How do you explore without a brain?

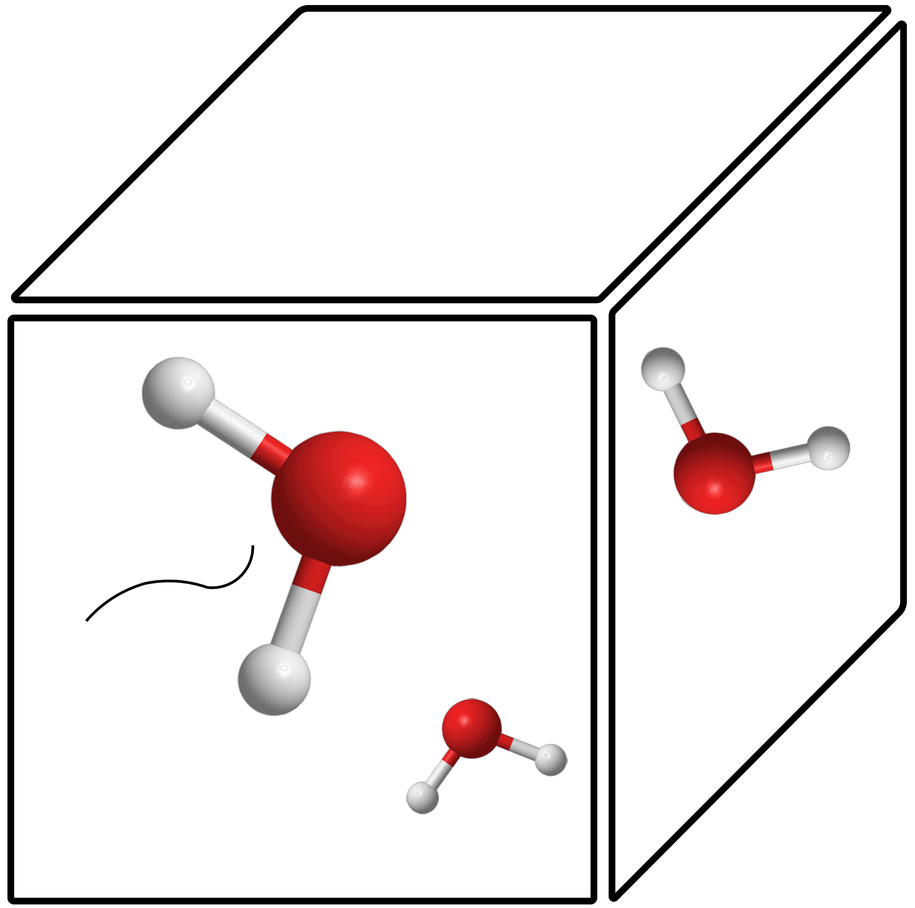
Readings for today

- Reid, C. R., Latty, T., Dussutour, A., & Beekman, M. (2012). Slime mold uses an externalized spatial “memory” to navigate in complex environments. Proceedings of the National Academy of Sciences, 109(43), 17490-17494.

- Huo, H., He, R., Zhang, R., & Yuan, J. (2021). Swimming Escherichia coli Cells Explore the Environment by Lévy Walk. Applied and Environmental Microbiology, 87(6), e02429-20.

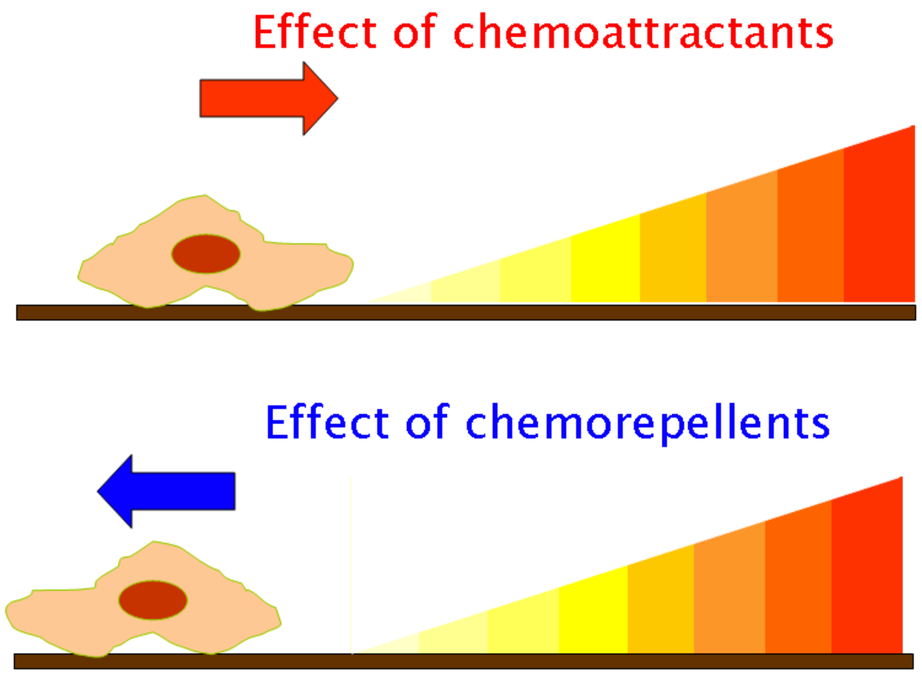
What is the optimal way to explore?

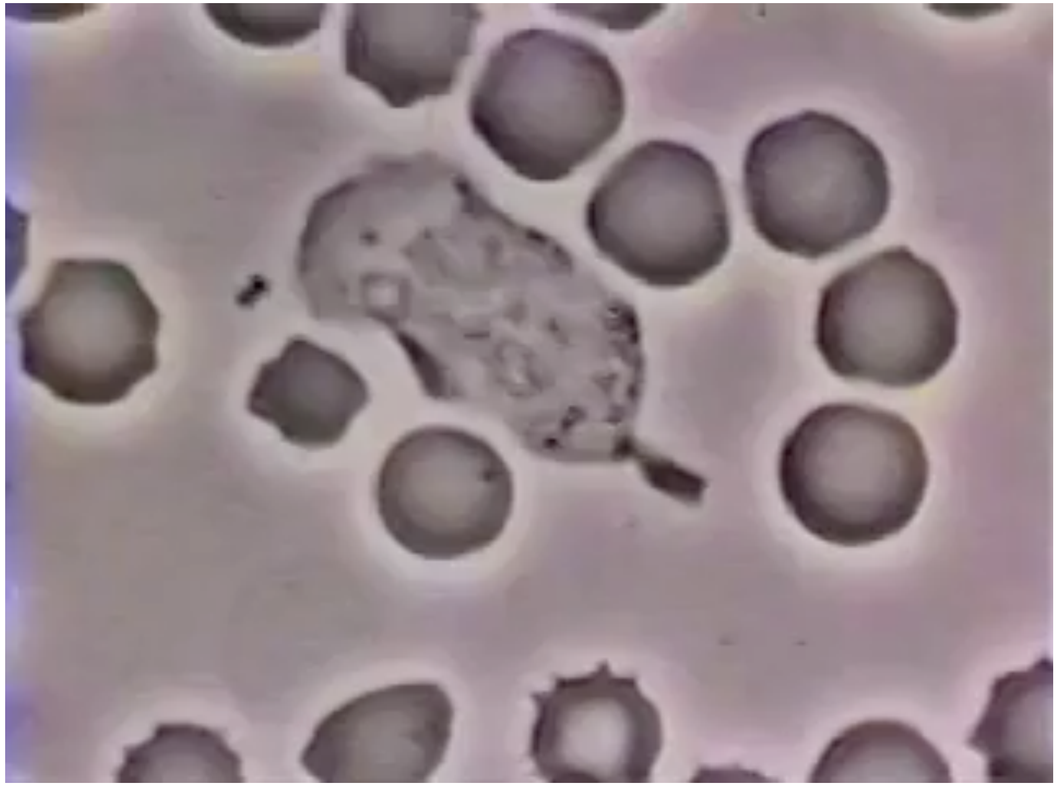
An optimal exploration policy is one that samples every option at least once.



Chemotaxis

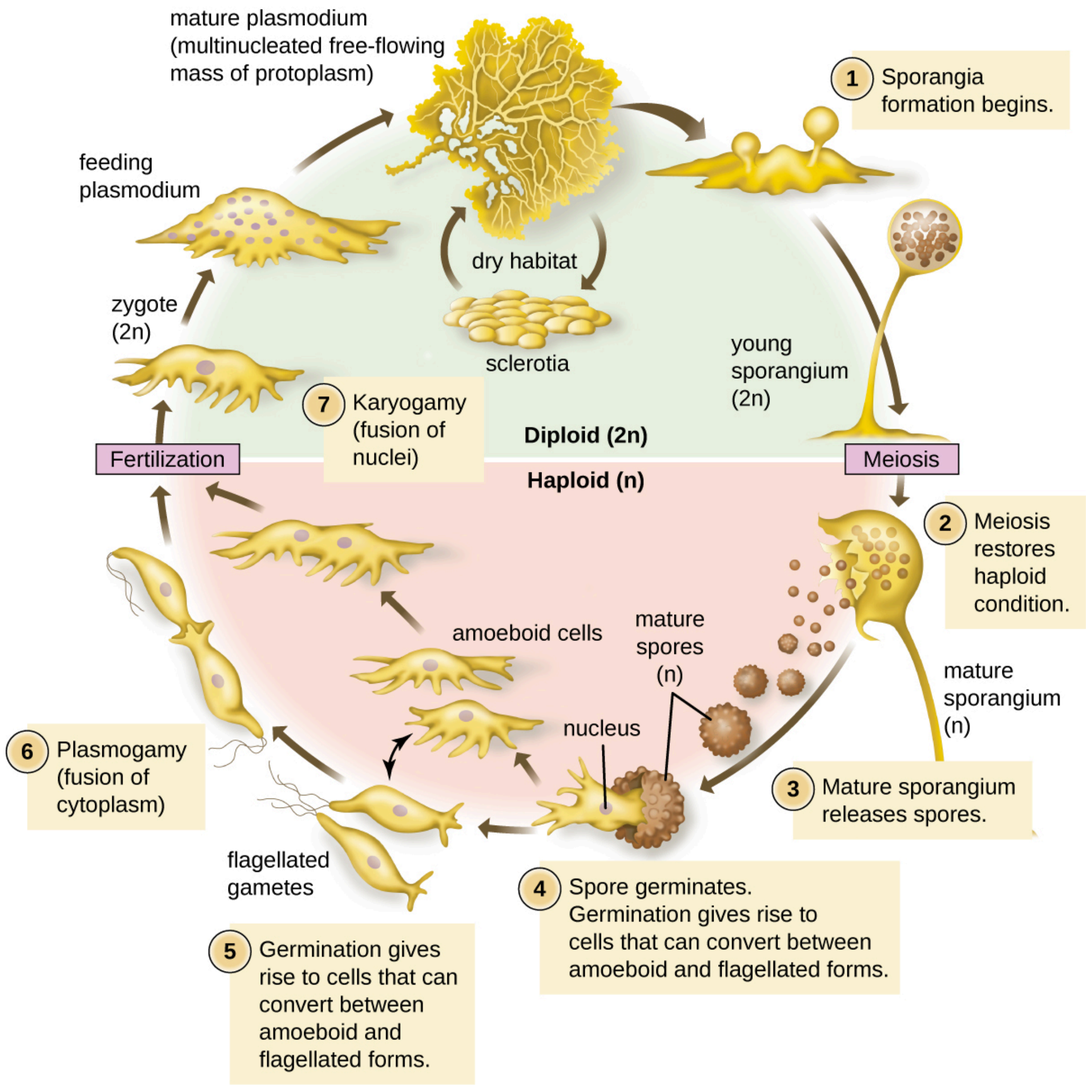
Movement in response to a chemical stimulus.



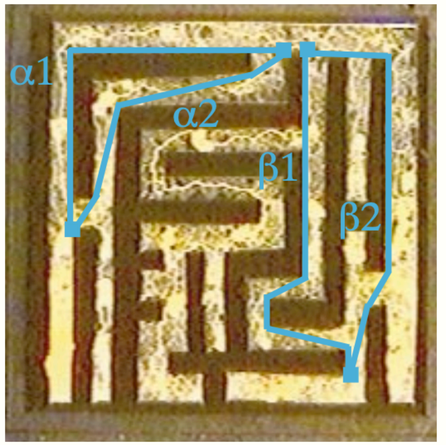


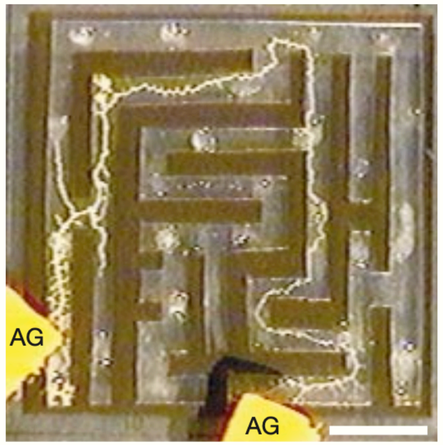
https://routledgetextbooks.com/textbooks/9780815344506/videos.php

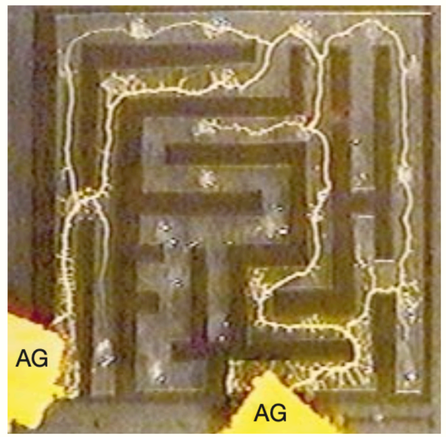
Organism 1: slime mold



Slime mold navigation







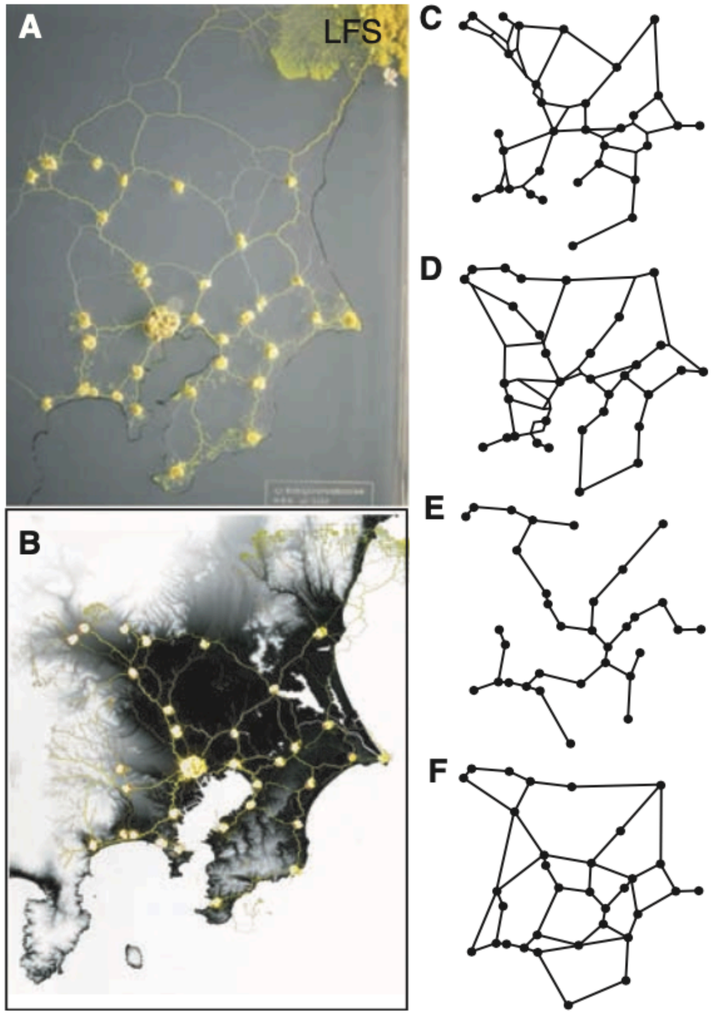
d

	None	β1	β2	β1, β2
None	2	0	0	0
α1	0	0	0	0
α2	0	5	6	3
α1, α2	0	0	0	3

Slime molds can find optimal foraging routes through nutrients (and obstacles)

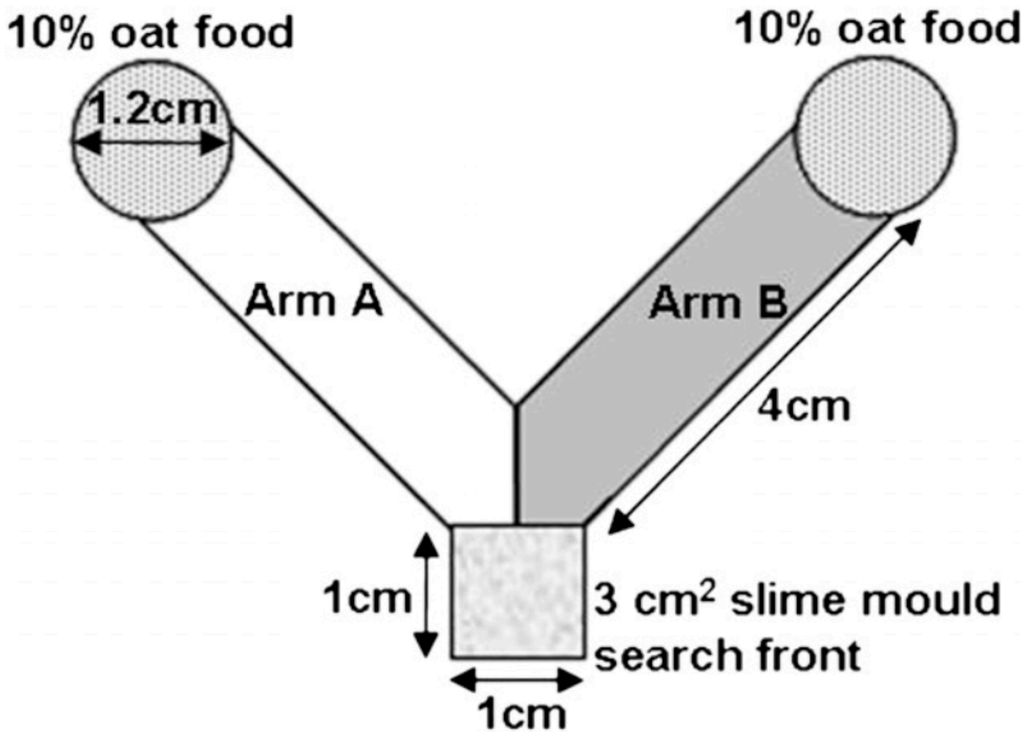
(Nagaki et al. 2000)

Path minimization



(Tero et al. 2010)

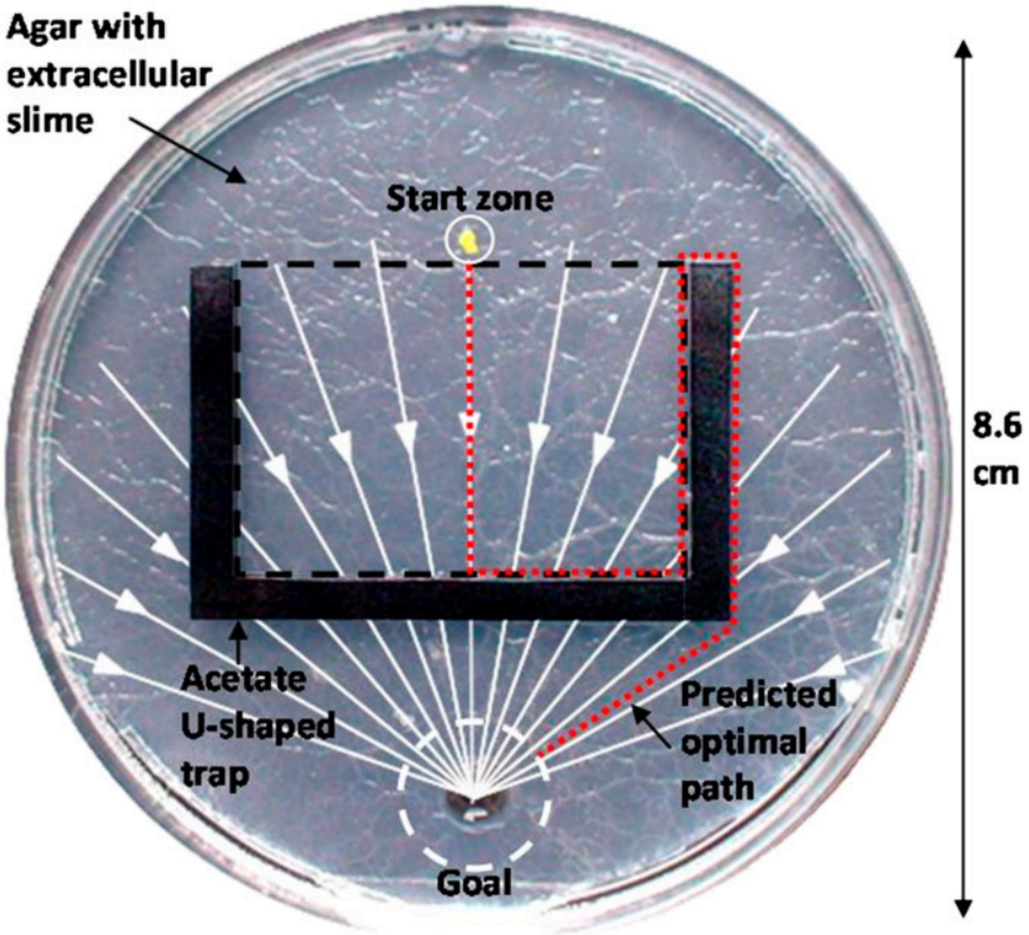
Making choices

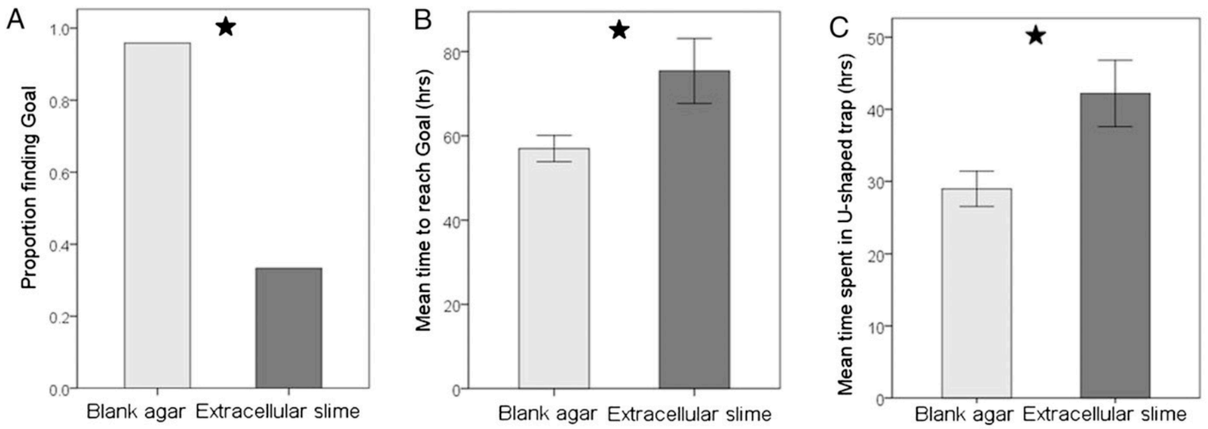


- Arm B contained extracellular slime (naturally secreted by slime molds).
- 39/40 molds chose arm without slime mold.
- Indicates it has been there before.

(Reid et al. 2012)

Spatial memory

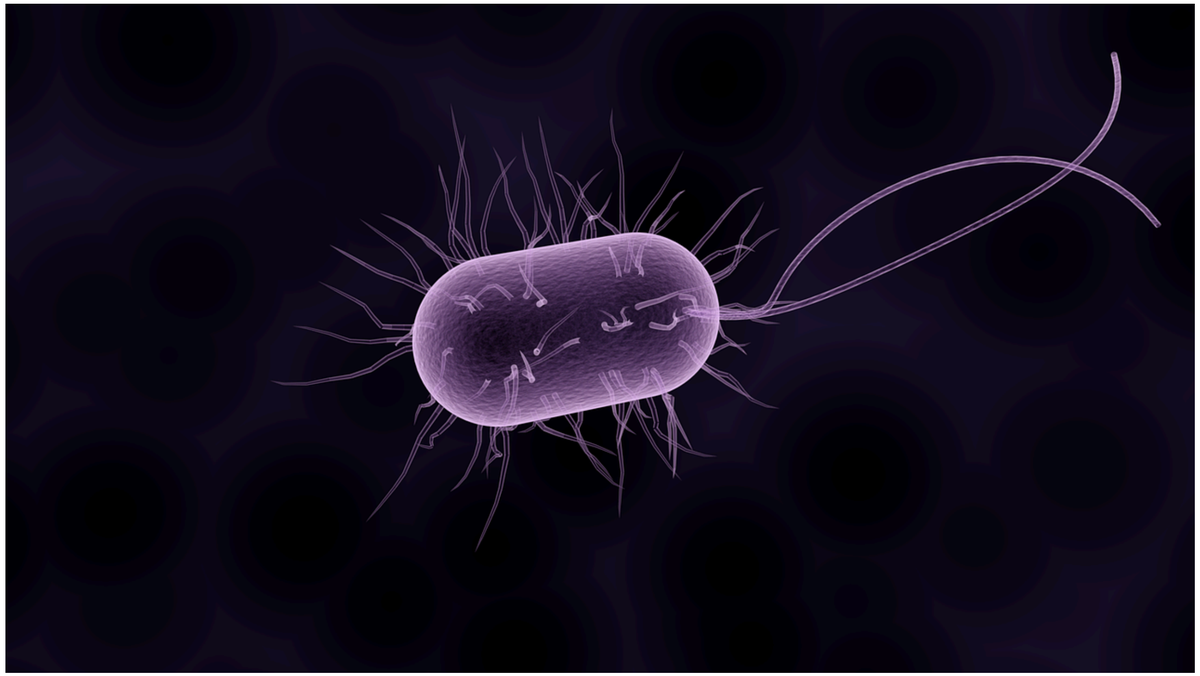


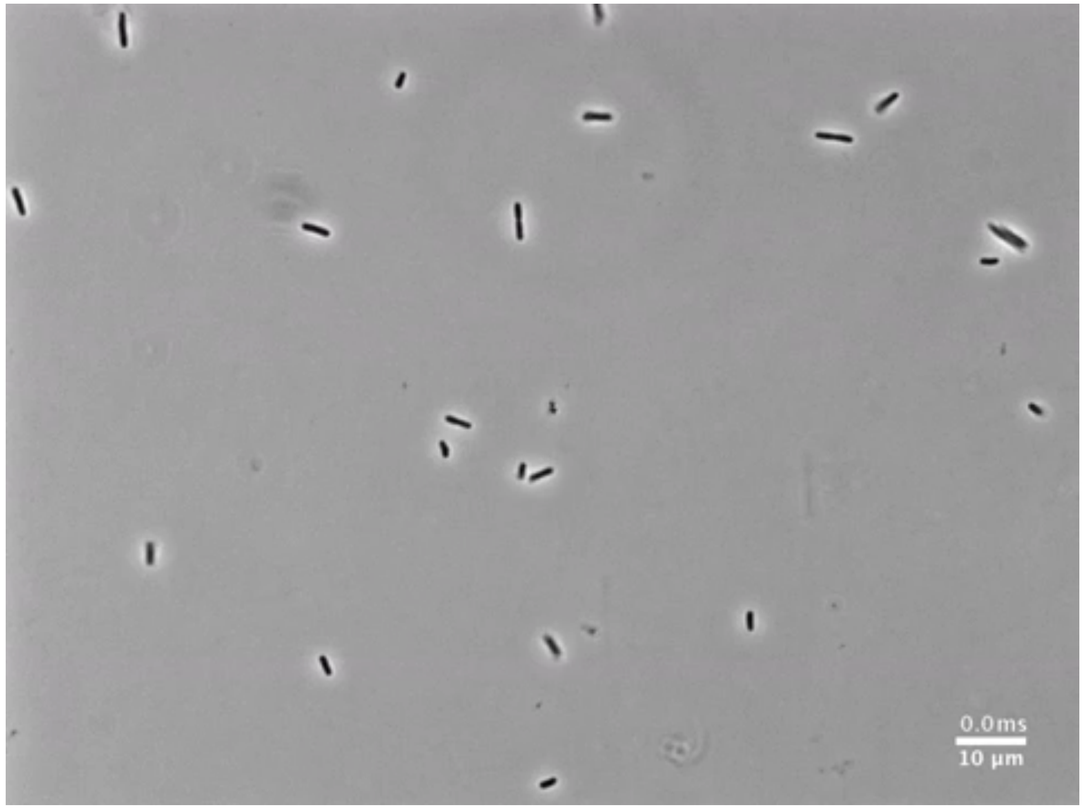


- Presence of extracellular slime impaired slime mold's ability to "solve" the maze.
- Chemical "I've been here" trail.

(Reid et al. 2012)

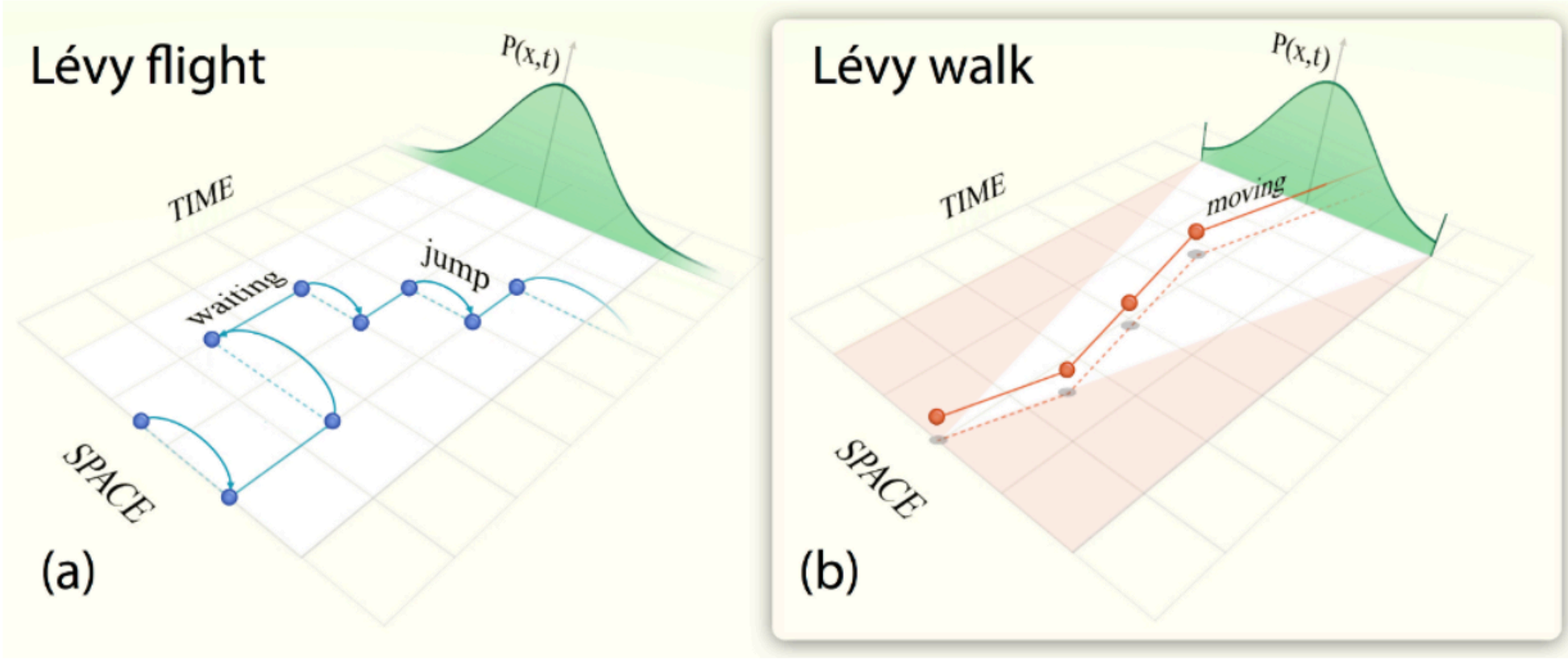
Organism 2: E. Coli





https://www.youtube.com/watch?v=ClDjFTSr4fY

Lévy flights and Lévy walks



(Zaburdaev et al. 2015)

Lévy Walk

Random walk in 2D space

$$\theta_i = v_i 2\pi, \quad v_i \sim N(\mu, \sigma)$$

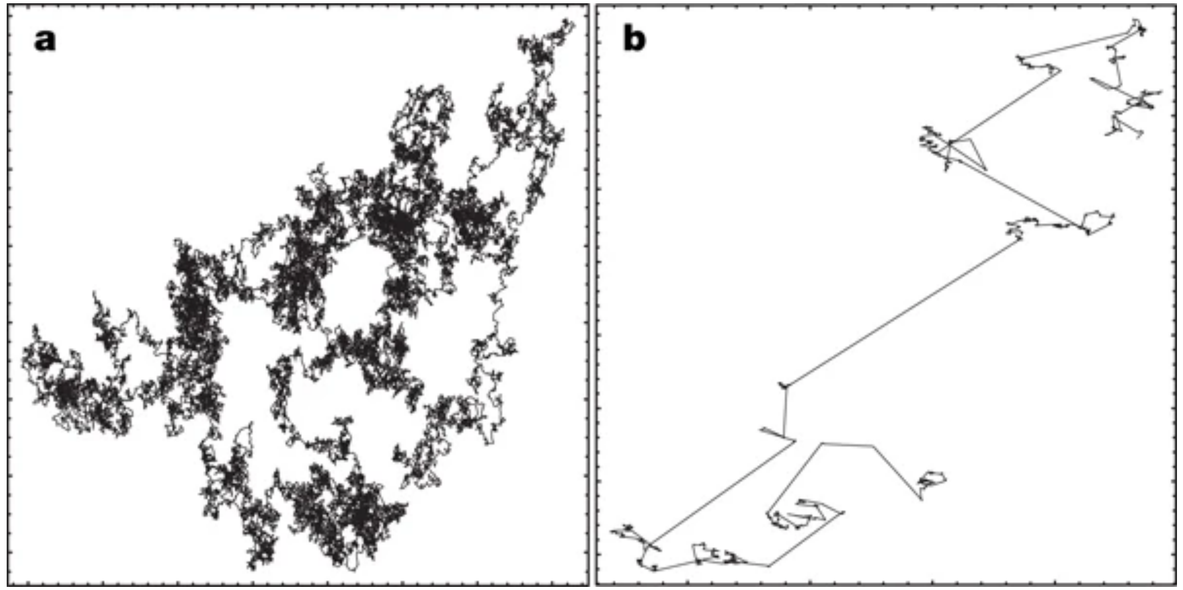
$$\delta_i = u_i^{-\frac{1}{\gamma}}, \quad u_i \sim N(\mu, \sigma)$$

$$x_i = x_{i-1} + \delta_i \cos(\theta_i)$$

$$y_i = y_{i-1} + \delta_i \sin(\theta_i)$$

Brownian motion ($\gamma = 1$)

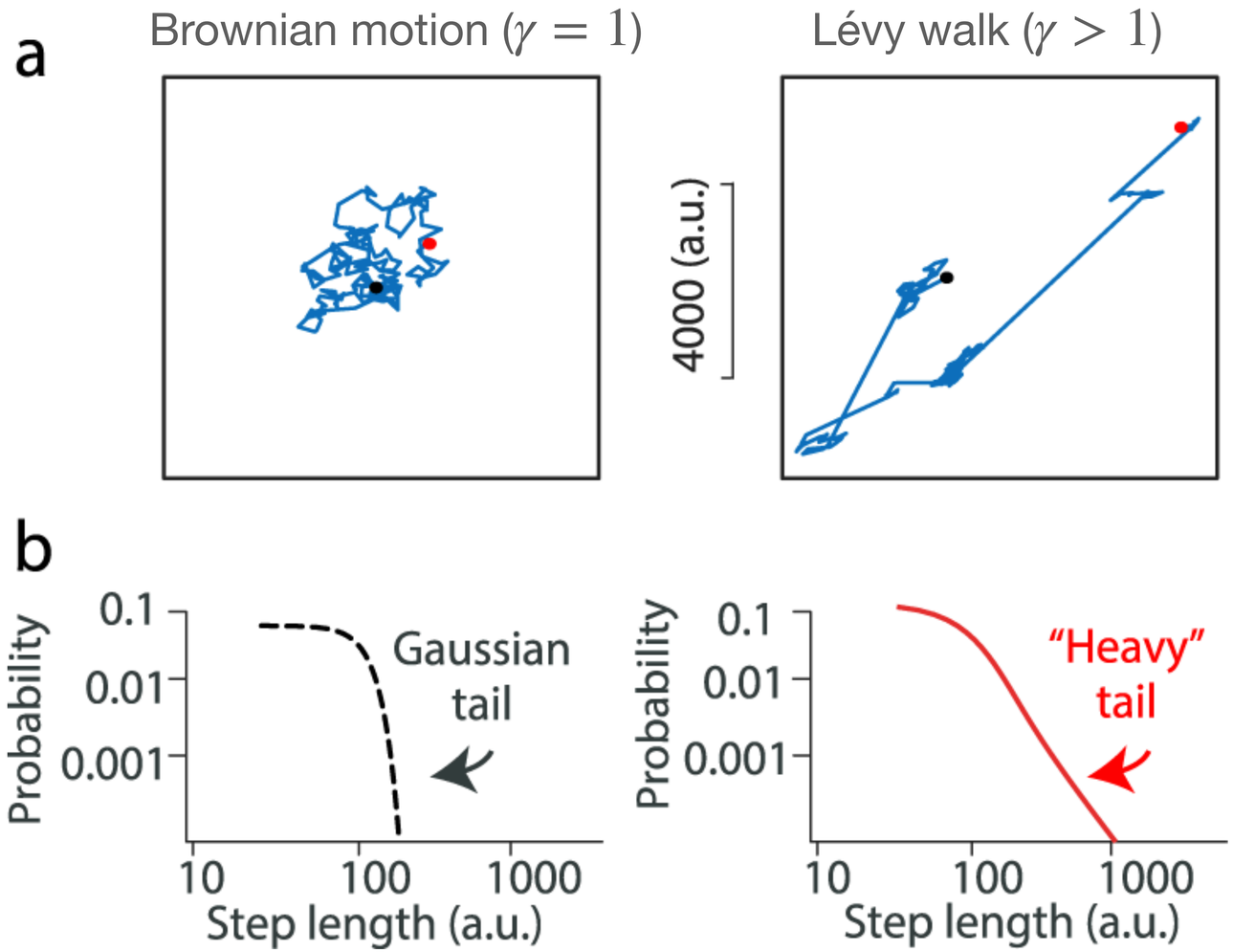
Lévy walk ($\gamma > 1$)



(Barthelemy et al. 2008)

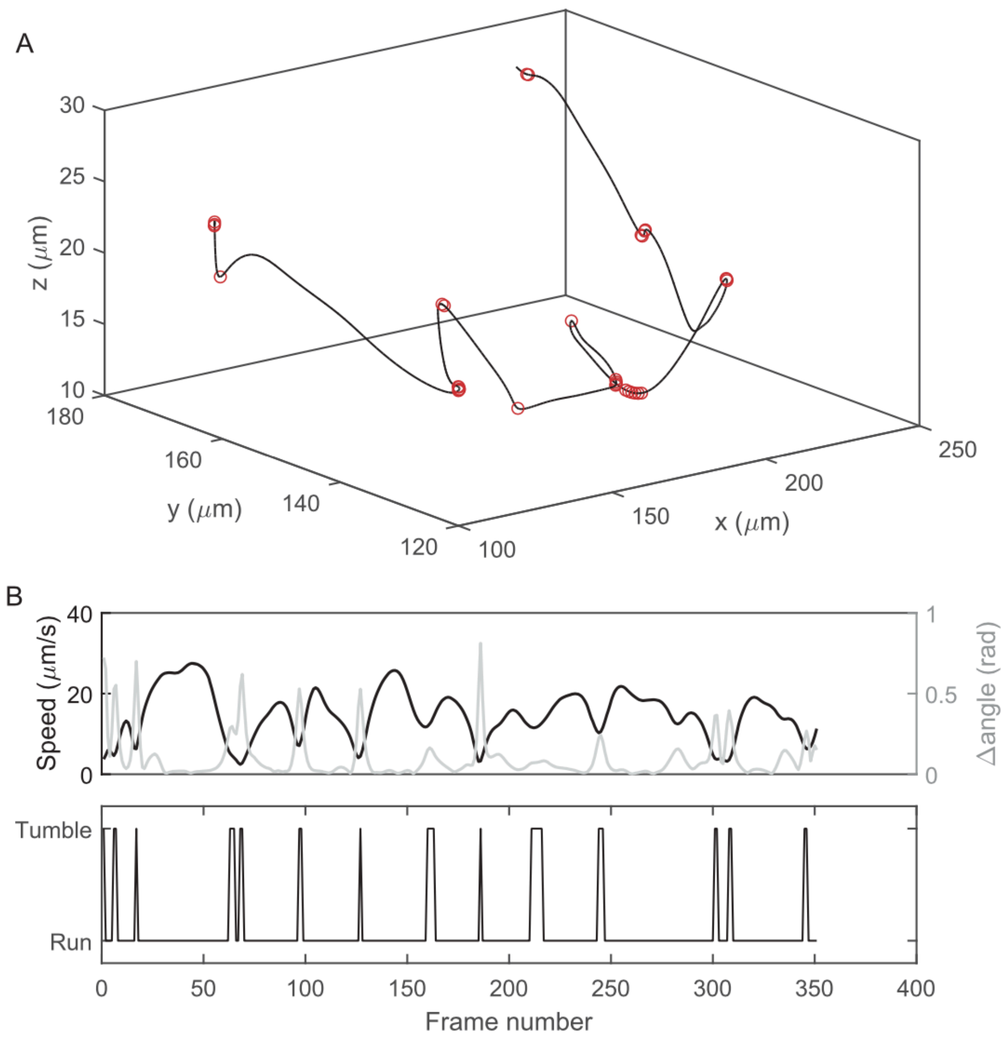
Power Law

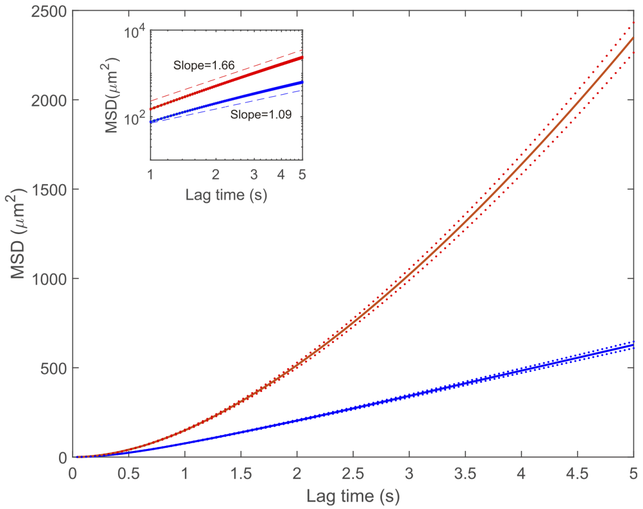
Lévy walks produce probability distributions with “heavy” (aka- long) tails, compared to Brownian motion.

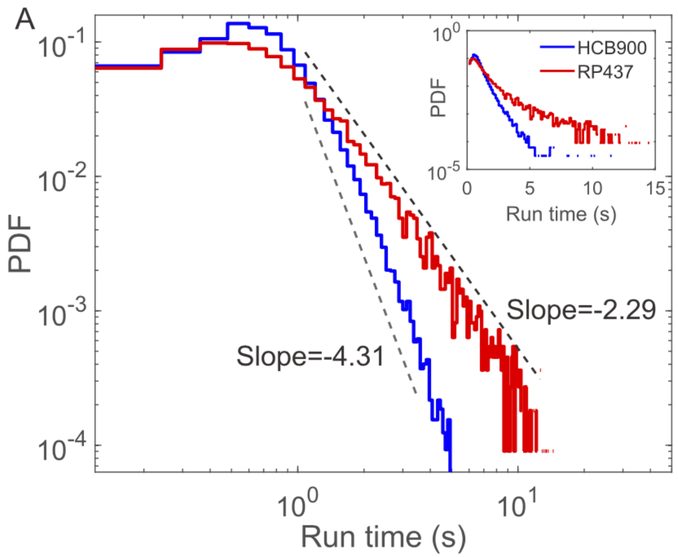


(Liu et al. 2021)

Do *e coli* use Lévy flights to explore?



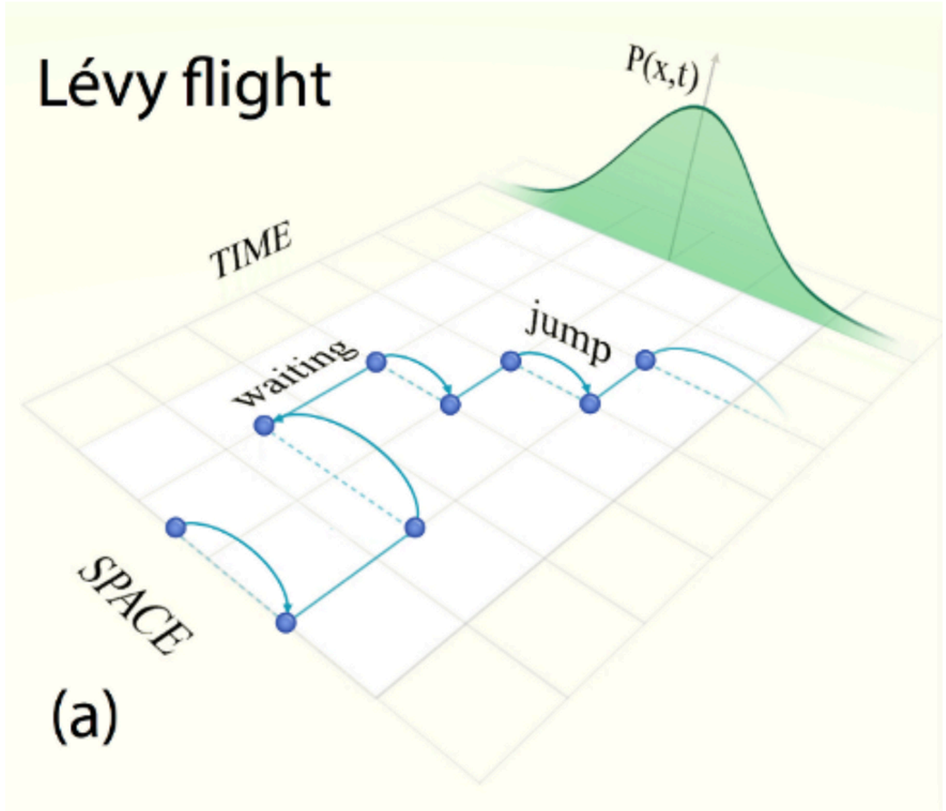


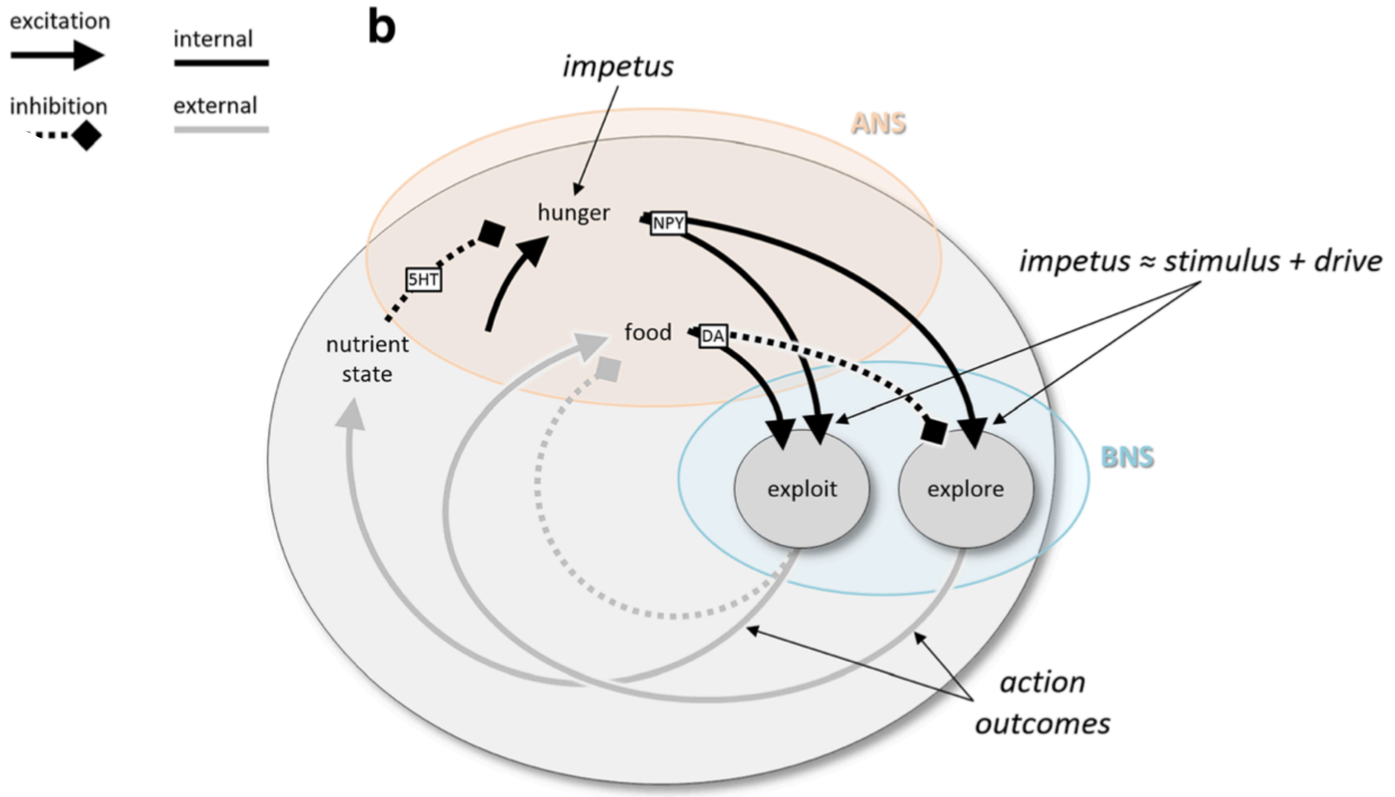


Compared to mutants (HCB900) who lack a critical part of the chemotaxis pathway, wild type *e coli* exhibit super diffusivity in their movements consistent with a Lévy walk process.

(Huo et al. 2021)

Lévy flights as explore-exploit processes





(Cisek 2019)

Things organisms without brains can do

- Use sensory signals as a drive for movement (slime mold, *e. coli*).
- Find optimal (i.e., shortest) paths through the environment (slime mold).
- Use Lévy walks/flights to increase efficiency of random exploration (*e. coli*).

Food for thought

- What “cognitive” abilities are needed to explore like a slime mold? What abilities are needed to explore like an *e. coli* bacteria?
- Does relying on externalized processes (e.g., extracellular slime as a spatial memory) count as cognition?
- If organisms without central nervous systems can effectively forage using Lêvy flight style processes, then what does having a brain buy you? Does this type of exploration really count as “learning?