# *Physarum Computing*

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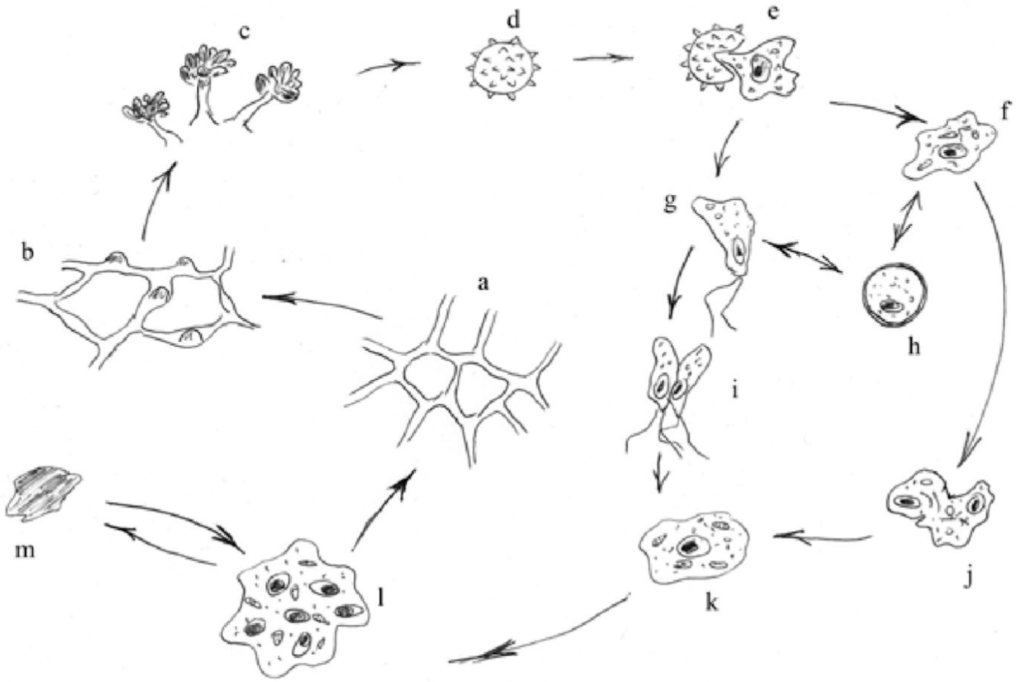
# *Physarum polycephalum*

- Multi-headed slime mold
- Responds to attractants and repellents
  - Attractant: food
  - Repellent: light
- Can survive long periods of time in unfavorable conditions
- Easy to cultivate and dispose of after experiments

Source: [1], Image: https://upload.wikimedia.org/wikipedia/commons/6/6d/Physarum_polycephalum_plasmodium.jpg

# Lifecycle

- Plasmodium (l)
  - Vegetative state
  - When food source is exhausted, moves into phase (a)
- Sclerotium (m)
  - Survival state




Source: [1], Image from [1]

# Plasmodium

- Extends tube-like structures (pseudopodia) over favorable terrain
- When food source is found, plasmodium concentrates on source
- When multiple food sources are found, pseudopodia form an optimized tube connecting sources

Source: [1]

# Plasmodium Foraging


Video: https://www.youtube.com/watch?v=nxqlZjgKqb0

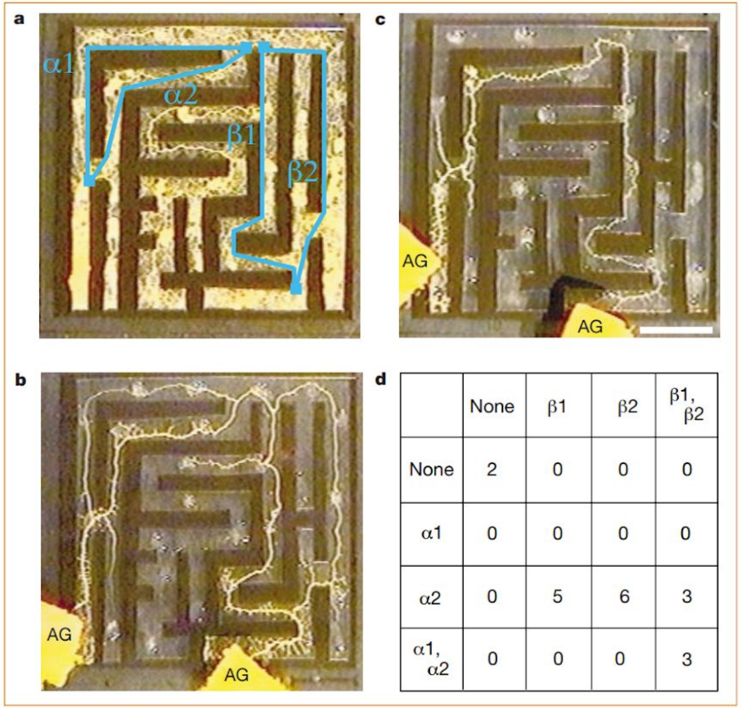
# *Physarum* Computation

- Examples to discuss
  - Shortest path (Nakagaki et al, 2000)
  - AND, OR, NOT gates (Tsuda et al, 2004)
  - Robot controller (Tsuda et al, 2007)
  - Delaunay triangle approximation (Shirikawa et al, 2009)
- Other examples
  - Proximity graphs (Adamatzky, 2008)
  - Spanning trees (Adamatzky, 2007)
  - Primitive memory (Saigusa et al, 2008) and storage modification (Adamatzky, 2007)
  - Spatial logic and process algebra (Adamatzky, 2009)
  - Reversible logic gates (Schumann, 2017) [6]
  - Steiner Tree (Caleffi et al, 2014) [7]
    - This is an NP-hard problem!

Source: [1] unless otherwise noted

# Shortest Path

- Place agar in maze to allow plasmodium to fill maze
- Place oat flakes at ends of maze
- Plasmodium will propagate to the two food sources
- Thin tube connecting the two sources will remain
    - Thin tube contains the shortest path through the maze!



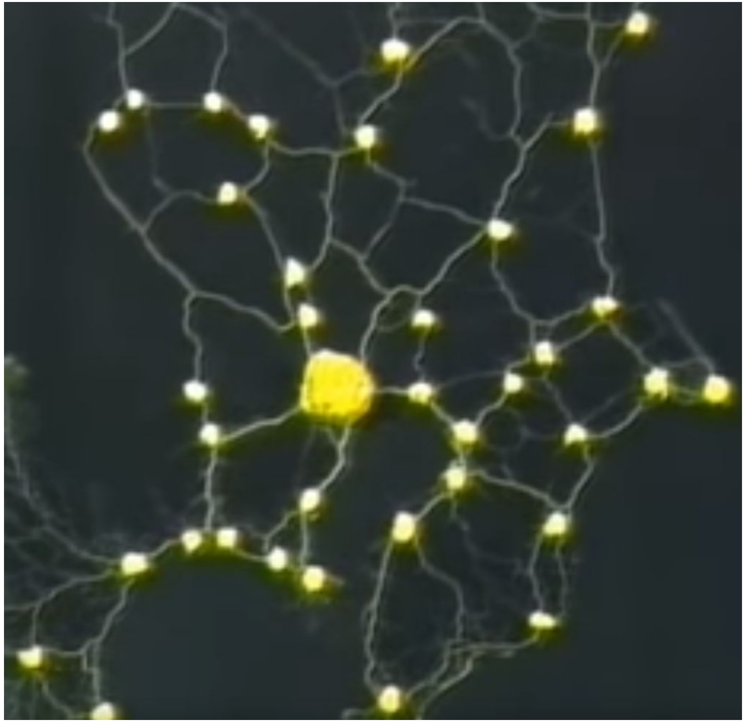

| | None | β1 | β2 | β1, β2 |
|---|---|---|---|---|
| None | 2 | 0 | 0 | 0 |
| α1 | 0 | 0 | 0 | 0 |
| α2 | 0 | 5 | 6 | 3 |
| α1, α2 | 0 | 0 | 0 | 3 |

Source: [2], Image from [2]

# Shortest Path


Video: https://www.youtube.com/watch?v=czk4xgdhdY4

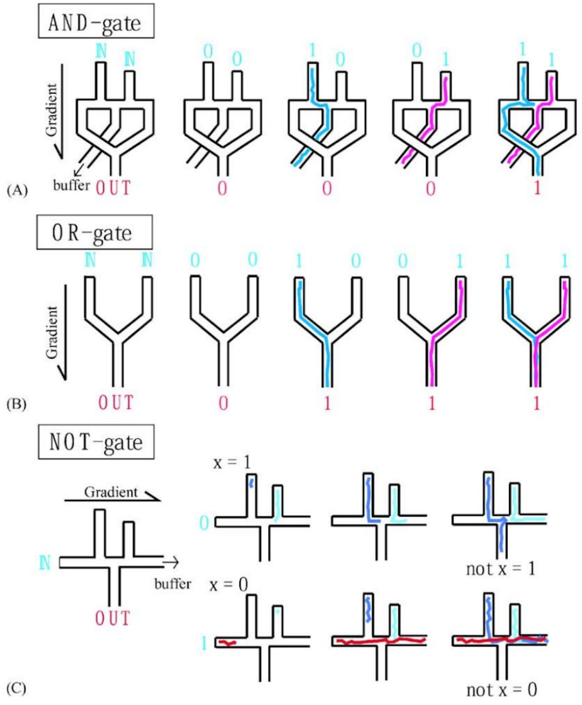
# Shortest Path 2: Tokyo Drift



Video: https://www.youtube.com/watch?v=GwKuFREOgmo

# Logic Gates

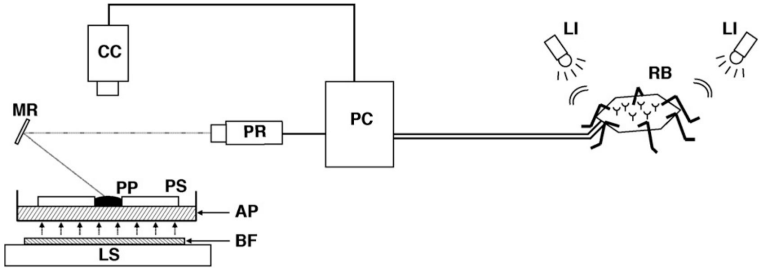
- Gradient contains attractant for plasmodium
- Plasmodium are repelled by other plasmodium
- Important note: the behaviors shown in the image are not guaranteed
    - AND and NOT gates had non-zero failure rate




Source: [3], Image from [3]

# Robot Controller

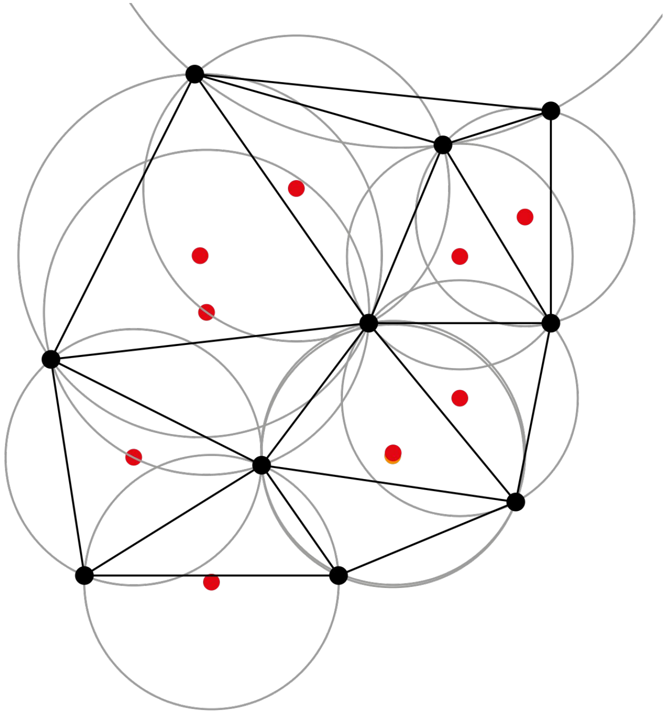
- Conventional robotic systems have difficulty responding to dynamic environments
- Biological organisms can easily respond to such conditions
- Use plasmodium as controller for robot
  - Robot receives and sends light to the plasmodium
  - Plasmodium response used as control for robot's movement




Source: [4], Images from [4]

# Delaunay triangulation

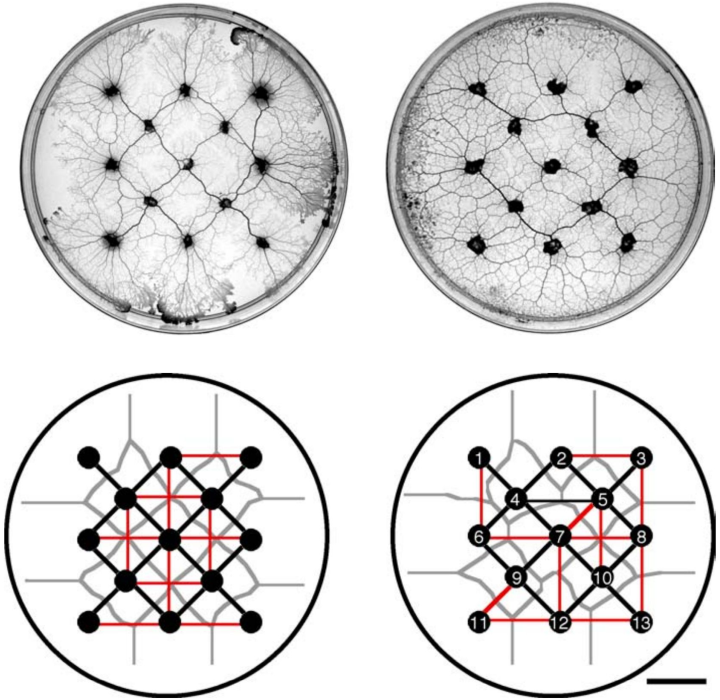
- Given a set *P* of points (black points in image), provide a set of triangles such that no point is inside of any triangle's circumcircle
    - Red points correspond to centers of circumcircles, connecting these produces a Voronoi tesselation
    - Circumcircles are shown in gray
- Useful in graphics for generating triangle meshes



Source: [5], Image: https://upload.wikimedia.org/wikipedia/commons/thumb/1/1f/Delaunay_circumcircles_centers.svg/1280px-Delaunay_circumcircles_centers.svg.png

# Delaunay triangulation

- Similar process to shortest path
- Point set to triangulate are the food sources
- Red lines correspond to lines in the perfect triangulation that are not in the computed approximation




Source: [5], Image from [5]

# Limitations

- Solutions to problems are generally *approximate*
    - Logic gates operated correctly only 76% of time
    - General-purpose, high-precision computation is not possible under these circumstances
- Computation is significantly slower than conventional computing
    - At the same time, it doesn't require power to operate

Source: [3]

# Conclusion

- *Physarum polycephalum* demonstrates complex foraging/migration behaviors
- These behaviors can be leveraged to perform computation
- Examples have demonstrated the feasibility of this approach for common problems such as shortest path, logic gate implementation, and triangulation
- Perhaps an extreme version of low-power electronics!

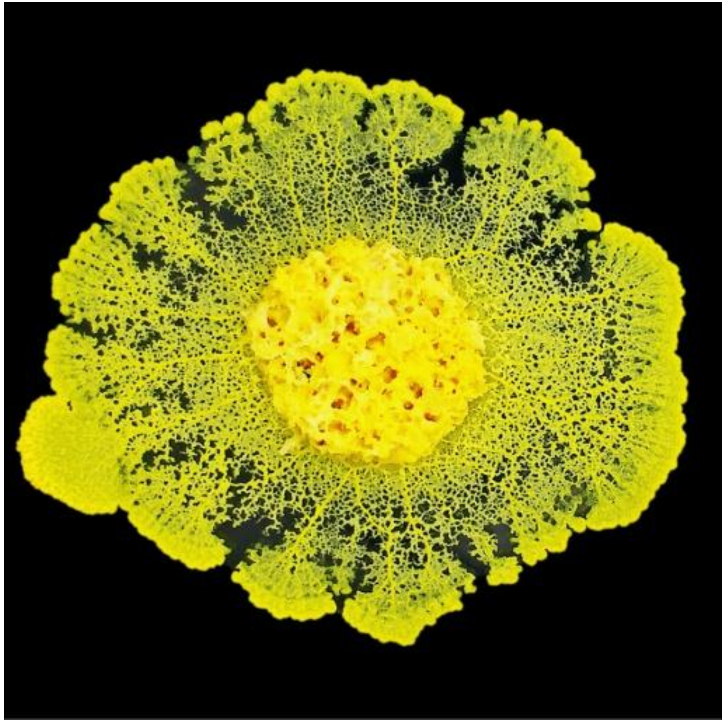


Image: https://3c1703fe8d.site.internapcdn.net/newman/gfx/news/hires/2016/ahandoutpict.jpg

# References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6. Schumann, Andrew. "Conventional and unconventional reversible logic gates on Physarum polycephalum." *International Journal of Parallel, Emergent and Distributed Systems* 32.2 (2017): 218-231.
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