On the Power of Echo-Location: Bat Algorithms

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Behavior of Microbats

- 1000 different species, size range from tiny bumblebee bats to giant bats (wingspans of 2m, weight 1kg)
- Use echolocation (especially “microbats’”; “megabats” not much)
  - Type of sonar to detect prey, avoid objects, locate roosting crevices in dark
  - Emit loud sound pulse and listen for echoes (that bounce from objects)
  - Frequency of signals vary across species/hunting strategy
- Microbats – use time delay from emission & detection of echo, time difference between 2 ears, and loudness variation (of echo)
  - Build 3D “model” of surroundings/world
  - Can detect distance/orientation of target, type of prey, even moving speed

Echolocation Acoustics

- Pulses last only 8-10 ms but have constant frequency (25 kHz-150 kHz)
- Bats might emit 10-20 ultrasonic bursts every second
- Pulse emission can speed up to 200 pulses per sec when near prey
- $\lambda = \frac{v}{f}$, where $v = 340$m/s (sound speed) @ room temperature
  - λ is wavelength (2 mm – 14 mm), f is constant frequency
- Loudness varies from loudest (hunting prey) to quieter base (honing in on prey), traveling range is few meters
  - Not all bats are blind -- combine smell and sight w/ echolocation

General Principles / Idealization

1. All bats use echolocation (sense distance), “know” difference between food & prey, barriers
2. Bats fly randomly, velocity $\boldsymbol{v}_i$ and position $\boldsymbol{x}_i$, each can adjust frequency/wavelength of emitted pulses
   - Pulse emission rate $r \in [0,1]$ (based on closeness to target)
3. Loudness varies from large, positive A_0 to minimum value A_{min}

- No ray tracing used to estimate time delay & 3D topography

Some Approximations/Simplifications

- Frequency range f ∈ $[f_{min}, f_{max}]$ corresponds to wavelength range $\lambda \in [\lambda_{min}, \lambda_{max}]$ (so range [20 kHz,500 kHz] → [0.7 mm, 17 mm])
  - Detectable range (largest wavelength) should be comparable to size of target domain (or could vary frequency & fix wavelength)
  - Assume f ∈ $[0, f_{max}]$, pulse range in [0,1]
    - 0 = no pulses,
    - 1 maximum pulse rate emission

Some actual bats…

Bat Algorithm Dynamics

Bat Algorithm

```
Initialize the bat population x_i and v_i  (i = 1, 2, ..., n)
Initialize frequencies f_i, pulse rates r_i and the loudness A_i
while (t <Max number of iterations)
    Generate new solutions by adjusting frequency,
    Update velocities and locations/solutions [(10.1) to (10.3)]
    if  (rand > r_i)
        Select a solution among the best solutions
        Generate a local solution around the selected best solution
    end if
    Generate a new solution by flying randomly
    if  (rand < A_i & f(x_i) < f(x_*))
        Accept the new solutions
        Increase r_i and reduce A_i
    end if
    Rank the bats and find the current best x_*
end while
```

Toy Problem

There are many standard test functions for validating new algorithms. As a simple benchmark, let us look at the eggcrate function

$$f = x^2 + y^2 + 25(\sin^2 x + \sin^2 y), \quad (x, y) \in [-2\pi, 2\pi] \times [-2\pi, 2\pi].$$

We know that f has a global minimum $f_{\min} = 0$ at $(0, 0)$. In our implementation, we use $n = 25$ to 50 virtual bats, and $\alpha = 0.9$. For the multimodal eggcrate function, a snapshot of the last 10 iterations is shown in Figure 10.2, where all bats move toward the global best $(0, 0)$.

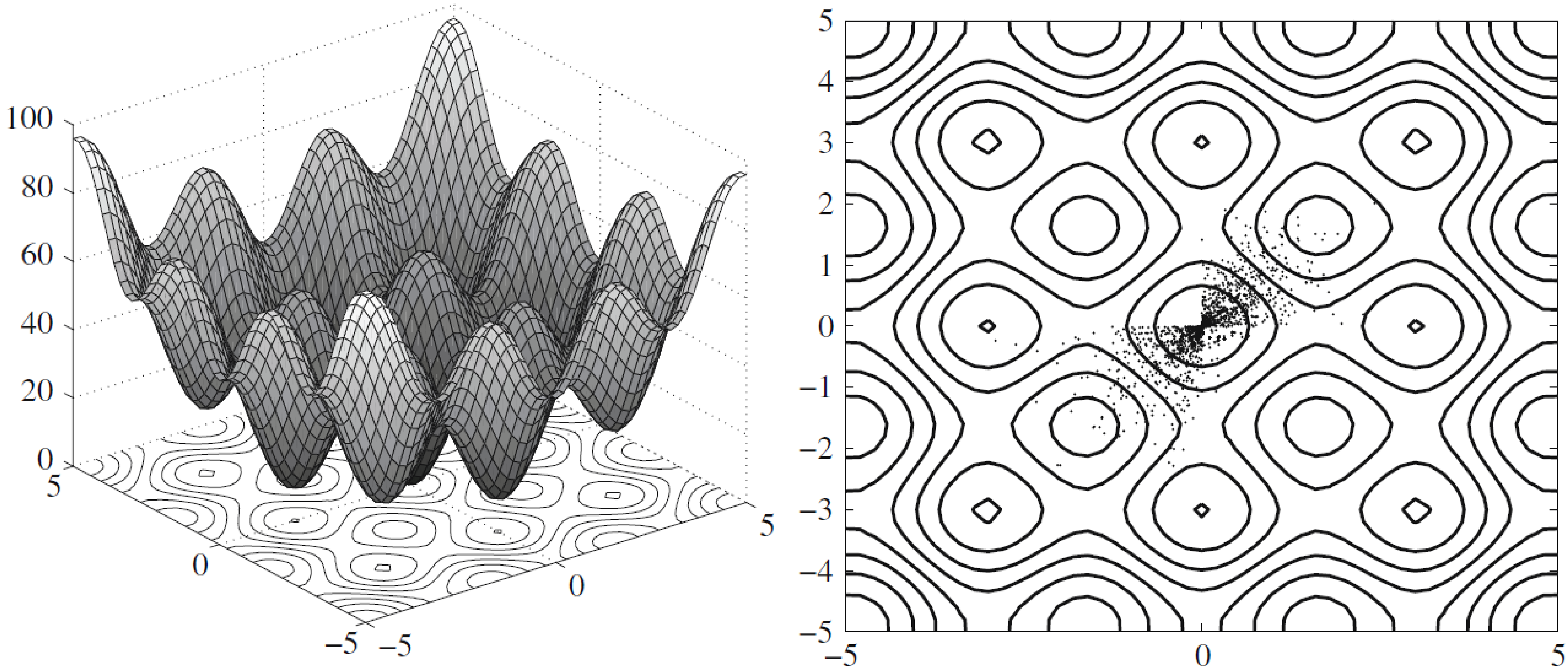

Figure 10.2 The eggcrate function (left) and the locations of 40 bats in the last 10 iterations (right).

The Binary Bat Algorithm (BBA)

- Model search space as *d*-dimensional Boolean lattice
  - Bats move across corners & nodes of hypercube
  - Feature represented by bat's position as binary vector
- Restrict bat's position using sigmoid function:

$$x_i^j = \begin{cases} 1 & \text{if } S(v_i^j) > \rho, \\ 0 & \text{otherwise} \end{cases} \text{ and, } \quad S(v_i^j) = \frac{1}{1 + \exp[-v_i^j]}$$

  - Note: $\rho \sim U(0,1)$ and $\boldsymbol{v}_i^j$ (*j*th dimension of bat *i*)

- Could use other methods of discretization (such as those in PSO, FA)

Why is BA Efficient?

- *Frequency tuning*
  - BA uses echolocation and frequency tuning to solve problems
  - BA possesses advantages of other metaheuristic algorithms, i.e., PSO, SA
- *Automatic zooming*
  - BA has a distinct advantage over other metaheuristic algorithm
    - BA can “zoom in” to regions where promising solutions have been found
  - Zooming accompanied by automatic switch from explorative moves to local intensive exploitation
    - Gives BA quick convergence rate (at least in early iterations) compared to others
- *Parameter control*
  - BA uses (meta-)parameter control – varies values of A and r as iterations proceed
  - Automatic switch from exploration to exploitation when optimal solution is approaching

Some Applications of BA

- Continuous Optimization
- Combinatorial Optimization and Scheduling
- Inverse Problems & Parameter Estimation
- Classifications, Clustering, & Data Mining
- Image Processing
- Fuzzy Logic

Questions?