Universität Hamburg
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MIN Faculty
Department of Informatics

Firefly Algorithm for Target Tracking in Aerial Swarm Robotics

[https://farm5.static.flickr.com/4299/36105876845_eeb2a9b096_b.jpg]

Outline

- Motivation
- Target Tracking as an optimization problem
- Nature-Inspired Metaheuristics
- The Firefly Algorithm
- Evaluation
- Conclusion

[https://www.firefly.org/images/pictures/boy-catching-fireflies.jpg]

Motivation *...Not!*

Public Surveillance

[http://1.bp.blogspot.com/-WSLRddK9-J4/VUh0S150uCI/AAAAAAAA-CsI/VJuFt1Dfj4o/s1600/domestic-drone-cartoon.jpg]

Drone Delivery

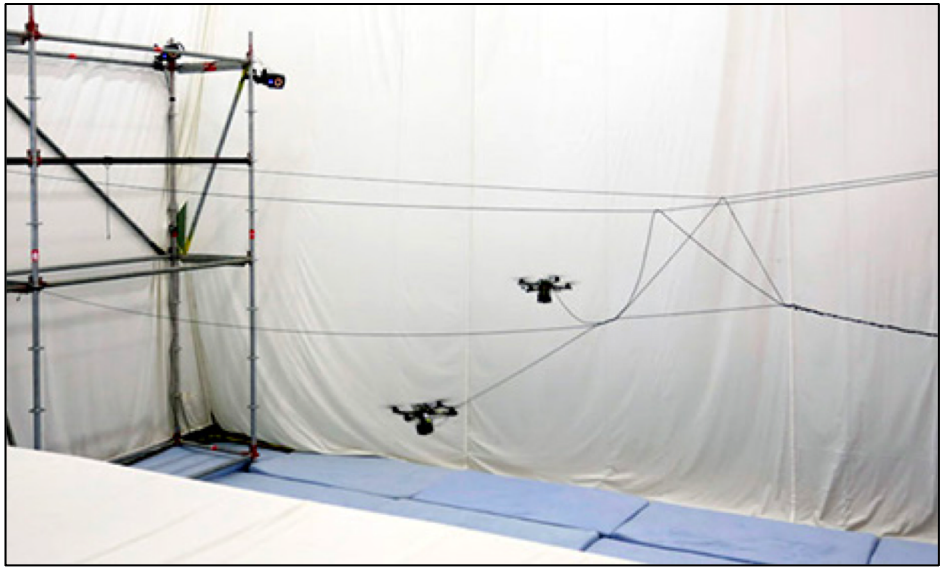
[https://pixabay.com/get/eb3db0092af0053ed1584d05fb0938c9bd22ffd41cb515429df4c77aa6/drone-2816244_1280.jpg]

Motivation

Wildfire detection and control

[http://www.cobizmag.com/Articles/The-futurist-Life-in-the-drone-zone/western-wildfires-fire-retardant-drones-sm.png]

Collaborative construction– [1]



[https://spectrum.ieee.org/image/MjY3MzQyMw.jpeg]

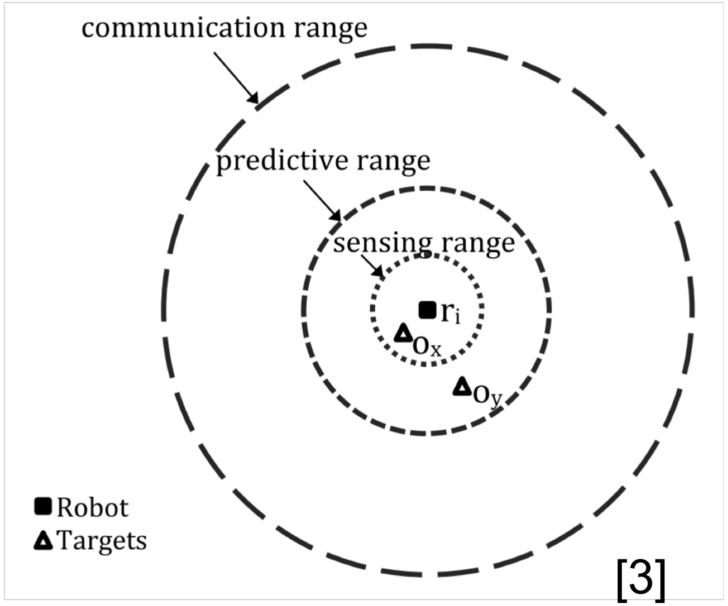
Swarm Target Tracking

[https://www.ted.com/talks/raffaello_d_andrea_the_astounding_athletic_power_of_quadcopters]

Swarm Target Tracking

- A robot is observing a target when the target is within its sensing range.
- Swarming enables distributed sensing, parallel actuations & fault tolerance

→ multi-objective, multi-modal optimization [2]



[3]

[http://2.bp.blogspot.com/-9nILTAIsVeY/VQula-vzxjVI/KTd9aliS5Sk/s1600/big-hero-6-villain.jpg]

Nature-Inspired Metaheuristics

[http://www.kinderstube-sachsen.de/uploads/pics/480x240_1-18_2_01.jpg]

Terminology:

- heuristic *(εὑρίσκω - "I find“)*:

  technique for finding an approximate solution

→ trade optimality, completeness, accuracy or precision for speed

- metaheuristic (μετά - "beyond”):

  higher-level procedure guiding a heuristic under incomplete information

→ vary in the weighting of exploitation vs. exploration

[4]

Nature-Inspired Metaheuristics

- Particle Swarm Optimization
- Firefly Algorithm
- Bat Algorithm
- Artificial Bee Colony Optimization
- Eagle Strategy
- Shuffled Frog Leaping Algorithm
- Cuckoo Search
- Flower Pollination Algorithm

Fireflies

[https://www.thisiscolossal.com/wp-content/uploads/2016/07/2016-summer-firefly-selects-spoon-and-tamago-1.jpg]

Fireflies

Glowworm larvae

[https://www.firefly.org/images/pictures/glow-worm.jpg]

Lampyridae

[https://www.firefly.org/images/pictures/firefly-pics2.jpg]

Photuris lucicrescens („femme fatale“)

[https://upload.wikimedia.org/wikipedia/commons/5/52/Photuris_lucicrescens.jpg]

The Firefly Algorithm

Simplifications:

- All fireflies are **unisex.**
- Attractiveness is **proportional** to light intensity.
  If there are no fireflies brighter than a given firefly, it will **move randomly**.
- Light intensity is affected by the landscape of the **fitness function**. [5]

→ broadcast-like communication

[http://static-35.sinclairstoryline.com/resources/media/ffc55c6a-991b-478e-88d5-d8bb2b1de80b-large16x9_FireflyGarbettBoom.jpg]

The Firefly Algorithm

The movement of a firefly ***i*** attracted to another more attractive (brighter) firefly ***j*** is determined by:

$$x_i^{t+1} = x_i^t + \beta_0 e^{-\gamma r^2{}_{ij}} \left(x_j^t - x_i^t\right) + \alpha\ \epsilon_i^t$$

[5]

The Firefly Algorithm

The movement of a firefly i attracted to another more attractive (brighter) firefly j is determined by:

$$\boxed{x_i^{t+1}} = \boxed{x_i^t} + \boxed{\beta_0 e^{-\gamma r^2{}_{ij}} \left(x_j^t - x_i^t\right)} + \boxed{\alpha\ \epsilon_i^t}$$

future trajectory | current trajectory | attraction (exploitation) | randomisation (exploration) [5]

The Firefly Algorithm

The movement of a firefly ***i*** attracted to another more attractive (brighter) firefly ***j*** is determined by:

γ = light absorption coefficient ϵ^t =vector of random numbers

$$\boxed{x_i^{t+1}} = \boxed{x_i^t} + \boxed{\beta_0 e^{-\gamma r^2{}_{ij}} \left(x_j^t - x_i^t\right)} + \boxed{\alpha\ \epsilon_i^t}$$

[5]

β_0 = attractiveness at r = 0 α = randomization coefficient

$0 < \alpha < 1$

<u>Special cases:</u>

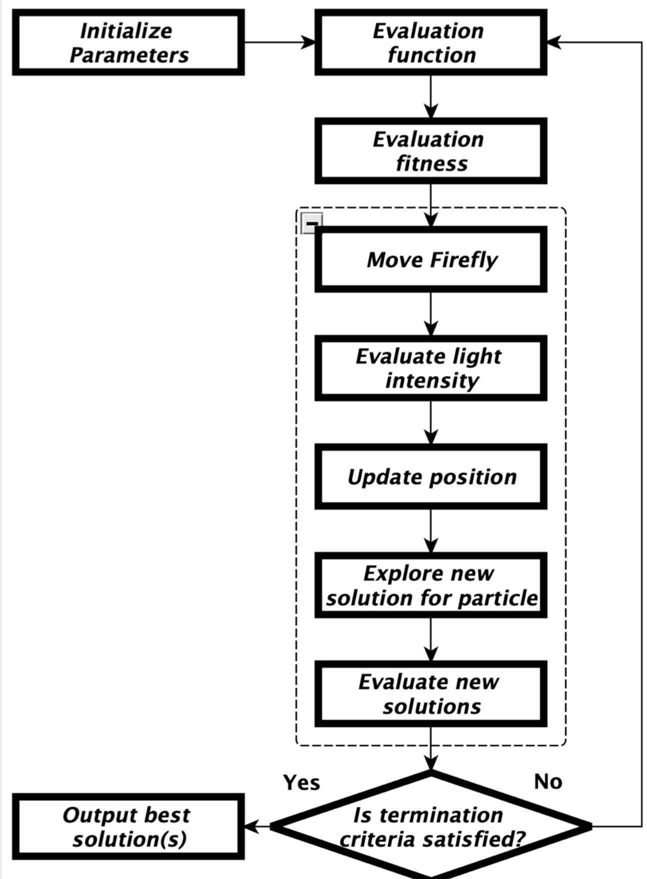
- when β_0 => 0 → Simulated Annealing
- when X^t_j => **g*** → Particle Swarm Optimisation

Firefly Algorithm - Pseudocode

Firefly Algorithm

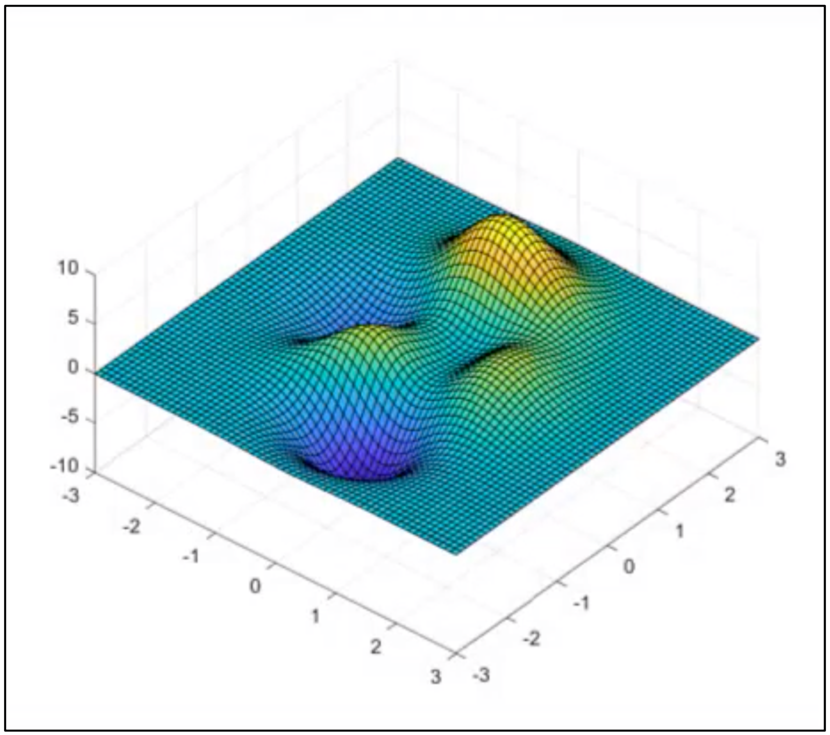
Objective function $f(\mathbf{x}), \quad \mathbf{x} = (x_1, ..., x_d)^T$
Generate initial population of fireflies $\mathbf{x}_i$ $(i = 1, 2, ..., n)$
Light intensity I_i *at* $\mathbf{x}_i$ *is determined by* $f(\mathbf{x}_i)$
Define light absorption coefficient γ
while $(t < MaxGeneration)$
for $i = 1 : n$ *all* n *fireflies*
  for $j = 1 : i$ *all* n *fireflies*
    if $(I_j > I_i)$, *Move firefly* i *towards* j *in d-dimension;* **end if**
    Attractiveness varies with distance r *via* $\exp[-\gamma r]$
    Evaluate new solutions and update light intensity
  end for j
end for i
Rank the fireflies and find the current best
end while
Postprocess results and visualization

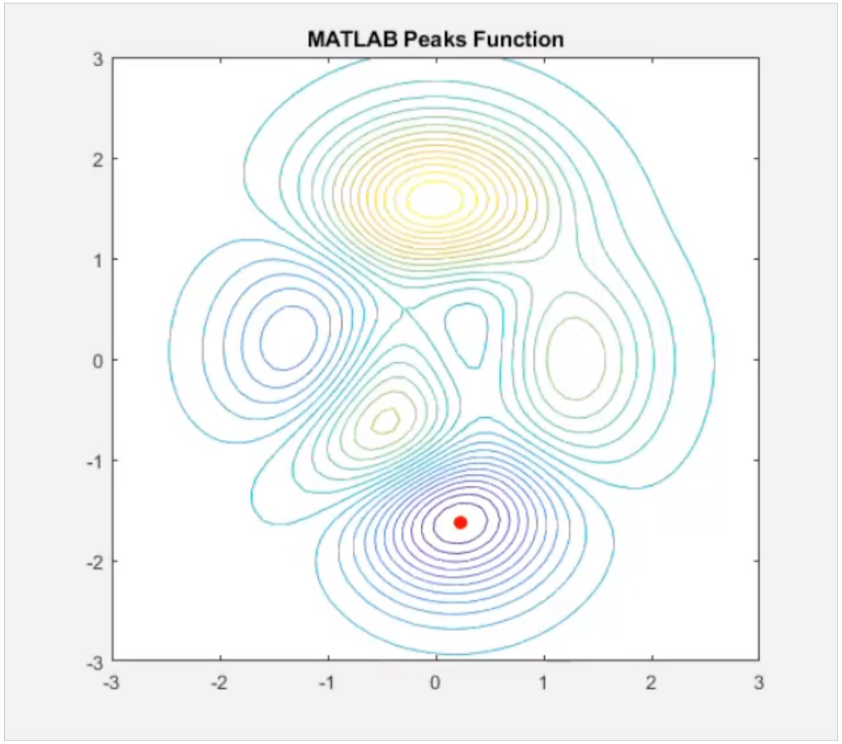
[6]



[7]

Evaluation: Procedure



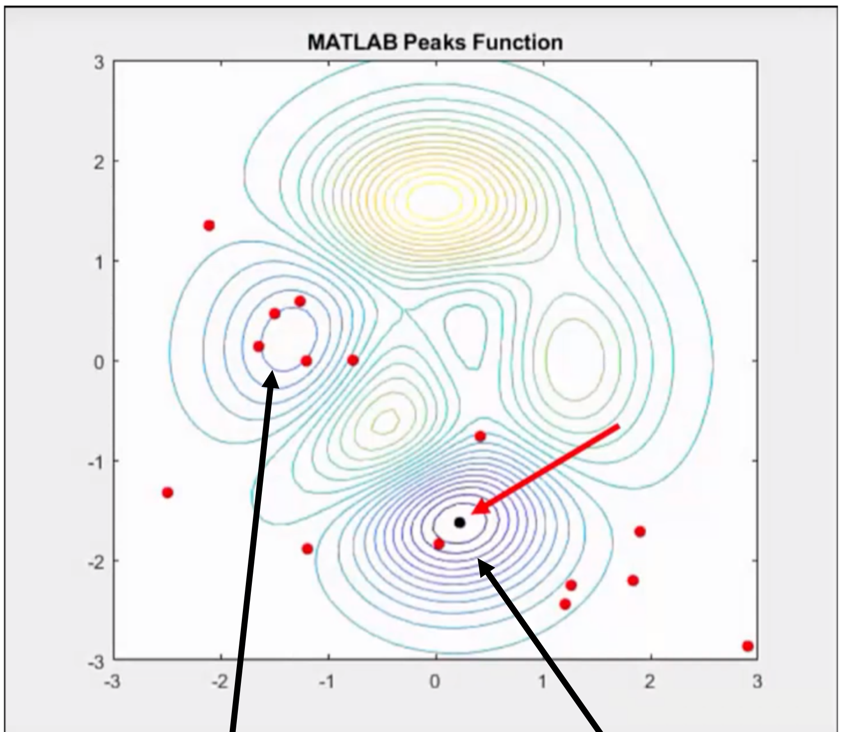


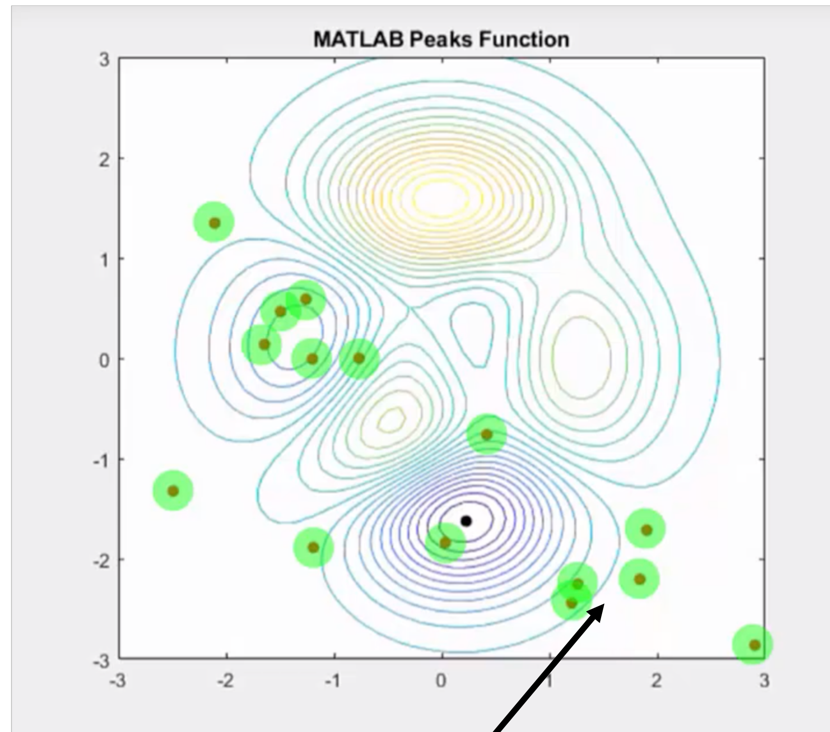
Non-convex stochastic test function

2D representation

[https://www.youtube.com/watch?v=LPKg_luHxpc]

Evaluation: Procedure

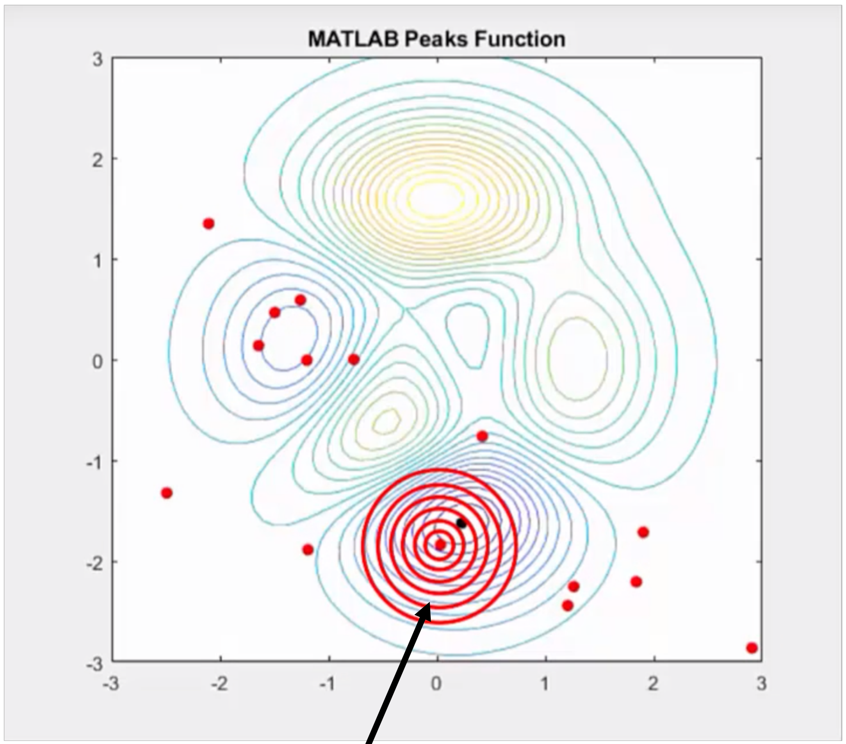


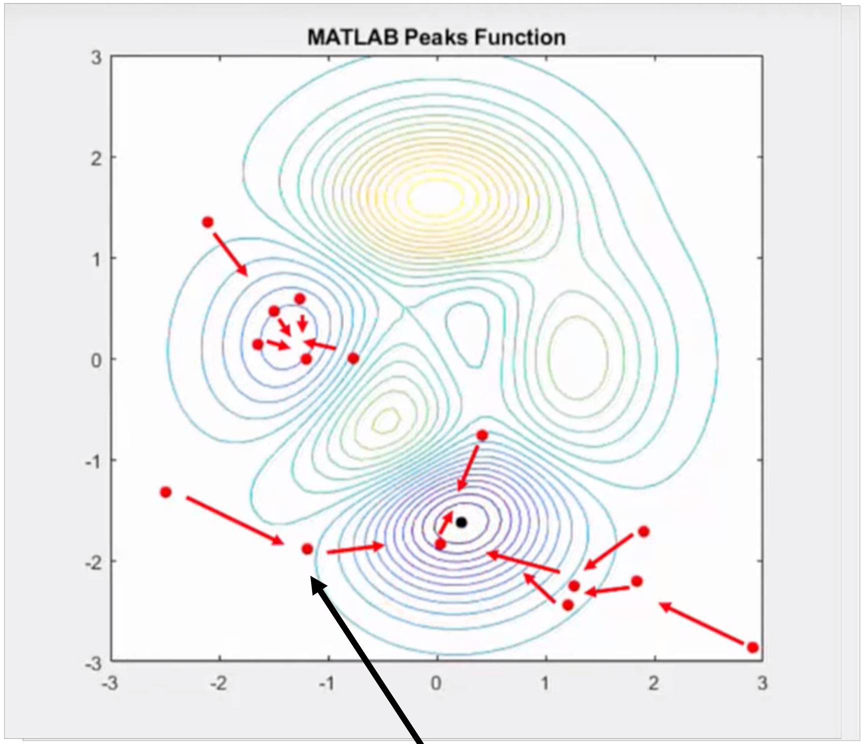


Local minimum Global minimum (Randomly) initialized fireflies

[https://www.youtube.com/watch?v=LPKg_luHxpc]

Evaluation: Procedure



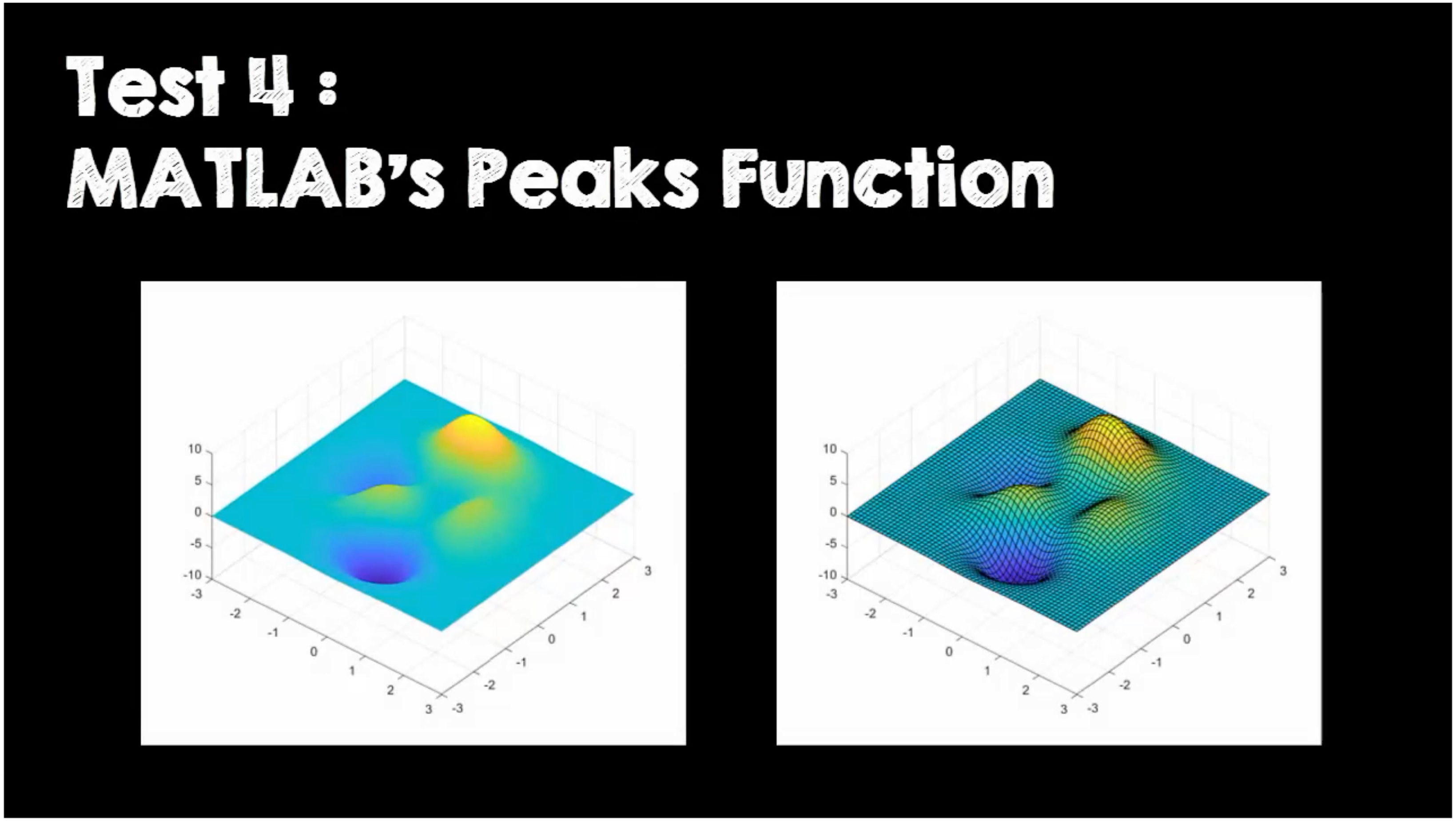


Light intensity in terms of fitness function

Brighter firefly attracts less brighter one

[https://www.youtube.com/watch?v=LPKg_luHxpc]

Evaluation: Procedure



[https://www.youtube.com/watch?v=LPKg_luHxpc]

Evaluation: Quantative

Table 1: Comparison of algorithm performance

Functions/Algorithms	GA	PSO	FA
Michalewicz's (d=16)	$89325 \pm 7914 (95\%)$	$6922 \pm 537 (98\%)$	$3752 \pm 725 (99\%)$
Rosenbrock's (d=16)	$55723 \pm 8901 (90\%)$	$32756 \pm 5325 (98\%)$	$7792 \pm 2923 (99\%)$
De Jong's (d=256)	$25412 \pm 1237 (100\%)$	$17040 \pm 1123 (100\%)$	$7217 \pm 730 (100\%)$
Schwefel's (d=128)	$227329 \pm 7572 (95\%)$	$14522 \pm 1275 (97\%)$	$9902 \pm 592 (100\%)$
Ackley's (d=128)	$32720 \pm 3327 (90\%)$	$23407 \pm 4325 (92\%)$	$5293 \pm 4920 (100\%)$
Rastrigin's	$110523 \pm 5199 (77\%)$	$79491 \pm 3715 (90\%)$	$15573 \pm 4399 (100\%)$
Easom's	$19239 \pm 3307 (92\%)$	$17273 \pm 2929 (90\%)$	$7925 \pm 1799 (100\%)$
Griewank's	$70925 \pm 7652 (90\%)$	$55970 \pm 4223 (92\%)$	$12592 \pm 3715 (100\%)$
Shubert's (18 minima)	$54077 \pm 4997 (89\%)$	$23992 \pm 3755 (92\%)$	$12577 \pm 2356 (100\%)$
Yang's ($d = 16$)	$27923 \pm 3025 (83\%)$	$\boxed{14116} \pm \boxed{2949} \boxed{(90\%)}$	$7390 \pm 2189 (100\%)$

[6]

mean # of iterations

standard deviation

success rate

Evaluation: Qualitative

Pro:

- Performant
- Distributed by default, automatic subdivision
- Fault tolerant / adaptive

→ Suitable for multi-objective, multi-modal problems

Con:

- No optimality guaranteed (w/o Lévy Flights)
- No theoretical analysis on convergence yet

→ Further research needed

[http://www.fireflyexperience.org/photos/firefly_72678_2.jpg]

Conclusion

" There ain't no such thing as a free lunch" - [8]

- Aerial swarm tracking is a dynamic, multi-objective, multimodal optimization problem
- Firefly algorithm in particular shows suitability due to robustness, scalability and flexibility

[https://i.ytimg.com/vi/vldWhL5JQxg/hqdefault.jpg]

Thank you!

[http://www.fireflyexperience.org/photos/firefly_81933.jpg]

References

- [1] F. Augugliaro, A. Mirjan, F. Gramazio, M. Kohler, and R. D'Andrea, "Building tensile structures with flying machines", IEEE/RSJ International Conference on Intelligent Robots and Systems, 2013.
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- [5] Yang, Xin-She. (2010). Nature-Inspired Metaheuristic Algorithms.
- [6] Yang, Xin-She. (2010). Firefly Algorithm, Levy Flights and Global Optimization. 10.1007/978-1-84882-983-1_15.
- [7] Khaze, Seyyed Reza et al. "Evaluation the efficiency of artificial bee colony and the firefly algorithm in solving the continuous optimization problem." CoRR abs/1310.7961 (2013): n. pag.
- [8] David H. Wolpert, William G. Macready: No free lunch theorems for search. Vol. 10, Technical Report SFI-TR-95-02-010, Santa Fe Institute, 1995.
- [9] Di Somma, Marialaura. (2016). Optimal Operation Planning Of Distributed Energy Systems Through Multi-objective Approach: A New Sustainability-oriented Pathway.
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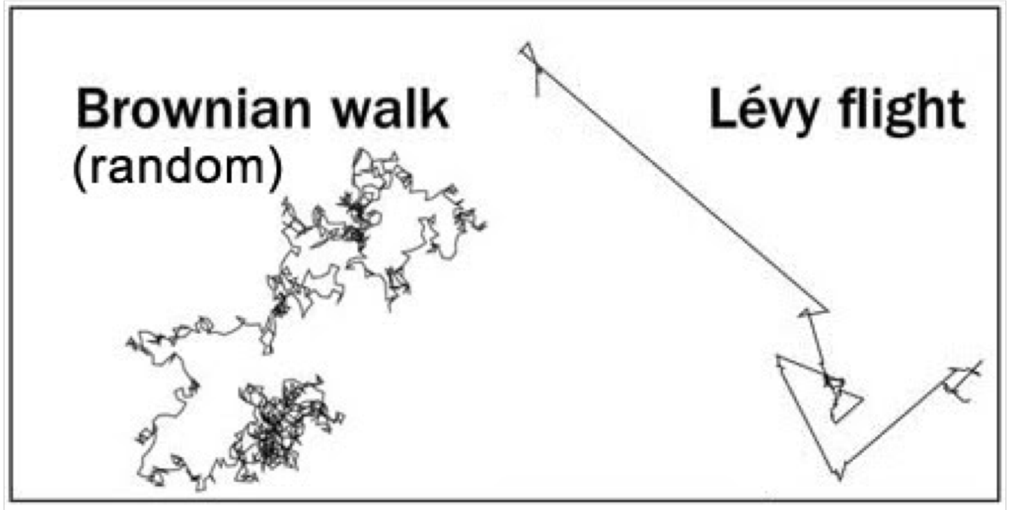
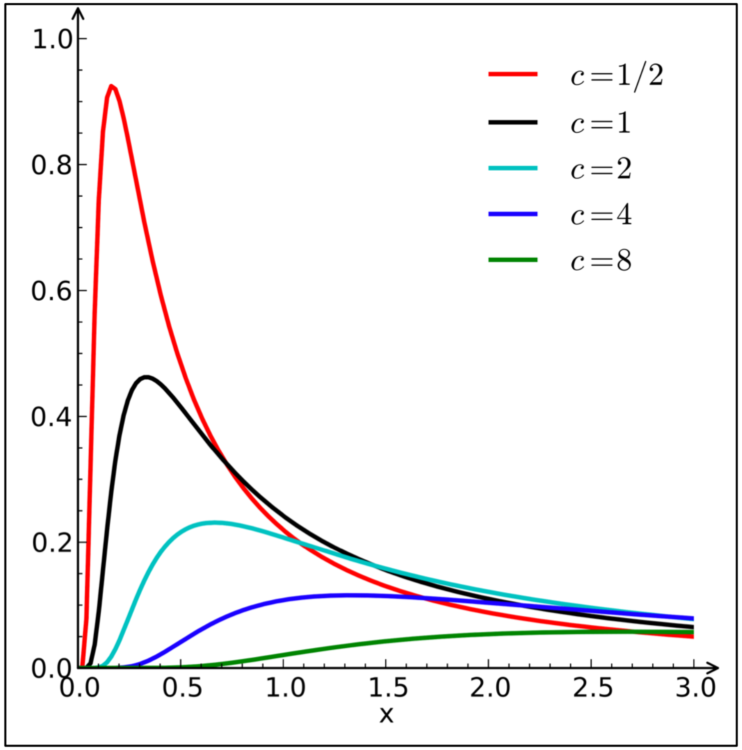
Backup: Lévy Flights





$$f(x;\mu,c)=\sqrt{\frac{c}{2\pi}}\;\frac{e^{-\frac{c}{2(x-\mu)}}}{(x-\mu)^{3/2}}$$

[6]

μ = location parameter

c = scale parameter

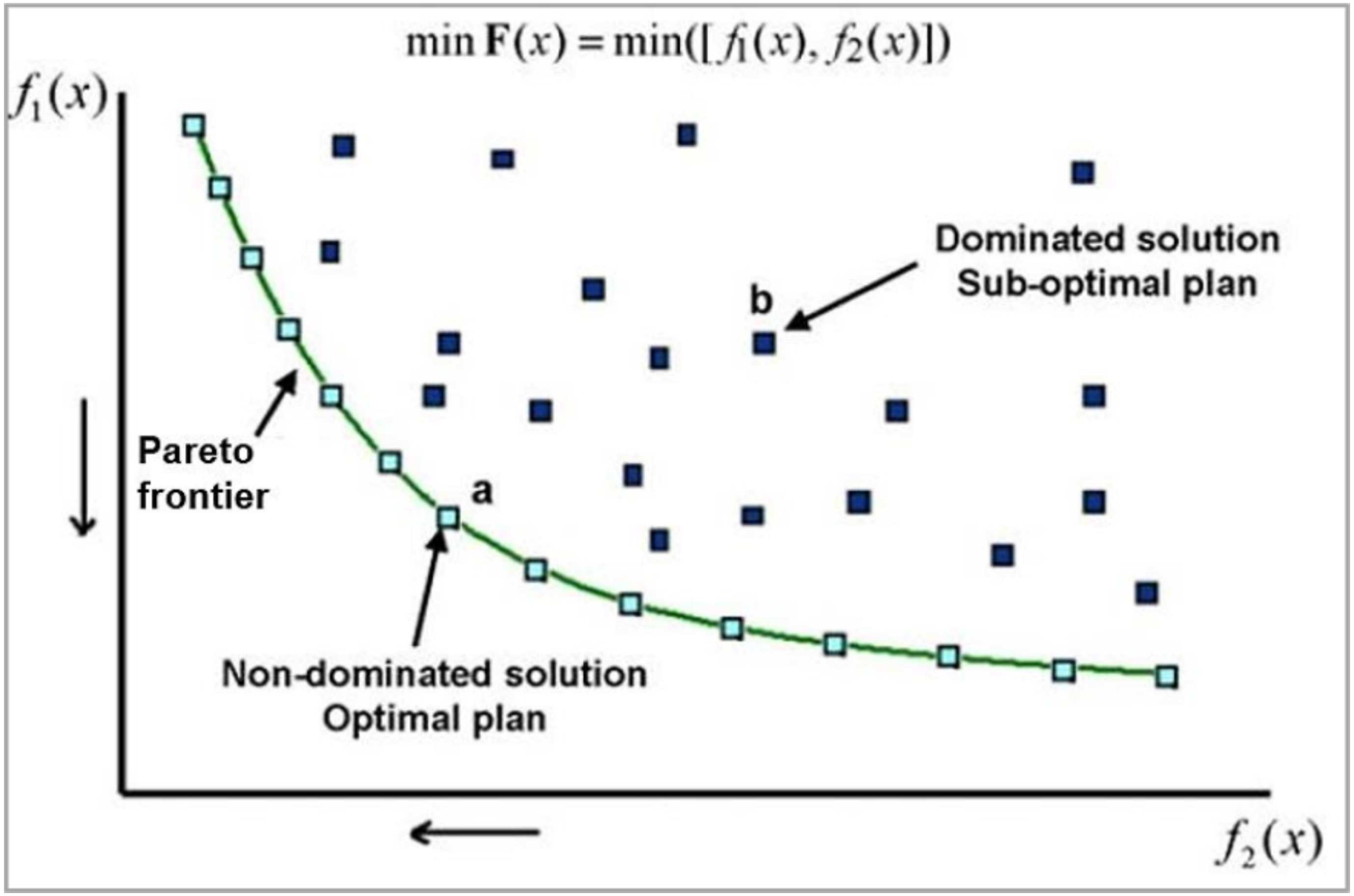
Backup: Lévy-Flight Firefly Algorithm - Pseudocode

```
begin
   Objective function f(x),      x = (x_1, ..., x_d)^T
   Generate initial population of fireflies x_i (i = 1, 2, ..., n)
   Light intensity I_i at x_i is determined by f(x_i)
   Define light absorption coefficient γ
   while (t < MaxGeneration)
   for i = 1 : n all n fireflies
      for j = 1 : i all n fireflies
            if (I_j > I_i)
            Move firefly i towards j in d-dimension via Lévy flights
            end if
            Attractiveness varies with distance r via exp[−γr]
            Evaluate new solutions and update light intensity
      end for j
   end for i
   Rank the fireflies and find the current best
   end while
   Postprocess results and visualization
end
```

Figure 1: Pseudo code of the Lévy-Flight Firefly Algorithm (LFA).

[6]

Backup: Multi-objective optimization



[9]

Backup: Multi-objective firefly algorithm - Pseudocode

Define objective functions $f_1(\boldsymbol{x}), ..., f_K(\boldsymbol{x})$ where $\boldsymbol{x} = (x_1, ..., x_d)^T$
Initialize a population of n fireflies $\boldsymbol{x}_i$ $(i = 1, 2, ..., n)$
while (t <MaxGeneration)
  for $i, j = 1 : n$ (all n fireflies)
    Evaluate their approximations PF_i and PF_j to the Pareto front
        if $i \neq j$ and when all the constraints are satisfied
    if PF_j dominates PF_i,
      Move firefly i towards j using (2)
      Generate new ones if the moves do not satisfy all the constraints
    end if
    if no non-dominated solutions can be found
      Generate random weights w_k $(k = 1, ..., K)$
      Find the best solution $\boldsymbol{g}_*^t$ (among all fireflies) to minimize ψ in (4)
      Random walk around $\boldsymbol{g}_*^t$ using (5)
    end if
    Update and pass the non-dominated solutions to next iterations
  end
  Sort and find the current best approximation to the Pareto front
  Update $t \leftarrow t + 1$
end while
Postprocess results and visualisation;

Figure 1: Pseudo Code: Multiobjective firefly algorithm (MOFA).

[10]