Bat Algorithm

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Agenda

- Algorithm Origin
- Bat Echolocation
- Simulation of bat behavior
- Bat Algorithm (BA)
- BA as an extension of PSO
- Variants of BA
- Applications

The Algorithm Origin

- Authors: Xin-She Yang
- Title: A New Metaheuristic Bat-Inspired Algorithm,
- Publication: *Nature Inspired Cooperative Strategies for Optimization (NISCO **2010**)* (Eds. J. R. Gonzalez et al.), in Studies in Computational Intelligence, Springer Berlin, 284, Springer, 65-74 (2010).
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How are bats fascinating?

- Bats are the only mammals that possess wings.
- There are around 1000 different species of bats, most of them are insectivore.
- They are of the order of Chiroptera.

- Two main Types of bats

Mega-bats

- ✓ Size: big
- ✓ Vision: well-developed
  - ➢ Visual cortices
  - ➢ Good visual acuity
- ✓ Smell sense
- ✓ No Echolocation

Micro-bats

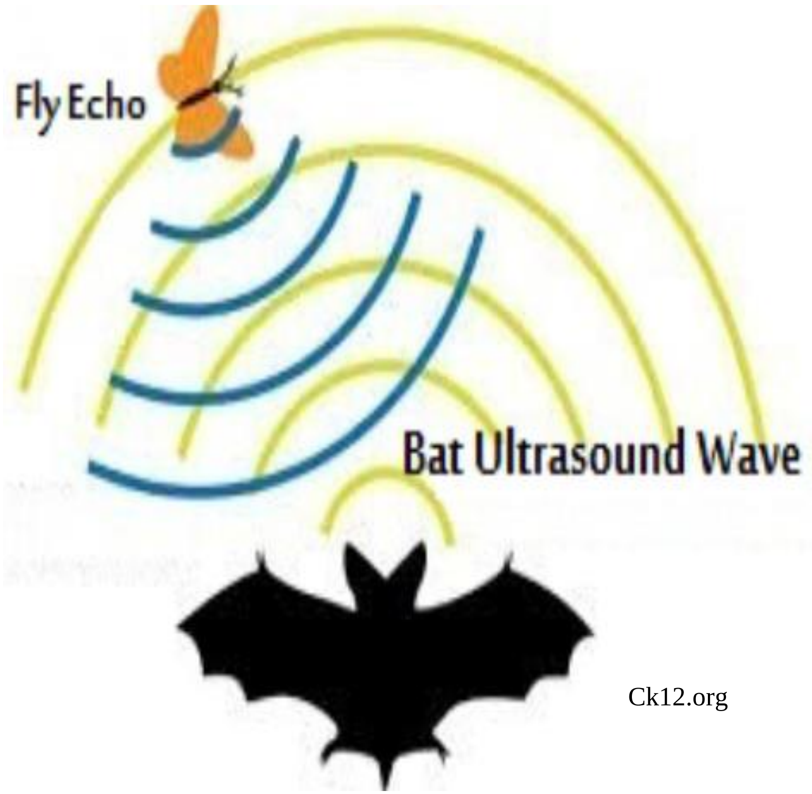
Use a sound called ***Echolocation*** to

- ✓ detect preys
- ✓ Avoid obstacles
- ✓ Locate the roosting crevices
- ✓ All these tasks are performed in complete darkness

Bats of intermediary size use a certain degree of echolocation.

Bat Echolocation

- Echolocation consists in producing a sonar composed of 2 steps:
    - emitting sound pulses
    - and then detecting surrounding objects from the reflected echo
- The sonar is also used under water by some kinds of fishes.
- It is also used by humans (Japanese) to attract and catch fishes.
- Micro-bats perceive their environment by:
    - Measuring the distance and orientation of the objects.
    - Detecting the type and the speed of the preys.



Bat Echolocation phenomenon

Simulation of Bats Behavior using Echolocation

- As for all the nature and biology-inspired approaches, bat-inspired approach simulates the movement of bats when searching for preys.

- The real bats are simulated by artificial bats as follows:

The natural bats

- Environment: the nature and the roosting crevices where the bats live.
- Swarm: bats from roosting crevices
- Target: preys (insects)
- Movement: natural based on echolocation and hunting strategies
- Bats evaluation (position, velocity …)

The artificial bats

- Search space: set of all possible solutions encapsulated in artificial bats
- Population of artificial bats or solutions
- Target: optimal solutions
- Movement: determined by mathematical equations based on simulated echolocation
- Fitness function

Approximations and Simplifications

- Bats use echolocation to sense distance and perceive in a magical way their surroundings.

- Bats fly randomly with:
  - velocity $\boldsymbol{v_i}$
  - at position $\boldsymbol{x_i}$
  - with a fixed frequency $\boldsymbol{f_{min}}$,
  - varying wavelength $\boldsymbol{\lambda}$ and loudness $\boldsymbol{A_0}$ to search for prey.

- They automatically adjust the wavelength of their emitted pulses and adjust the rate of pulse emission $\boldsymbol{r}$ from [0,1], depending on the proximity of their prey.

- The loudness varies from a positive large value $\boldsymbol{A_0}$ to a minimum value $\boldsymbol{A_{min}}$.

Bat Motion

- x' is the best solution of the current iteration.
- x* is the best solution of all the previous iterations.
- The movement of a bat is modelled as:

$$f_i = f_{min} + (f_{max} - f_{min})\beta$$
$$v_i^t = v_i^{t-1} + (x_i^t - x_*)f_i$$
$$x_i^t = x_i^{t-1} + v_i^t$$

where β is an empirical parameter

- The best solution of one iteration is

$$x_{new} = x' + \varepsilon * A_i$$

- The update of loudness and pulse rate

$$A_i^t = \alpha A_i^{t-1}$$

$$r_i^{t+1} = r_i^0(1 - e^{\gamma t})$$

Bat Algorithm

begin
generate at random a population of ***k*** bats (***k*** solutions);
for each bat i **do**
define its loudness A_i, its pulse frequency f_i and its velocity v_i;
set its pulse rate to r_i ;
select the best solution x^*;
while ((Max-Iter not reached) **do**
for each i = 1 to ***k*** **do**
compute a new solution (f_i, v_i, x_i) using these formulas

$$f_i = f_{min} + (f_{max} - f_{min})\beta$$
$$v_i^t = v_i^{t-1} + (x_i^t - x_*)f_i$$
$$x_i^t = x_i^{t-1} + v_i^t$$

if (rand > r_i) **then**
select a solution x' among the best solutions;
improve the solution using this formula ;

$$x_{new} = x' + \varepsilon * A$$

end if;
generate at random a new solution (f_i, v_i, x_i) ;
if (rand<A_i) **and** ($f(x_i) < f(x^*)$) **then**
accept the new solution;
increase r_i and reduce A_i using these formulas **end if**

$$A_i^t = \alpha A_i^{t-1}$$
$$r_i^{t+1} = r_i^0(1 - e^{\gamma t})$$

end for
Rank the bats and find the current best solution x* ;
end while
end

Data structures

- **The Bats Table.**
  - The bats table memorizes the pulse frequency, the velocity and the position of each bat at time ***t*** (each iteration).
  - Each entry corresponds to a bat for the current iteration.
  - ***x**** is the best solution found so far, by any bat in the swarm, from the beginning of the bat process. ***x'*** is the best solution found at one iteration.

Bats Table

	f_i	v_i^t	x_i^t
bat 1			
bat 2			
bat *i*			
bat *k*			

x* | ***x'***

Parameters setting

- The parameters for BA are :

- Maximum number of iterations.
- Number of bats.
- f_{min}
- f_{max}
- $\boldsymbol{\alpha}$
- $\boldsymbol{\gamma}$

Bat Algorithm: An extension of PSO

- BA can be seen as a hybridization of PSO and a local search.

BA
Balances between

PSO

Similar rules motion

- ✓ (f_i, v_i, x_i)

Local search

based on simulated annealing controlled by:

- ✓ Loudness
- ✓ Pulse rate

Important Features

- **BA is equivalent to PSO** when:
  - f_i is a random number,
  - $A_i = 0$
  - $r_i = 1$

- **BA is equivalent to Harmony Search** when:
  - $A_i = r_i$

- **BA is then more powerful than PSO and Harmony Search**

Some Variants of BA

- FLBA: Fuzzy Logic Bat Algorithm
  - Khan, K., Nikov, A., Sahai A., A Fuzzy Bat Clustering Method for Ergonomic Screening of Office Workplaces,S3T 2011, Advances in Intelligent and Soft Computing, 2011, Volume 101/2011, 59-66 (2011).

- MOBA: Multi-Objective Bat Algorithm
  - Yang, X. S., Bat algorithm for multi-objective optimization, Int. J. Bio-Inspired Computation, Vol. 3, No. 5, pp. 267–274, (2011).

- BBA: Binary Bat Algorithm
  - Nakamura, R. Y. M., Pereira, L. A. M., Costa, K. A., Rodrigues, D., Papa, J. P., Yang, X. S., (2012), BBA: A binary bat algorithm for feature selection, in: 25th SIBGRAPI Conference on Graphics, Patterns and Images (SIBGRAPI), 22-25 Aug. 2012, IEEE Publication, pp. 291-297.
  - S. Mirjalili, S. M. Mirjalili, X. Yang, Binary Bat Algorithm, Neural Computing and Applications, 2014, Springer.

Some Variants of BA

- EBA (Evolving Bat Algorithm)
  - P. W. Tsai, J. S. Pan, B. Y. Liao, M. J. Tsai, V. Istanda, Bat algorithm inspired algorithm for solving numerical optimization problems, Applied Mechanics and Materials, Vo.. 148-149, pp.134-137 (2012)
- IBA (Improved Bat Algorithm)
  - Y. Selim and U. K. Ecir, "Improved Bat Algorithm (IBA) on Continuous Optimization Problems," Lecture Notes on Software Engineering, vol. 1, no. 3, pp. 279-283, 2013.

Applications

- Continuous Optimization
  - Non-linear problems
  - Mathematic Continuous Functions
- Combinatorial Optimization
  - Scheduling problems
- Data Mining
  - Clustering problems
  - Classification problems
  - Association Rules Mining
- Computer Vision
  - Image matching

A Case Study: Max-SAT

Definition

Let $V = \{v_1, v_2, \dots, v_n\}$ be a set of Boolean variables

- a **literal** is a Boolean variable that appears with or without the negation operator.
- a **clause** is a Boolean disjunction of literals.
- the problem SAT is defined by the following (instance, question) pair:

Instance: **m** clauses over **n** Boolean variables (a CNF Boolean formula)
Question: is there an instanciation or interpretation of variables for which all the clauses are true simultaneously?

Example

$V = \{v_1, v_2, v_3, v_4\}$, $C = \{c_1, c_2, c_3\}$ such that:

$$\begin{cases} c_1 = v_1 + v_2 + \overline{v_4} \\ c_2 = v_2 + \overline{v_3} + v_4 \\ c_3 = \overline{v_1} + \overline{v_2} + v_3 \end{cases}$$

Where bar sign denotes the negation operator and '+' the disjunctive operator. One possible solution is the instanciation {T, T, T, T} respectively assigned to {v1, v2, v3, v4}.

Solving Max-SAT with BA

Solution coding

- a solution is a vector of n Boolean values, each one assigned to a variable.
- It is then a chain of n bits.

Search space

- the set of all potential instanciations for the instance.
- It is then the set of all Boolean vectors of length equal to n.
- its size is equal to 2^n.

Fitness function

- for Max-SAT
  - ✓ the number of satisfied clauses. The function is to be maximized or
  - ✓ the number of unsatisfied clauses. The function here is to be minimized.
- for Max-w-SAT
  - ✓ the sum of the weights of the satisfied clauses. The function is to be maximized or
  - ✓ the sum of the weights of the unsatisfied clauses. The function is to be minimized.

Distance between two solutions

- **Hamming Distance** between two strings x and y of same length equal to n:
  - it is equal to the number of entries with different symbols
    - $distance(x,y) = \sum_{i=1}^{i=n} x_i \oplus y_i$

      where $x_i \oplus y_i = \begin{cases} 0 & if \quad x_i = y_i \\ 1 & otherwise \end{cases}$
  - examples
    - ✓ x = ababcaabda, y = acabbaaada, then distance(x,y) = 3
    - ✓ x = 0010101110, y = 0100100000, then distance(x,y) = 5

- **Similarity** between two strings x and y of equal length
  - Similarity(x,y) = n- distance(x,y)

- **Dissimilarity** between two strings x and y of equal length
  - Dissimilarity(x,y) = distance(x,y)

- **The degree of diversity.**
  - The degree of diversity of a solution s relatively to a set S of other solutions is measured by the minimum of the distances between s and the elements in S.
  - It is calculated as: *diversity(s)* = Min { *distance(s,t), t* ∈ *S* }.

BA-SAT

begin
generate at random a population of *n* bats (*n* solutions);
for each bat *i* **do**
define its loudness A_i, its pulse frequency f_i and its velocity v_i;
set its pulse rate to r_i ;
select the best solution x^*;
while ((Max-Iter not reached) **do**
for each i = 1 to *n* **do**
compute a new solution (f_i, v_i, x_i) using these formulas
if (rand > r_i) **then**
select a solution x' among the best solutions;
improve the solution using the following formula ;
end if;
generate at random a new solution (f_i, v_i, x_i) ;
if (rand<A_i) **and** ($f(x_i) < f(x')$) **then**
accept the new solution; **end if**
increase r_i and reduce A_i using these formulas
end for
Rank the bats and find the current best x* ;
end while
end

In the initialization, consider a velocity as a distance, which is a non negative number.

$$f_i = f_{min} + (f_{max} - f_{min})\beta$$

$$v_i^t = \lfloor v_i^{t-1} + distance(x_i^t, x_*) f_i \rfloor$$

Invert v_i^t bits of x_i^{t-1} to obtain x_i^t

Perform a local search

$$A_i^t = \alpha\, A_i^{t-1}$$

$$r_i^{t+1} = r_i^0 (1 - e^{\gamma t})$$

Experiments

Table 1: Comparison of BA with GA, and PSO.

Functions/Algorithms	GA	PSO	BA
Multiple peaks	$52124 \pm 3277(98\%)$	$3719 \pm 205(97\%)$	$1152 \pm 245(100\%)$
Michalewicz's (d=16)	$89325 \pm 7914(95\%)$	$6922 \pm 537(98\%)$	$4752 \pm 753(100\%)$
Rosenbrock's (d=16)	$55723 \pm 8901(90\%)$	$32756 \pm 5325(98\%)$	$7923 \pm 3293(100\%)$
De Jong's (d=256)	$25412 \pm 1237(100\%)$	$17040 \pm 1123(100\%)$	$5273 \pm 490(100\%)$
Schwefel's (d=128)	$227329 \pm 7572(95\%)$	$14522 \pm 1275(97\%)$	$8929 \pm 729(99\%)$
Ackley's (d=128)	$32720 \pm 3327(90\%)$	$23407 \pm 4325(92\%)$	$6933 \pm 2317(100\%)$
Rastrigin's	$110523 \pm 5199(77\%)$	$79491 \pm 3715(90\%)$	$12573 \pm 3372(100\%)$
Easom's	$19239 \pm 3307(92\%)$	$17273 \pm 2929(90\%)$	$7532 \pm 1702(99\%)$
Griewangk's	$70925 \pm 7652(90\%)$	$55970 \pm 4223(92\%)$	$9792 \pm 4732(100\%)$
Shubert's (18 minima)	$54077 \pm 4997(89\%)$	$23992 \pm 3755(92\%)$	$11925 \pm 4049(100\%)$

Xin-She Yang, *Nature Inspired Cooperative Strategies for Optimization (NISCO **2010**)*, in Studies in Computational Intelligence, Springer Berlin, 284, Springer, 65-74 (2010)

Conclusions

Strength

- A promising algorithm for continuous optimization problems
  - ✓ Simulation of the original echolocation behavior of bats
    - ➢ A more sophisticated and structured process
  - ✓ Includes hybrid successful strategies of previous evolutionary algorithms such as:
    - ➢ Local search
    - ➢ Simulated annealing
    - ➢ PSO
  - ✓ Includes a random walk strategy
- Compared to other evolutionary algorithms, it has been shown to be more powerful than:
  - ✓ PSO
  - ✓ Genetic algorithm
  - ✓ Harmony search
- A good convergence
  - ✓ Thanks to the parameters α and γ that implement the convergence strategy inspired from the simulated annealing
- Numerous important variants:
  - ✓ MO-BAT, IBA, EBA, Fuzzy BA, …

Limitations and Perspectives

- **Limitations**
  - More analyses for algorithm convergence.
  - More comparisons with other functions and Problems with higher number of dimensions.

- **Perspectives**
  - More sophisticated modelling of pulse and loudness rates.
  - More variants.
  - More applications.

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Thank You !