \vec{A}_k \otimes \vec{D}_k \quad \text{where } k \in \{\alpha, \beta, \delta\}$$

$$\vec{X}_{t+1} = \frac{\vec{P}_\alpha + \vec{P}_\beta + \vec{P}_\delta}{3}$$

Solution Generation in GWO

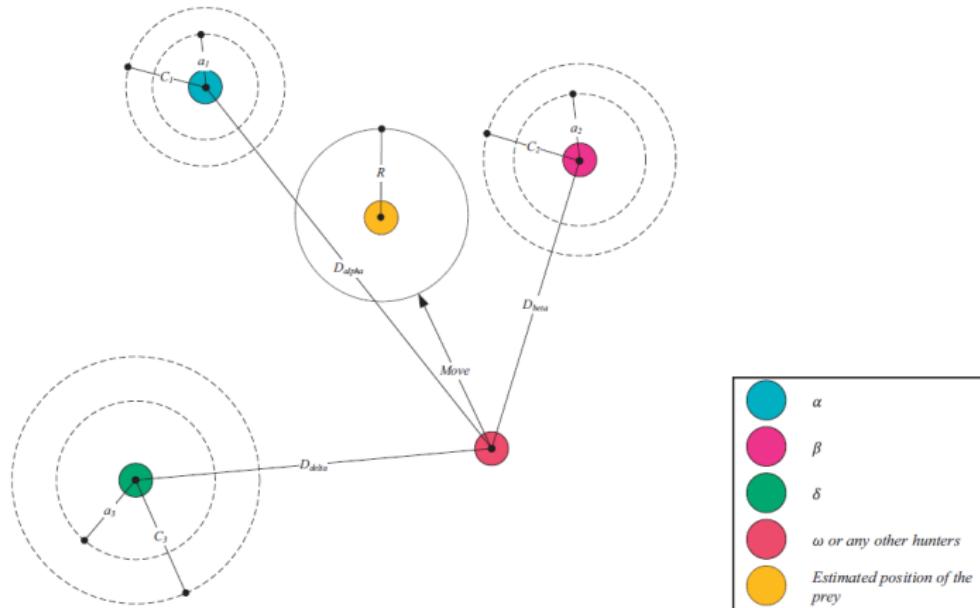


Figure taken from <https://doi.org/10.1016/j.advengsoft.2013.12.007>

Discussion

- GWO is similar to FIPS
- The 3 best individuals guide the search
- Like FIPS, new solutions are generated by a stochastic barycenter
- The only parameters that need to be changed are the population size and the number of function evaluations
- It needs further study to ascertain its performance and if the formulas can be simplified
- It seems to only work well when the best solution is zero
- There is ongoing research for solving this tendency

Ant Colony Optimization

- Inspired in ant foraging behavior
- Solutions are built by navigating in a graph
- A graph path represents a solution
- A path starts in the initial vertex
- In each vertex, the choice of next edge to visit is *probabilistic*
- The probability of choosing an edge depends on two criteria:
 - ▶ attractiveness
 - ▶ pheromone levels
- Initially, all graphs have the same pheromone level τ_0
- After each iteration, pheromone is deposited on each edge according to the quality of the solution
- Pheromone gradually evaporates from all edges

Edge choice

Attractiveness Heuristic that determines the *a priori* attractiveness of a given branch

Trail Pheromone quantity deposited in an edge depending on the contribution of that edge in good quality solutions (*a posteriori* contribution)

Probability of choosing an edge

$$p_{uv} = \frac{\tau_{uv}^\alpha \cdot \nu_{uv}^\beta}{\sum_{w \in \text{viz}(u)} \tau_{uw}^\alpha \cdot \nu_{uw}^\beta}$$

where:

- τ is the pheromone value deposited in the edge and ν is the heuristic.
- α e β are parameters that weigh the importance of each component.

Pheromone update

Evaporation Each branch evaporates using an evaporation coefficient

$$0 \leq \rho < 1$$

Deposit Each ant deposits pheromone on the edges used in a solution proportionally to the solution quality.

$$\tau_{uv} = (1 - \rho) \cdot \tau_{uv} + \sum_{k=1}^m \Delta_{\tau_{uv}}^k$$

The value $\Delta_{\tau_{uv}}^k$ corresponds to the contribution of edge uv to the solution found by ant k .

MAX-MIN Ant System

- There is a lower τ_{min} and upper τ_{max} bound for the pheromone
- Only the best ant deposits pheromone

$$\tau_{uv} = (1 - \rho) \cdot \tau_{uv} + \Delta_{\tau_{uv}^{best}}$$

$$\tau_{uv} = \begin{cases} \tau_{uv} & \text{if } \tau_{min} \leq \tau_{uv} \leq \tau_{max} \\ \tau_{min} & \text{if } \tau_{min} > \tau_{uv} \\ \tau_{max} & \text{if } \tau_{max} < \tau_{uv} \end{cases}$$

In the TSP, if D_{best} is the total distance of the best solution:

$$\Delta_{\tau_{uv}^{best}} = \begin{cases} 1/D_{best} & \text{if } (u, v) \text{ belongs to the best path} \\ 0 & \text{otherwise} \end{cases}$$

Advantages of MMAS

- Since the best ant deposits pheromone, there is a *bias* towards higher quality solutions
- In order to control the *bias* the τ_{min} and τ_{max} limits guarantee that:
 - ▶ there is always a minimum probability of choosing any edge in the graph
 - ▶ the probability of choosing a highly successful edge is never bigger than a given amount

Ant Colony System

- An *elitist* transition is chosen with probability q_0
- The pheromone update method has a *global* and *local* components
- In the *global* component, pheromone is deposited in the edges belonging to the best solution found thus far
- In the *local* component, the pheromone amount of the branches used by the ants is decreased

Ant Colony System: Transition rules

$$v = \begin{cases} \arg \max_{w \in \text{viz}(u)} \tau_{uw}^\alpha \cdot \nu_{uw}^\beta & \text{if } q \leq q_0 \\ V & \text{if } q > q_0 \end{cases}$$

where $0 \leq q_0 \leq 1$ is a probability, $q = U[0, 1]$ and V is chosen probabilistically according to the rule:

$$p_{uv} = \frac{\tau_{uv}^\alpha \cdot \nu_{uv}^\beta}{\sum_{w \in \text{viz}(u)} \tau_{uw}^\alpha \cdot \nu_{uw}^\beta}$$

Ant Colony System: pheromone update

global only for the best solution found thus far

$$\tau_{uv} = (1 - \rho) \cdot \tau_{uv} + \rho \cdot \Delta_{\tau_{uv}^{best}}$$

local for all solutions visited in the current iteration

$$\tau_{uv} = (1 - \rho) \cdot \tau_{uv} + \rho \cdot \tau_0 \setminus [1 \text{ em}]$$

τ_0 is the initial pheromone value of all the edges in the initial iteration

Ant Colony System: Advantages

- The transition method allows the introduction of some *elitism* depending on the value given to q_0
- As in MMAS, pheromone is only increased in the edges belonging to the *best solution* found
- The local update *lowers the attractiveness* of the edges traversed by the ants
- This characteristics fosters exploration

Applications

- Routing** Travelling salesman, vehicle routing, sequential ordering
- Assignment** Quadratic assignment, timetables, graph coloring
- Scheduling** Several scheduling problems
- Subsets** Knapsacking, cliques
- Bioinformatics** Shortest common supersequence problem, sequencing, protein folding, protein-ligand docking, haplotype inference
- Others** Constraint satisfaction, data mining

Using ant colonies in a problem

- Which variant to use and the parameters' values
- How to represent the solution as a graph
- How to compute the solution quality
- What heuristic to use for each edge ν_{uv}
- Is it possible to use the information of the partial solution in the heuristic?
- Is it possible to use local search?

Example: Travelling Salesman Problem

- Each ant starts in the beginning city
- The fitness function is the inverse of the total distance
- The probability of revisiting a city is zero
- The heuristic is the inverse of the distance between both cities

Example: Constraint satisfaction

- There is a set of variables X_1, \dots, X_n
- Each variable has several possible values (e.g., $X_1 \in \{x_{11}, \dots, x_{1m}\}$)
- There are constraints p_1, \dots, p_r where each constraint is a predicate (e.g., $p_1(X_1, \dots, X_n)$)

Example: Constraint satisfaction

- Establish an order for the variables
- There is an initial state S_0
- Each vertex of the graph is a variable assignment (e.g., $X_1 = x_{14}$)
- The objective function may be the number of valid constraints
- The heuristic may be the number of valid constraints after this assignment
- A solution to a problem with 3 variables could be
 $< S_0 > \rightarrow < X_1 = x_{14} > \rightarrow < X_2 = x_{22} > \rightarrow < X_3 = x_{31} >$

Example: Set covering problem

- We have a finite set of elements $A = \{a_1, \dots, a_n\}$
- And a set of subsets $B = \{B_1, \dots, B_I\}$ such as $B_i \subseteq A$ that covers A,

i.e., $\bigcup_{i=1}^I B_i = A$

- Each set B_i has an associated cost c_i
- The objective of the SCP is to find a subset $C \in B$ such as:

① $\bigcup_{B_i \in C} B_i = A$

② minimize $\sum_{B_i \in C} c_i$

Example: Set covering problem

- Each ant starts with the empty set and adds a set B_i each time
- Only use edges that add at least one a_j that is not in the current solution
- The heuristic of choosing the set B_i may be:
 - ① $\frac{1}{c_i}$
 - ② $\frac{|B_i|}{c_i}$
 - ③ $\frac{d_i}{c_i}$ where d_i is the number of elements of B_i that are not yet covered by the current solution
- An ant finishes building the solution when it has covered the entire set A
- Pruning may be performed *a posteriori* by removing superfluous sets
- Best solutions may use local search

Links

- Software: <https://github.com/thieunguyen5991/metaheuristics>