Biomimicry of Bacterial Foraging

for Distributed Optimization and Control

Kevin M. Passino[1]
Presented by: Alexander Van de Kleut[2]

[1]The Ohio State University
Electrical and Computer Engineering

[2]University of Waterloo
Centre for Theoretical Neuroscience

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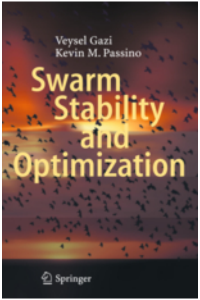

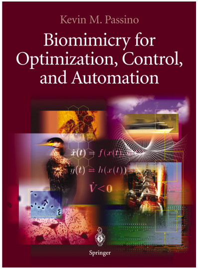

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Foraging

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- searching for nutrients
- avoiding noxious stimuli (toxins, predators, etc)

Social Foraging

- increases likelihood of finding nutrients
- better detection and protection from noxious stimuli
- gains can offset cost of food competition

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- We have some parameters θ and a loss function $J(\theta)$ that we want to minimize
- θ can represent the position of an organism in its environment
- J can represent the concentration of nutrients and noxious stimuli
    - smaller values of J = more nutrients, less noxious stimuli
    - higher values of J = more noxious stimuli, less nutrients
- In general, J and θ can be arbitrary
    - $\theta \in \mathbb{R}^p$
    - $J : \mathbb{R}^p \rightarrow \mathbb{R}$

E. coli

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- Social organism
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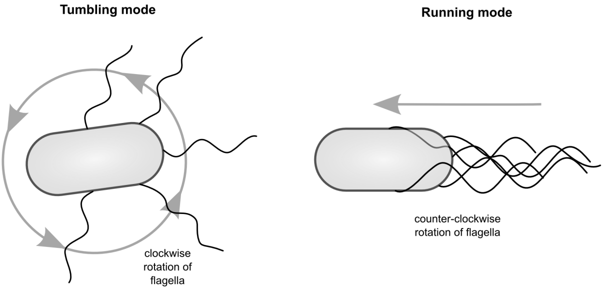
  - Encourages "swarming" or "clumping"

E. Coli Behaviour

- Swims using left-handed helical flagella ("propellers")
  - **Tumble**: flagella all rotate clockwise → pull on cell in all directions → random movement
  - **Run**: flagella all rotate counterclockwise → flagella form a bundle → push on cell in one direction → directed movement



E. Coli Behaviour

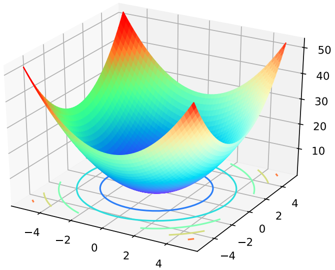
- If during a tumble E. Coli swims down a nutrient concentration gradient:
  - Prolongs time spent on a run
  - Continues moving in the same direction
- Otherwise:
  - Tends to switch to a tumble (search for more)
  - Moves randomly which searching for more nutrient gradients to exploit
- Call a tumble followed by a run a “chemotaxis step”

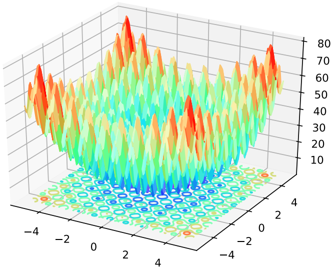
Algorithm for a Single Bacterium

for $j \leftarrow 1 \ldots N_c$ **do**:
    $\phi \sim \mathcal{U}$
    $\theta \leftarrow \theta + c\phi$
    while $J(\theta + c\phi) < J(\theta)$ **do**:
        $\theta \leftarrow \theta + c\phi$

- θ: p-dimensional vector (randomly initialized)
- N_c: number of chemotaxis steps
- $\phi \sim \mathcal{U}$: a random unit vector
- c: a step-size

Loss Function to Optimize





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