Levy Flight-Augmented Artificial Circulatory System Algorithm

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1 Mathematical Framework of LF-ACSA

Algorithm 1

1: **Objective:**

$$\min_{\mathbf{x}\in[\mathbf{l},\mathbf{u}]^d} f(\mathbf{x})$$

2: **Stimulation Function (SF):**

$$SF(\mathbf{x}; E_a, E_s, S) \;=\; \frac{(\mathbf{u}-\mathbf{l})\cdot S}{1+\exp\big(E_a(-\mathbf{x}+E_s)\big)}$$

3: **Constants (Neural / Hormonal):**

$$(E_a^{(n)}, E_s^{(n)}) = (1.8,\, 0.002), \qquad (E_a^{(h)}, E_s^{(h)}) = (0.66,\, 0.33)$$

4: **Lévy Flight (Mantegna):**

$$L(\beta) \sim |\Delta X|^{\,1-\beta}, \qquad \beta \in (1,3)$$

$$\Delta X \;=\; \frac{u}{|v|^{1/\beta}}, \quad u \sim \mathcal{N}(0,\sigma^2), \quad \boxed{v \sim \mathcal{N}(0,1)}$$

$$\sigma \;=\; \left(\frac{\Gamma(1+\beta)\,\sin(\pi\beta/2)}{\Gamma\big(\frac{1+\beta}{2}\big)\,\beta\,2^{(\beta-1)/2}}\right)^{1/\beta}$$

5: **Neural Update (Enhanced with Lévy Flight):**

$$\boxed{\mathbf{x}_{\text{new}} \;=\; \eta\cdot\text{LevyFlight}(d,\beta) \;\odot\; SF(\mathbf{x}_i; E_a^{(n)}, E_s^{(n)}, S)}$$

with elementwise (Hadamard) product $\odot$, and $\eta \equiv$ `levy_scale`.

6: **Hormonal Update (Original ACSA):**

$$\mu \;=\; \frac{1}{N}\sum_{i=1}^{N}\mathbf{x}_i, \qquad \mathbf{x}_{\text{new}} \;=\; \begin{cases} \mu \;+\; \text{rand}(d) \;\odot\; SF(\mathbf{x}_i; E_a^{(h)}, E_s^{(h)}, S), & \text{w.p. } 0.5 \\ \mathbf{xbest} \;+\; \text{rand}(d) \;\odot\; (\mu - \mathbf{x}_i), & \text{otherwise} \end{cases}$$

where $\text{rand}(d)$ is i.i.d. uniform in $[0,1]^d$, $\boldsymbol{\mu}$ is population mean, and $\rho \equiv$ `NH_rate`.

Algorithm 2 Pseudocode of LF-ACSA

Require: $f(\cdot)$, bounds $[\mathbf{l}, \mathbf{u}]$, dim d, pop size N, iterations T, NH rate ρ, scale S, Lévy params (β, η)

Initialize $\{\mathbf{x}_i\}_{i=1}^{N} \sim \mathcal{U}[\mathbf{l}, \mathbf{u}]$; compute $f_i = f(\mathbf{x}_i)$
$(\mathbf{x}, F) \leftarrow \arg\min_i f_i$; Convergence list $\mathcal{C} \leftarrow [F]$
for $t = 1$ to T **do**
  Sort indices by f_i in descending order (worst $\rightarrow$ best)
  $\mathcal{I}_n \leftarrow$ first $\lfloor \rho N \rfloor$ (neural), $\mathcal{I}_h \leftarrow$ remaining (hormonal)
  for $i \in \mathcal{I}_n$ **do**
    $\mathbf{sf} \leftarrow SF(\mathbf{x}_i; E_a^{(n)}, E_s^{(n)}, S)$
    $\mathbf{L} \leftarrow \eta \cdot \text{LevyFlight}(d, \beta)$ ▷ $\mathbf{L} = U/|V|^{1/\beta}$
    $\mathbf{x}' \leftarrow \text{clip}\big(\mathbf{L} \odot \mathbf{sf},\, \mathbf{l}, \mathbf{u}\big)$
    $f' \leftarrow f(\mathbf{x}')$; **if** $f' < f_i$ **then** $\mathbf{x}_i \leftarrow \mathbf{x}'$; $f_i \leftarrow f'$
  end for
  $\boldsymbol{\mu} \leftarrow \frac{1}{N} \sum_{i=1}^{N} \mathbf{x}_i$
  for $i \in \mathcal{I}_h$ **do**
    if rand() < 0.5 **then**
      $\mathbf{sf} \leftarrow SF(\mathbf{x}_i; E_a^{(h)}, E_s^{(h)}, S)$
      $\mathbf{x}' \leftarrow \boldsymbol{\mu} + \text{rand}(d) \odot \mathbf{sf}$
    else
      $\mathbf{x}' \leftarrow \mathbf{xbest} + \text{rand}(d) \odot (\boldsymbol{\mu} - \mathbf{x}_i)$
    end if
    $\mathbf{x}' \leftarrow \text{clip}(\mathbf{x}', \mathbf{l}, \mathbf{u})$; $f' \leftarrow f(\mathbf{x}')$
    if $f' < f_i$ **then** $\mathbf{x}_i \leftarrow \mathbf{x}'$; $f_i \leftarrow f'$
  end for
  $(\mathbf{x}, F) \leftarrow \arg\min_i f_i$; $\mathcal{C}$.append(F)
end for
return $(\mathbf{x}, \mathcal{C})$