Chapter 2
Particle Swarm Optimization

This chapter is devoted to particle swarm optimization (PSO), from early precursors to contemporary standard variants. The presentation begins with the main inspiration source behind its development, followed by early variants and discussion on their parameters. Severe deficiencies of early variants are also pointed out and their solutions are reported in a relative historical order, bringing the reader to contemporary developments, considered as the state-of-the-art PSO variants today.

MAIN INSPIRATION SOURCE

Bird flocks, fish schools, and animal herds constitute representative examples of natural systems where aggregated behaviors are met, producing impressive, collision-free, synchronized moves. In such systems, the behavior of each group member is based on simple inherent responses, although their outcome is rather complex from a macroscopic point of view. For example, the flight of a bird flock can be simulated with relative accuracy by simply maintaining a target distance between each bird and its immediate neighbors. This distance may depend on its size and desirable behavior. For instance, fish retain a greater mutual distance when swimming carefree, while they concentrate in very dense groups in the presence of predators. The groups can also react to external threats by rapidly changing their form, breaking in smaller parts and re-uniting, demonstrating a remarkable ability to respond collectively to external stimuli in order to preserve personal integrity.

Similar phenomena are observed in physical systems. A typical example is the particle aggregation caused by direct attraction between particles due to Brownian motion or fluid shear. Humans too are characterized by agnate behaviors, especially at the level of social organization and belief formulation. However, these interactions can become very complex, especially in the belief space, where, in contrast

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to the physical space, the same point (a belief or an idea) can be occupied concurrently by large groups of people without collisions. The aforementioned aggregating behaviors, characterized by the simplicity of animal and physical systems or the abstractness of human social behavior, intrigued researchers and motivated their further investigation through extensive experimentation and simulations (Heppner & Grenander, 1990; Reynolds, 1987; Wilson, 1975).

Intense research in systems where collective phenomena are met prepared the ground for the development of swarm intelligence, briefly described in the previous chapter. Notwithstanding their physical or structural differences, such systems share common properties, recognized as the five basic principles of swarm intelligence (Millonas, 1994):

1. **Proximity**: Ability to perform space and time computations.
2. **Quality**: Ability to respond to environmental quality factors.
3. **Diverse response**: Ability to produce a plurality of different responses.
4. **Stability**: Ability to retain robust behaviors under mild environmental changes.
5. **Adaptability**: Ability to change behavior when it is dictated by external factors.

Moreover, the social sharing of information among individuals in a population can provide an evolutionary advantage. This general belief, which was suggested in several studies and supported by numerous examples from nature, constituted the core idea behind the development of PSO.

**EARLY VARIANTS OF PSO**

The early precursors of PSO were simulators of social behavior for visualizing bird flocks. Nearest-neighbor velocity matching and acceleration by distance were the main rules employed to produce swarming behavior by simple agents in their search for food, in simulation experiments conducted by Russell C. Eberhart (Purdue School of Engineering and Technology, Indiana University Purdue University Indianapolis) and James Kennedy (Bureau of Labor Statistics, Washington, DC). After realizing the potential of these simulation models to perform optimization, Eberhart and Kennedy refined their model and published the first version of PSO in 1995 (Eberhart & Kennedy, 1995; Kennedy & Eberhart, 1995).

Putting it in a mathematical framework, let, $A \subset \mathbb{R}^n$, be the search space, and, $f: \mathbb{R} \rightarrow Y \subseteq \mathbb{R}$, be the objective function. In order to keep descriptions as simple as possible, we assume that $A$ is also the feasible space of the problem at hand, i.e., there are no further explicit constraints posed on the candidate solutions. Also, note that no additional assumptions are required regarding the form of the objective function and search space. As mentioned in the previous chapter, PSO is a population-based algorithm, i.e., it exploits a population of potential solutions to probe the search space concurrently. The population is called the *swarm* and its individuals are called the *particles*; a notation retained by nomenclature used for similar models in social sciences and particle physics. The swarm is defined as a set:

$$S = \{x_1, x_2, \ldots, x_N\},$$

of $N$ particles (candidate solutions), defined as:
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