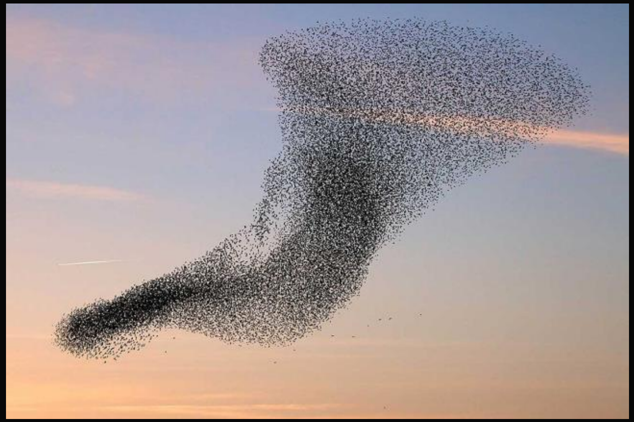
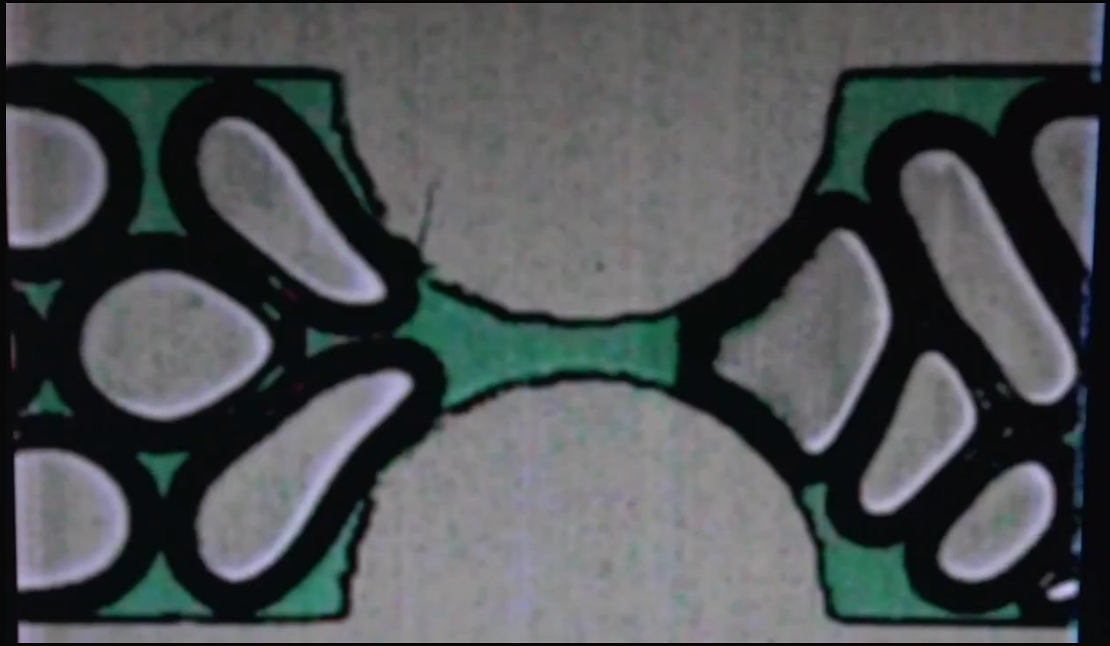
Computer modeling of physical phenomena



12-13.03.2024

Lecture III:
Things in motion

Sheep vs droplets

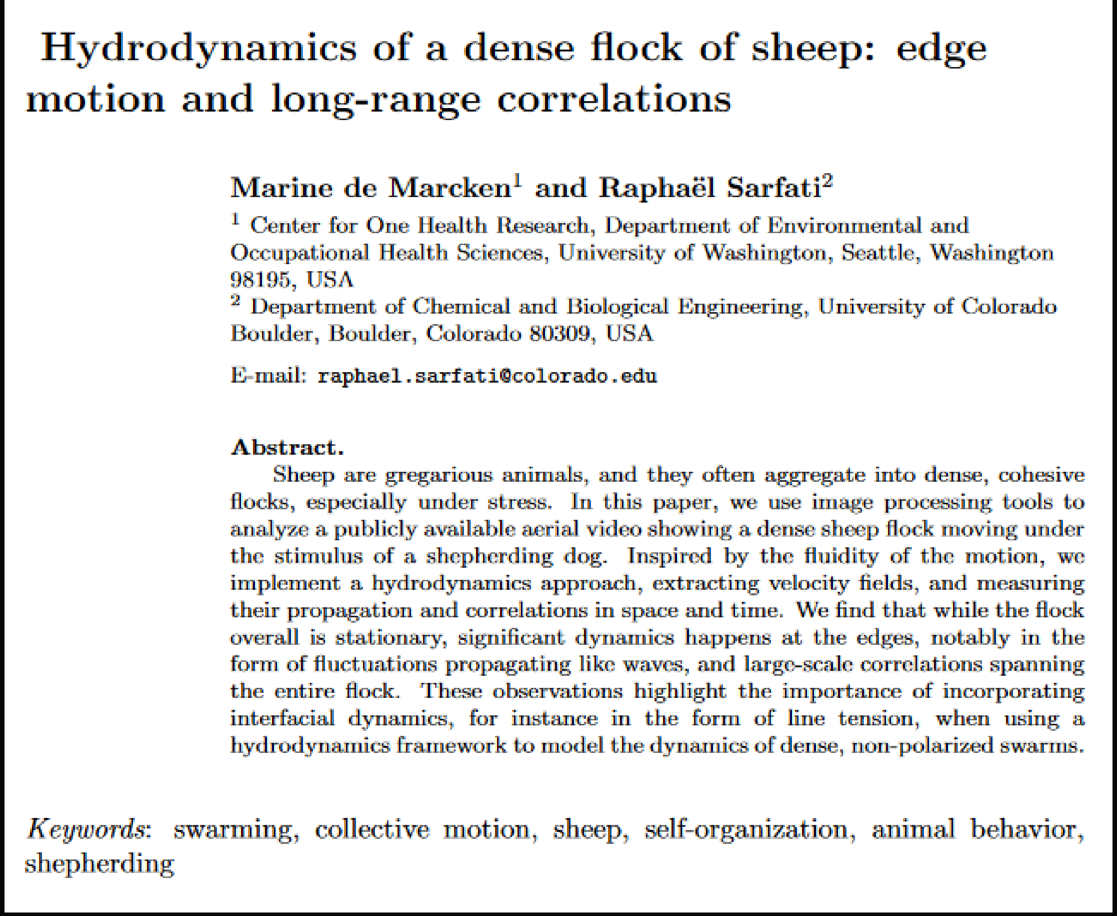


A fundamental question

Can the collective motion of a large number of macroscopic objects (herd of sheep, swarm of insects, crowd of people) be described in terms of simple interactions between these entities?

Physics of sheep?

Physics of sheep



Hydrodynamics of a dense flock of sheep: edge motion and long-range correlations

Marine de Marcken[1] and Raphaël Sarfati[2]

[1] Center for One Health Research, Department of Environmental and Occupational Health Sciences, University of Washington, Seattle, Washington 98195, USA

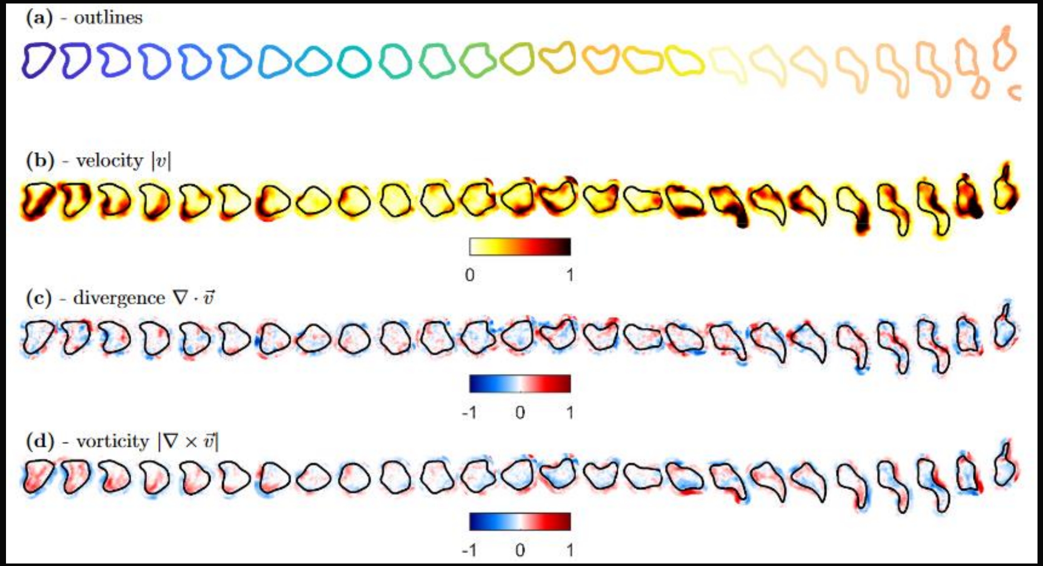
[2] Department of Chemical and Biological Engineering, University of Colorado Boulder, Boulder, Colorado 80309, USA

E-mail: `raphael.sarfati@colorado.edu`

Abstract.

Sheep are gregarious animals, and they often aggregate into dense, cohesive flocks, especially under stress. In this paper, we use image processing tools to analyze a publicly available aerial video showing a dense sheep flock moving under the stimulus of a shepherding dog. Inspired by the fluidity of the motion, we implement a hydrodynamics approach, extracting velocity fields, and measuring their propagation and correlations in space and time. We find that while the flock overall is stationary, significant dynamics happens at the edges, notably in the form of fluctuations propagating like waves, and large-scale correlations spanning the entire flock. These observations highlight the importance of incorporating interfacial dynamics, for instance in the form of line tension, when using a hydrodynamics framework to model the dynamics of dense, non-polarized swarms.

Keywords: swarming, collective motion, sheep, self-organization, animal behavior, shepherding

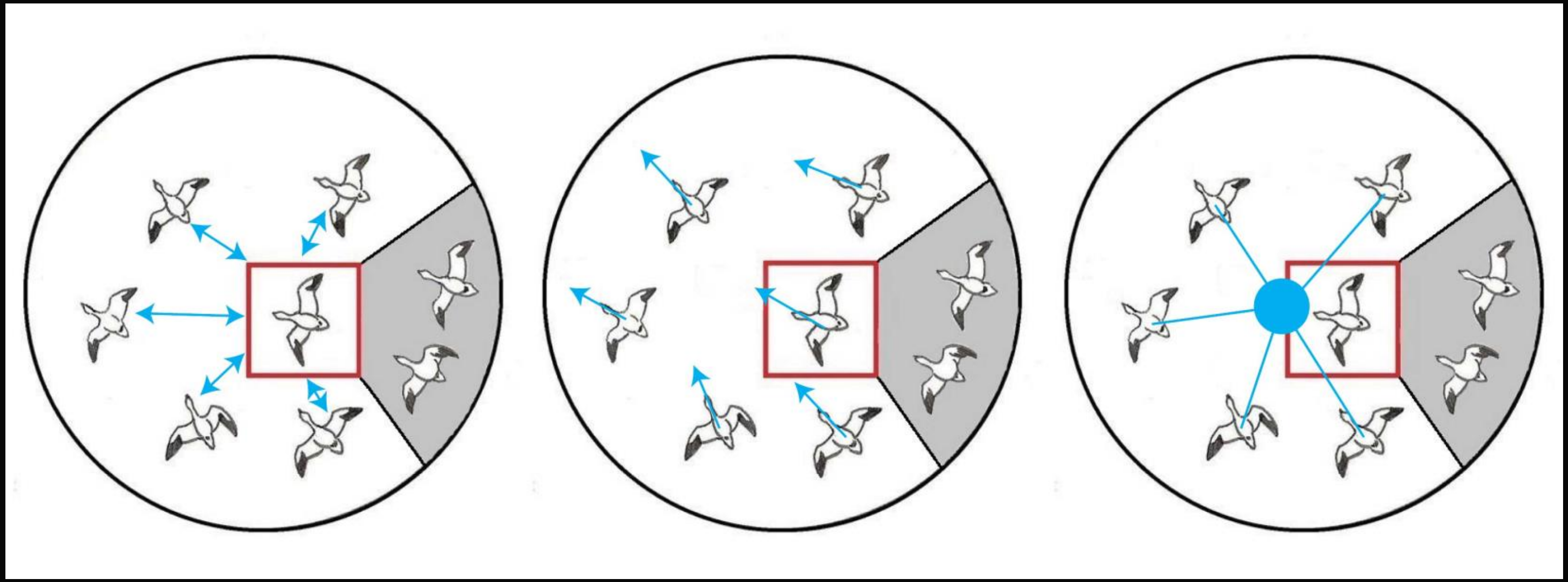


Herds, swarms, flocks, schools...

http://www.hintsandthings.co.uk/kennel/collectives.htm

Starlings

Reynolds model

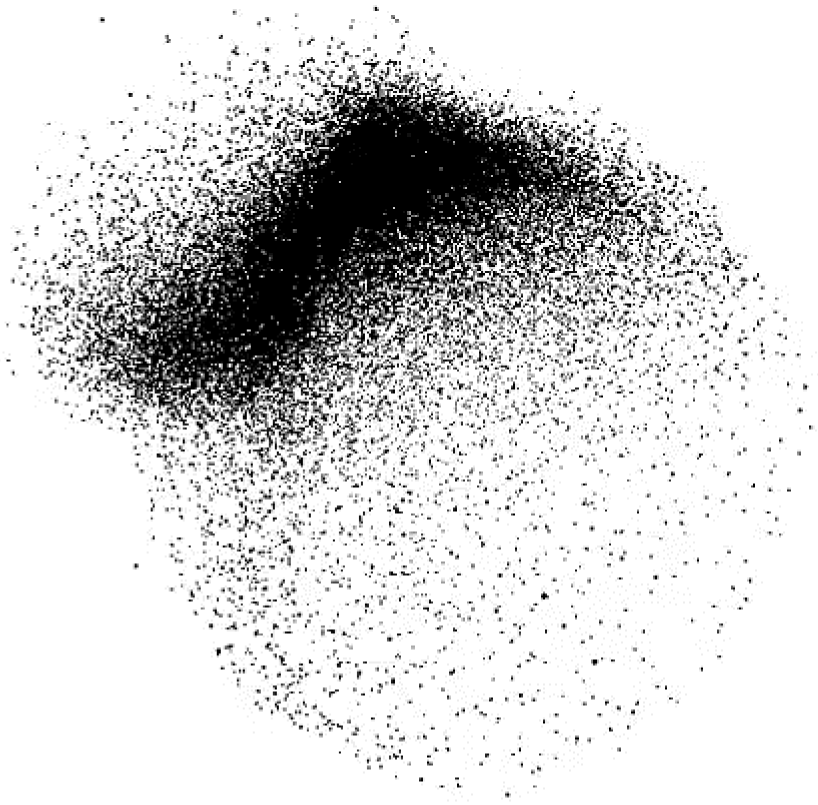


1) Separation: Move to avoid crowding local flockmates.

2) Alignment: Match orientation and velocity of the neighbours.

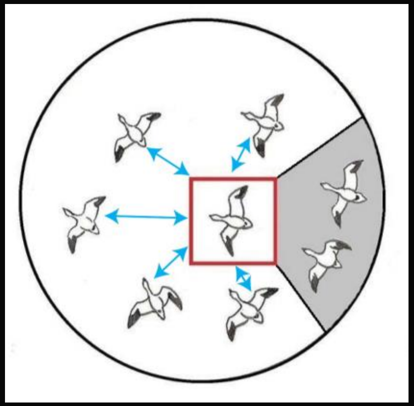
3) Cohesion: Move towards the average position of the neighbours.

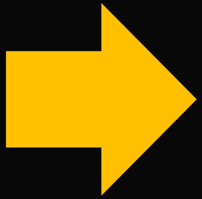
C. W. Reynolds. Flocks, herds, and schools: A distributed behavioral model, *Computer Graphics*, 25, 1987



Self-organization of the flock

- the flock behaves like a living creature, with structures or waves appearing within it on the scale of tens or even hundreds of meters
- individual starlings interact with their local flockmates only and follow simple rules





Applications

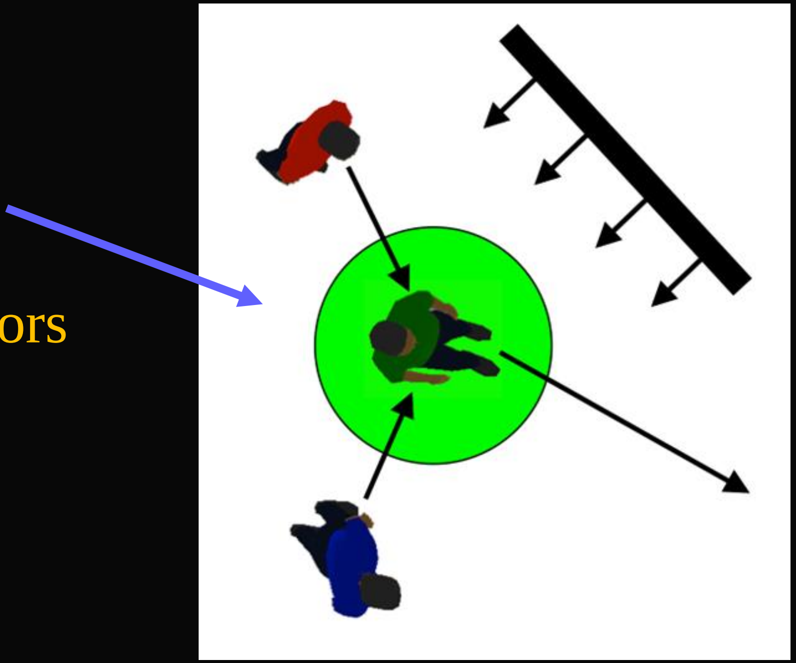
Applications

Pedestrian motion

Lane formation

The model

external factors
(fire etc.)



interaction with obstacles
(repulsion)

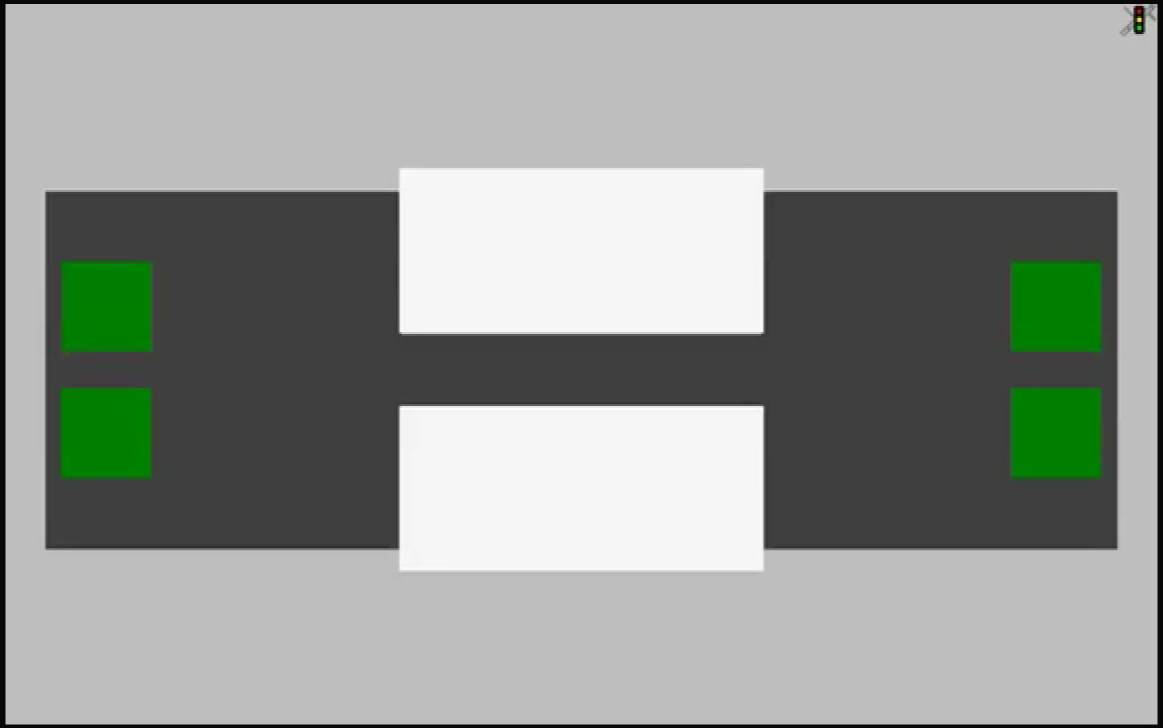
attraction towards the target

interaction with other pedestrians
(repulsion)

+ random fluctuation

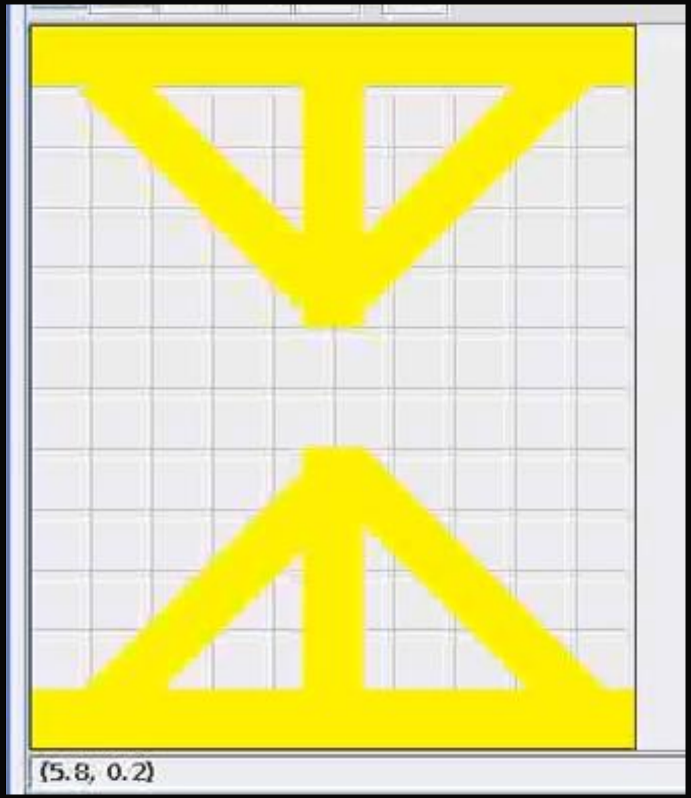
Pedestrians navigate the obstacles (including other pedestrians) while trying to get to the target as fast as possible.

Lane formation



The motion self-organizes – the emerging mode of traffic is more effective than the random mode.

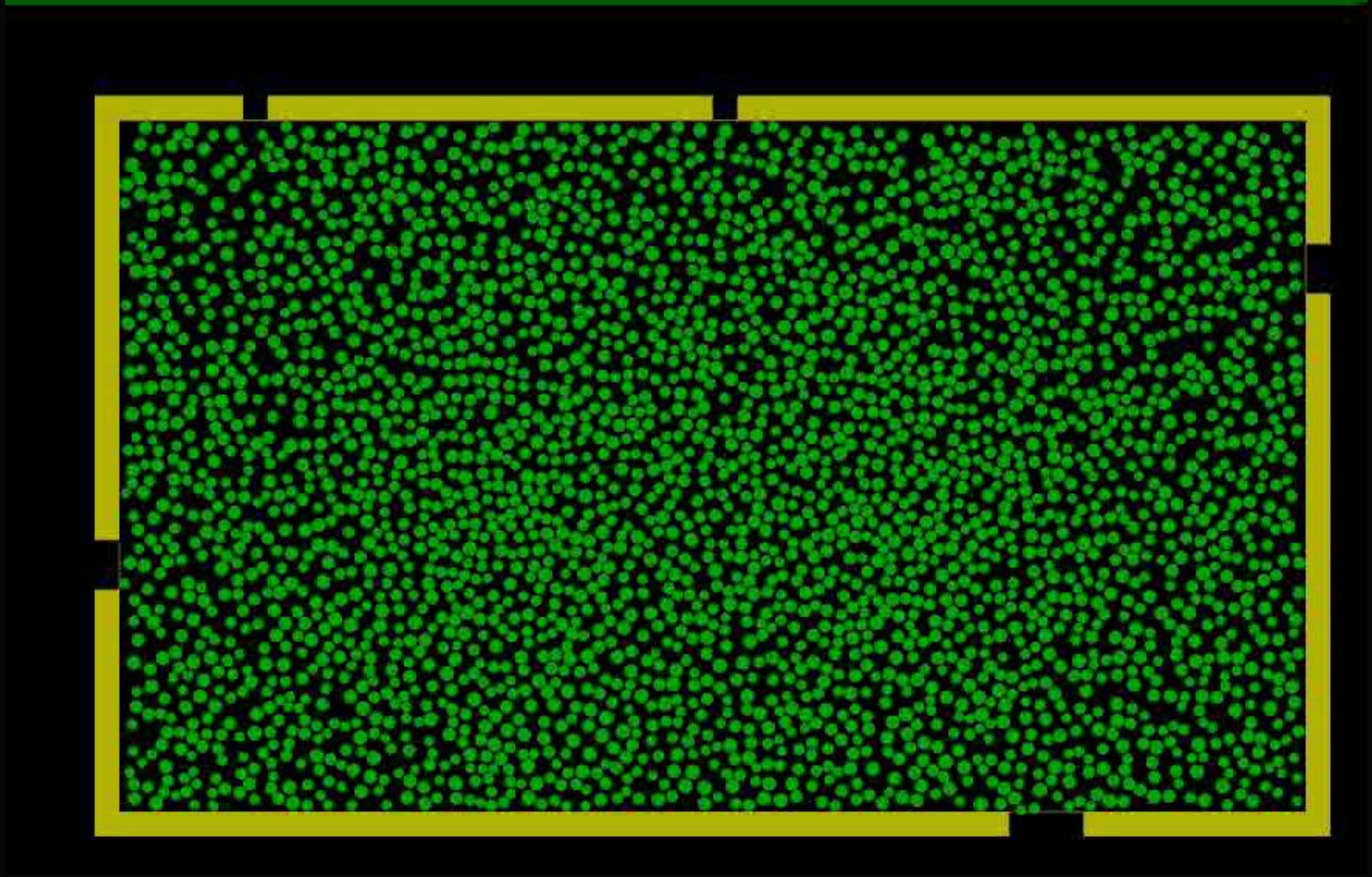
The door problem



Again self-organization – first one side, then the other. Leader paves the way for the others, who are following him.

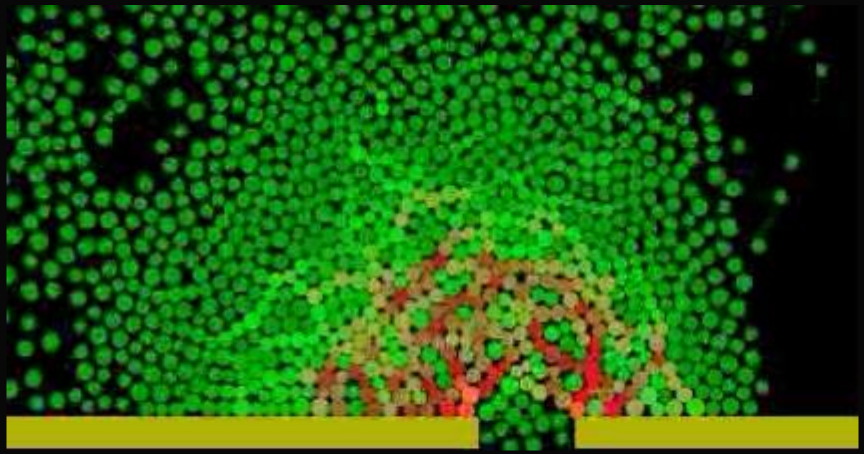
Panic

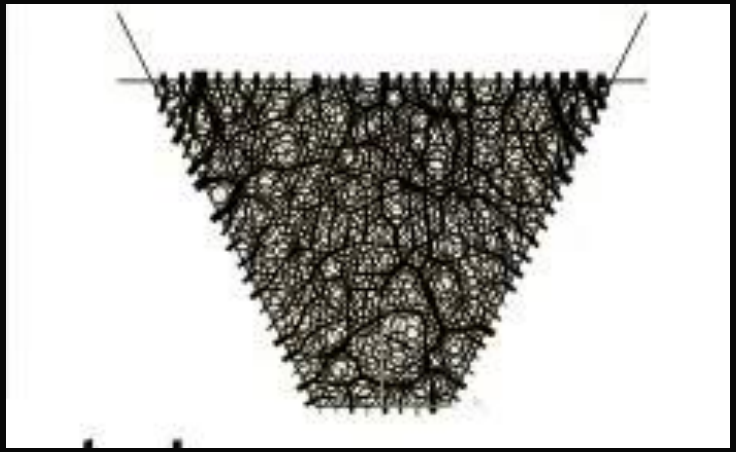
Panic



Helbing, D., Farkas, I., & Vicsek, T. (2000). Simulating dynamical features of escape panic. *Nature*, *407*(6803), 487.

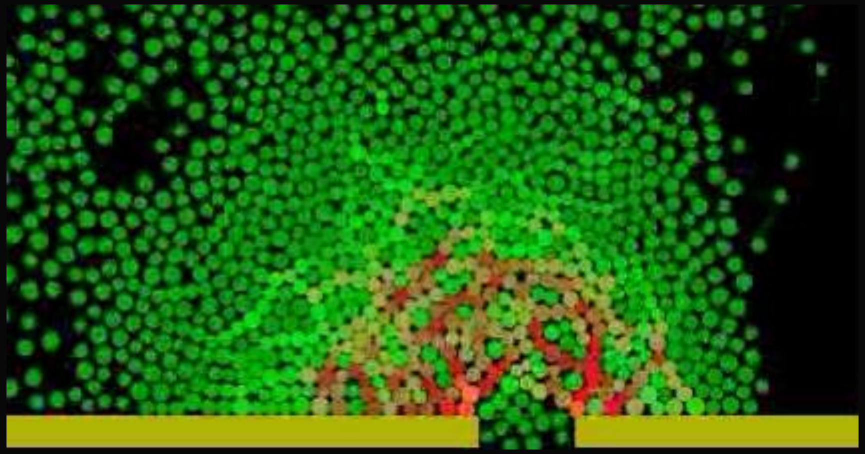
Force chains





similar to stuck salt shaker…

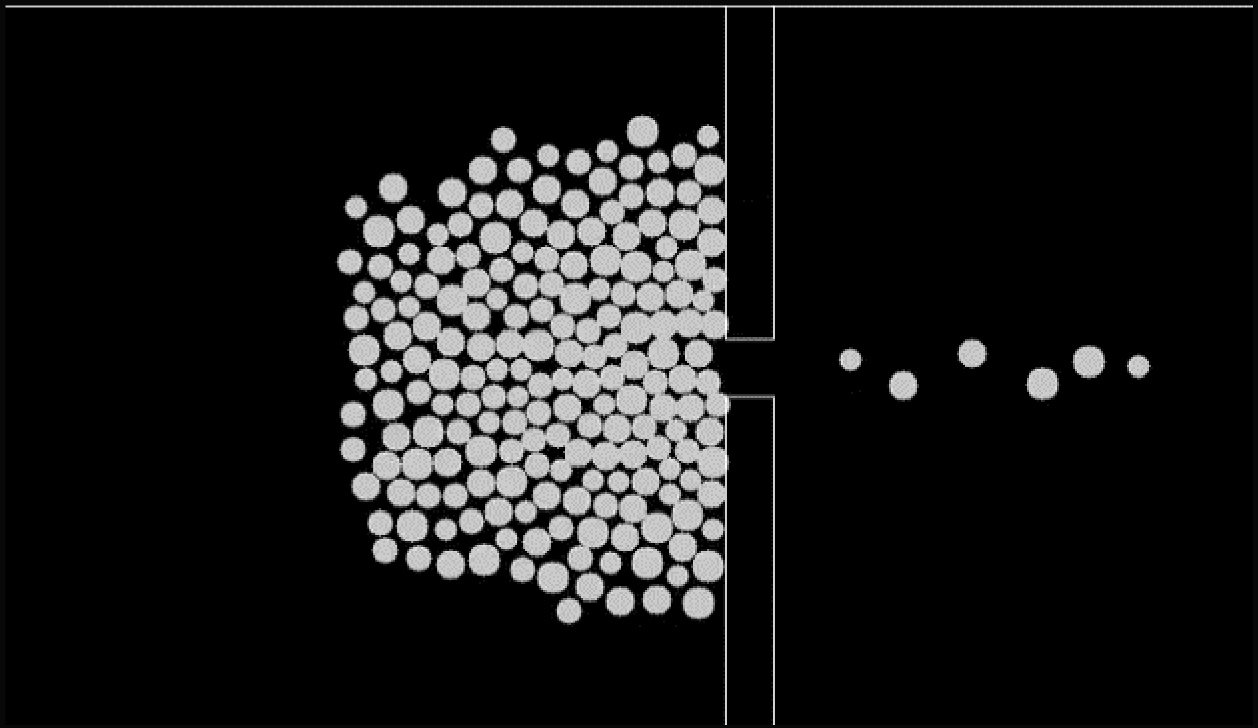
Human crystals



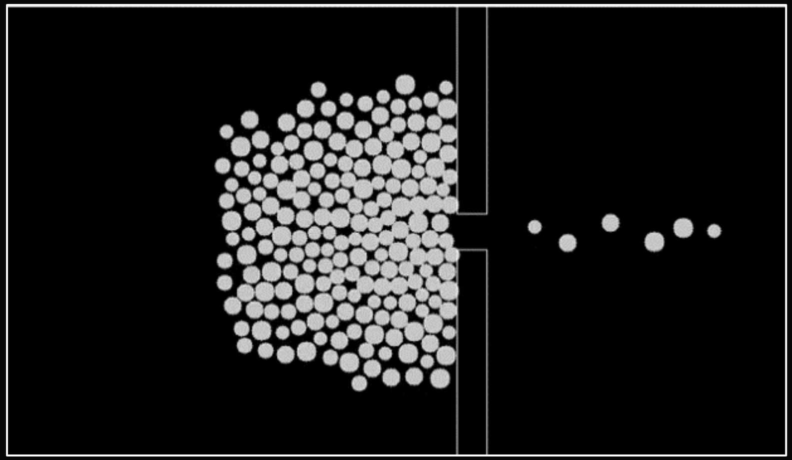
In a dense crowd, people mutually block themselves, the exit jams.

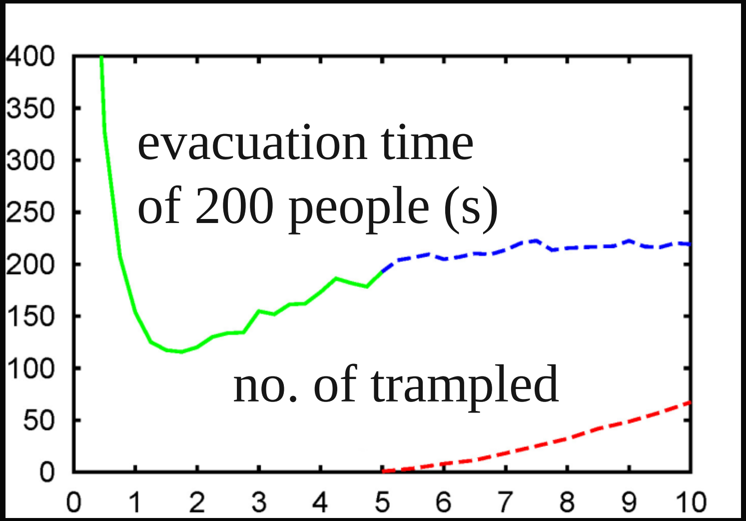
Again self-organization, this time harmful.

Panic once again



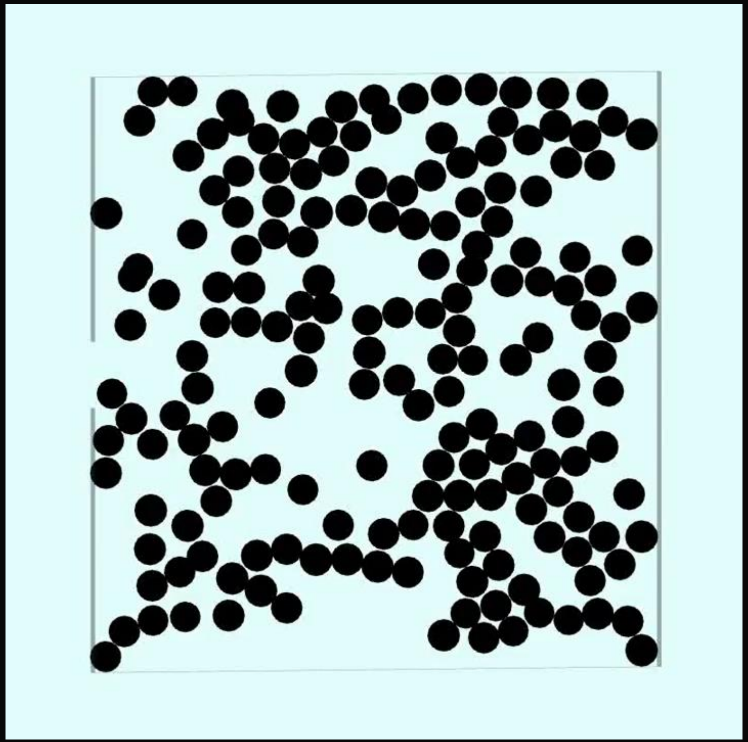
The faster you go, the longer it takes

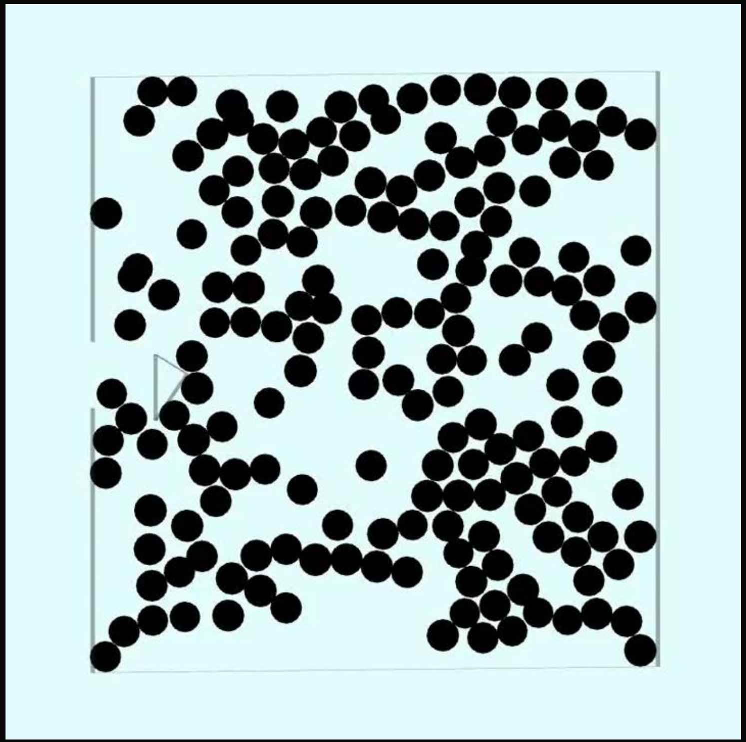




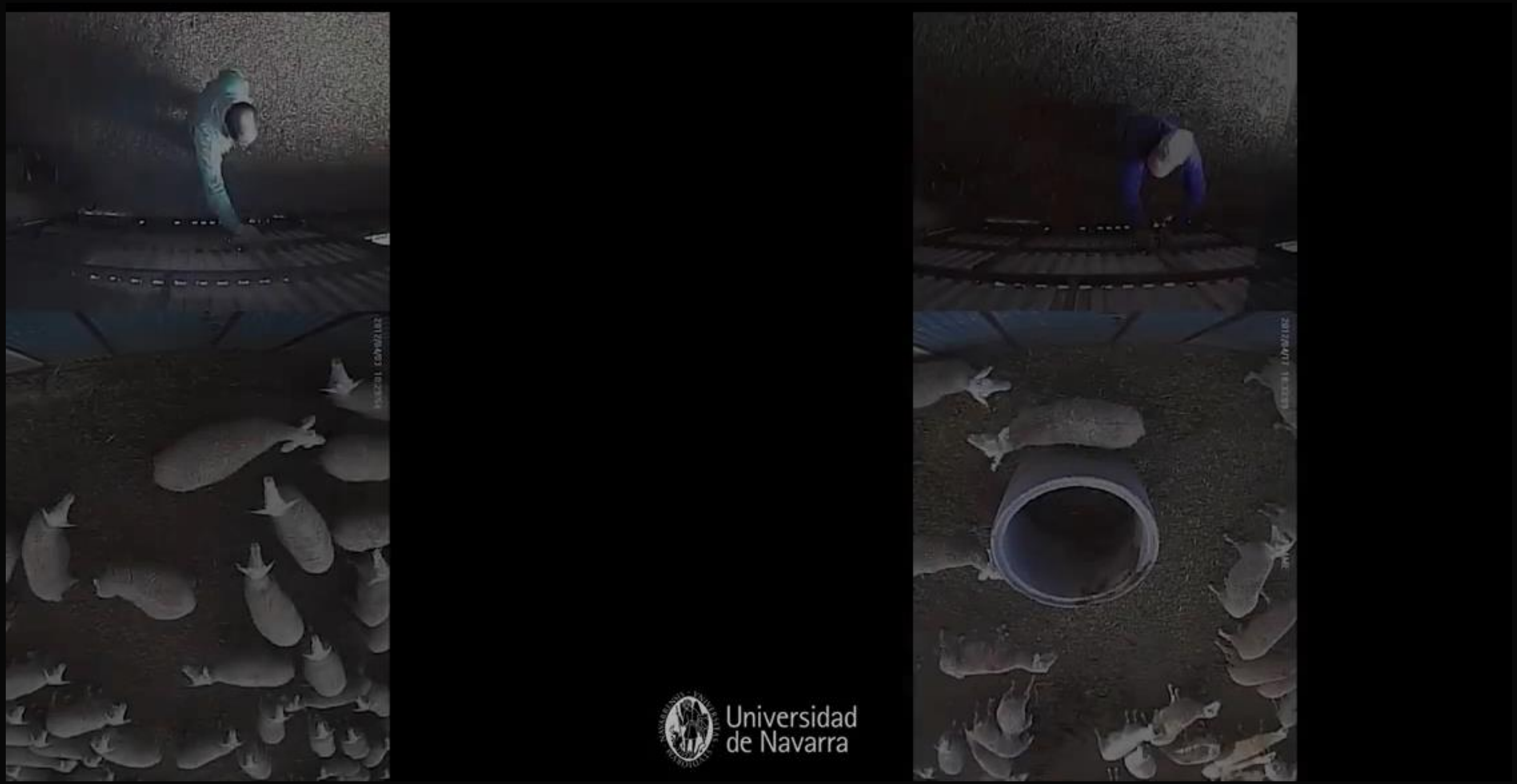
escape speed (m/s)

An obstacle helps

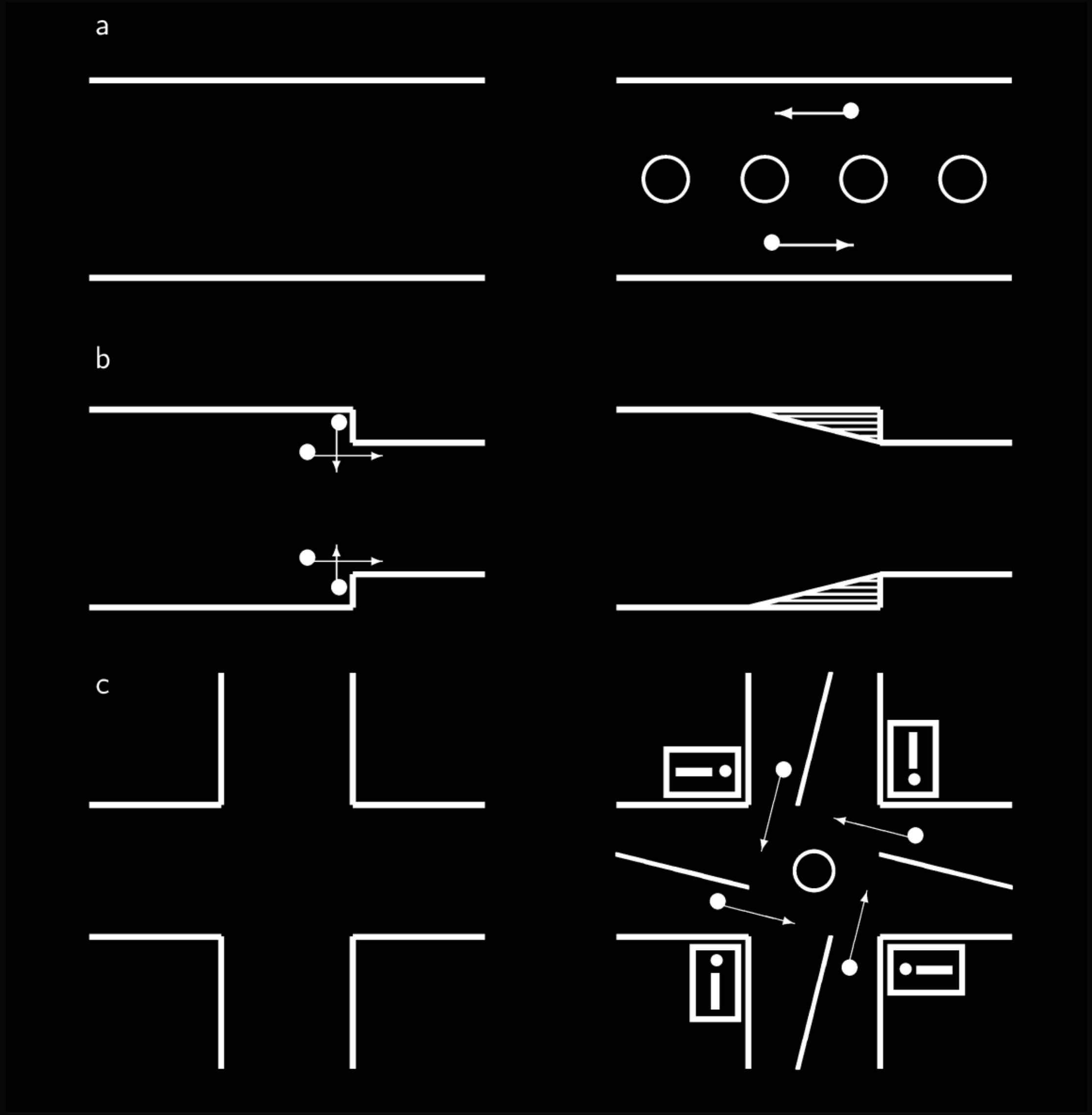




Same with sheep…

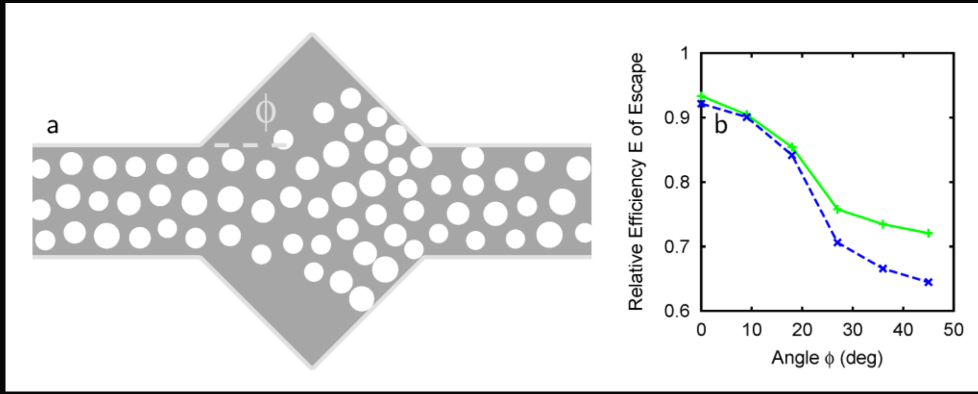


Some other hints



Some other hints (2)

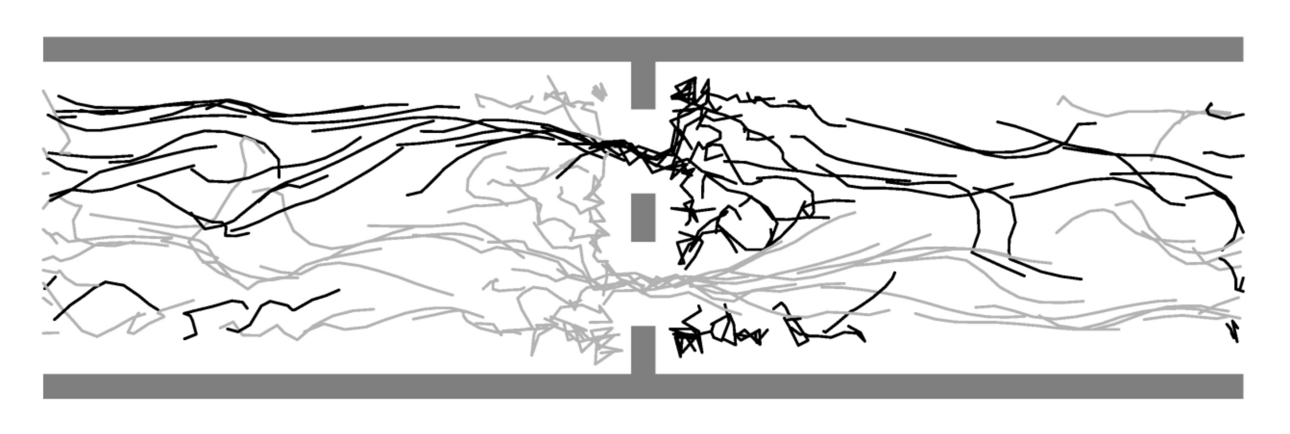
treacherous corridor widenings:

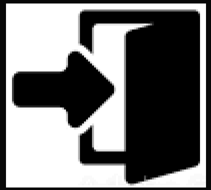


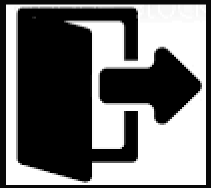
columns in passages:

Some other hints (3)

double door:







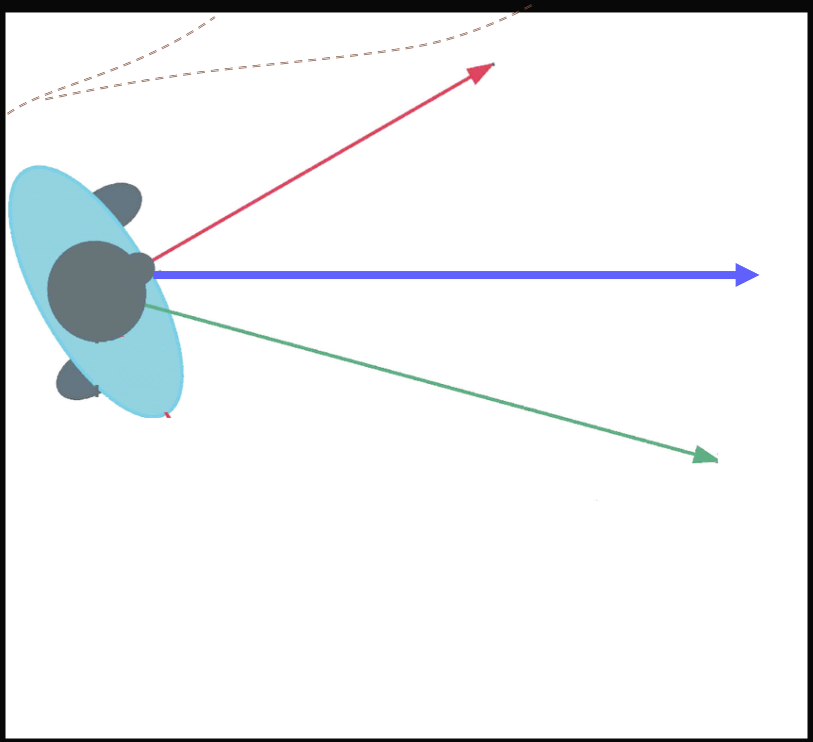
Paths people take…

Use or block?

Treading dynamics

Helbing, D., Keltsch, J. and **Molnár**, P. (1997) Modeling the evolution of human **trail** systems. Nature 388,47–50.

Model



attraction towards well-trodden path

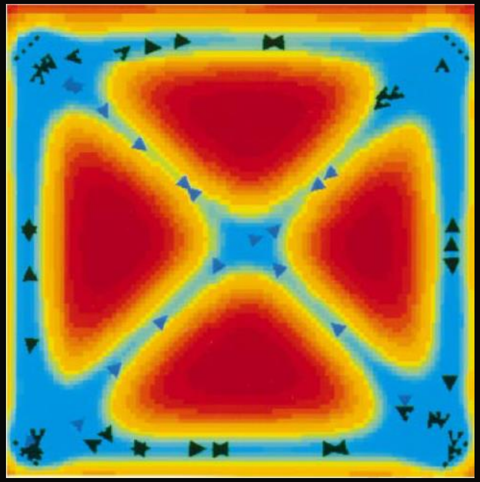
net force

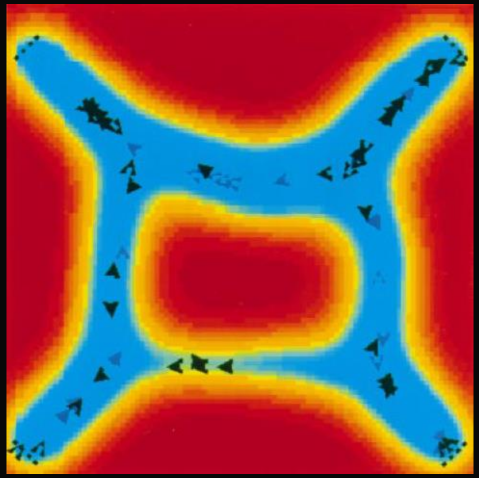
attraction to the destination

+ random fluctuations

Additionally, by treading the path we are making it more attractive for the others.

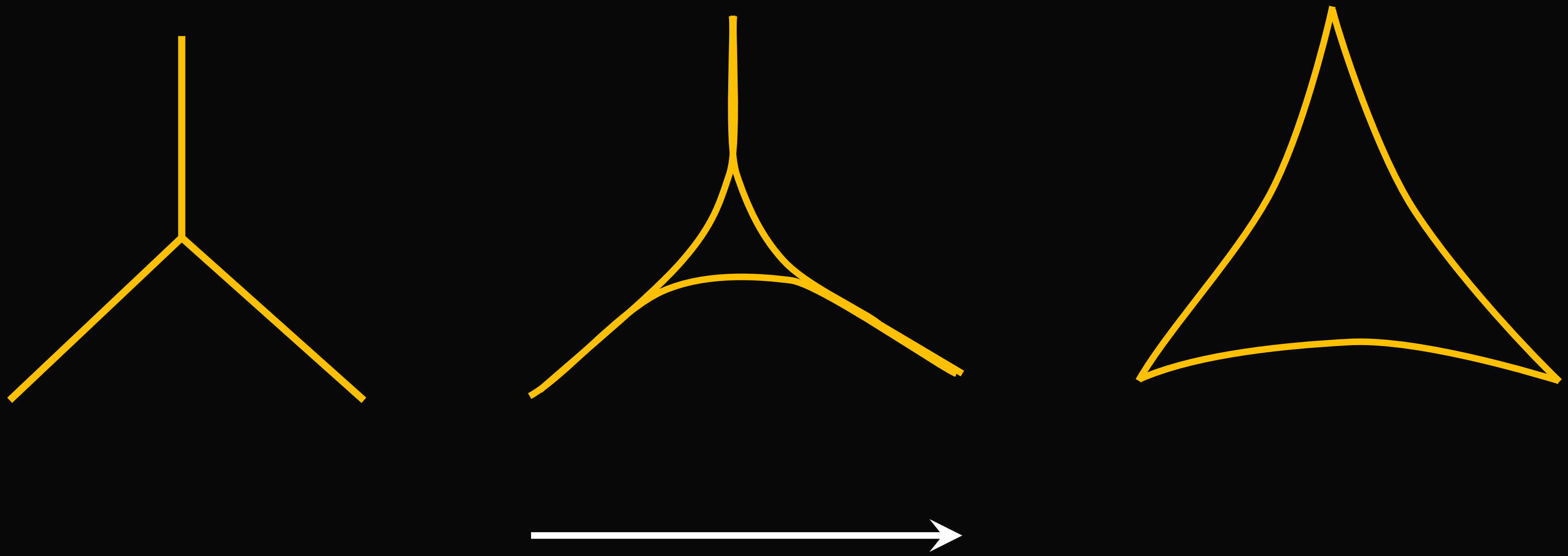
Simulation





Application of the model to four destinations shows how the network evolves from the direct connections to a certain trade-off between the length of individual connectors and the total length of the trails.

Different shapes



ease of walking on untrodden grass

Michigan state

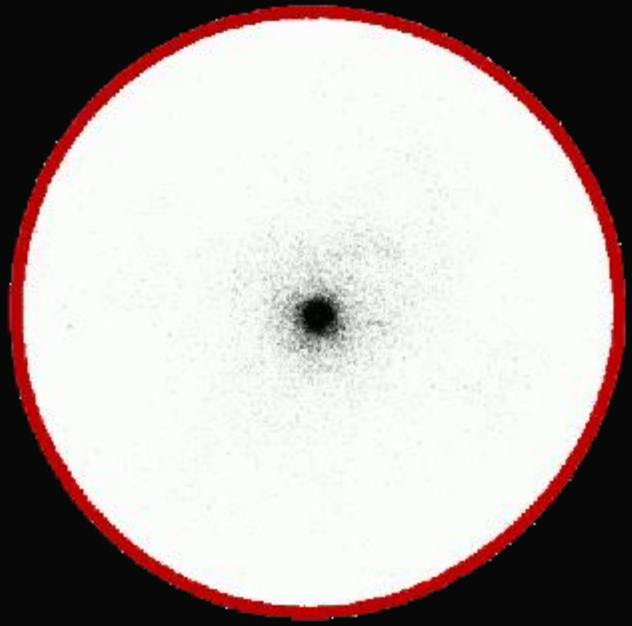
Can we use it?

Organic design: Michigan State University campus

Simulation (2)

Paths ants take…

Experiment

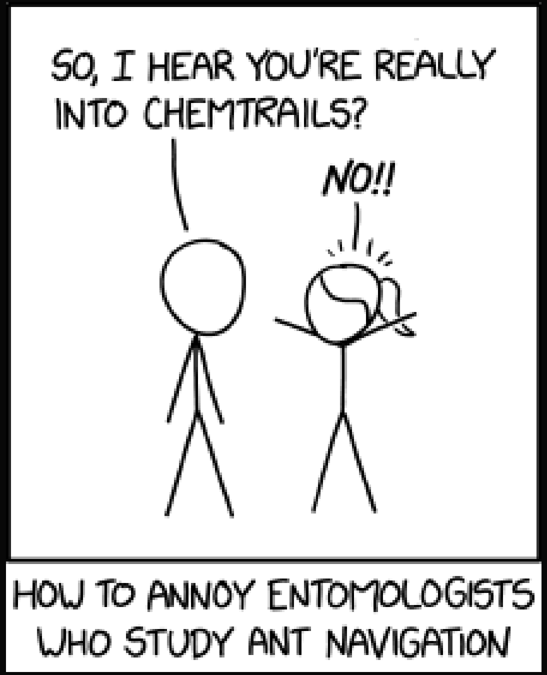


Argentine ants (*Linepithema humile*) on a circular arena over one hour

Perna et al. Plos Computat. Biol. (2012)

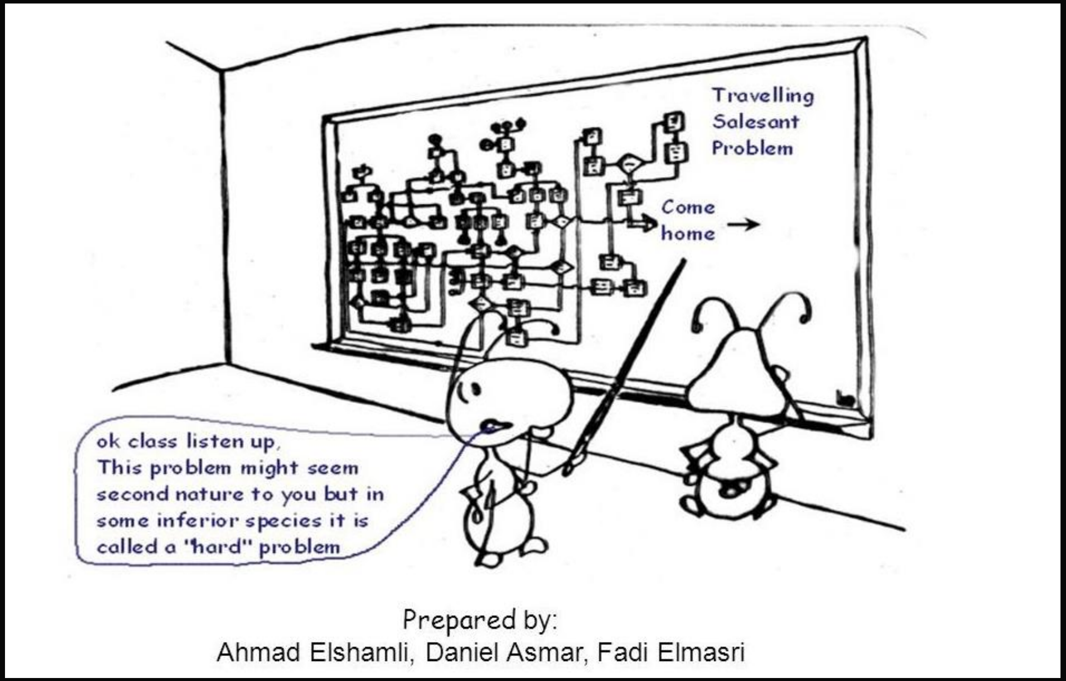
Leaving pheromones

Ants have reverse chemtrails – regular citizens spraying chemicals everywhere they go to control the government.



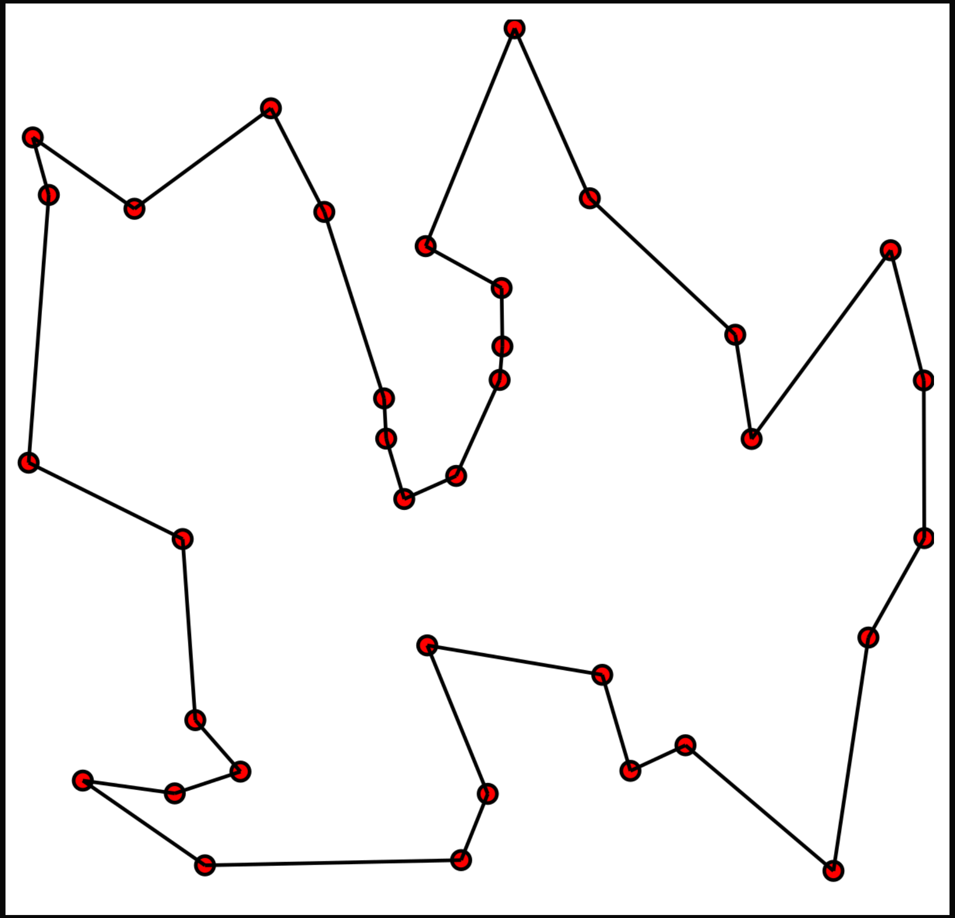
Ant trail optimization

- Ants are very good in dynamic finding of short paths through graphs.
- Ant colony optimization algorithms are used in such problems like protein folding or vehicle rooting.
- They have also been used to produce near-optimal solutions to the travelling salesman problem.

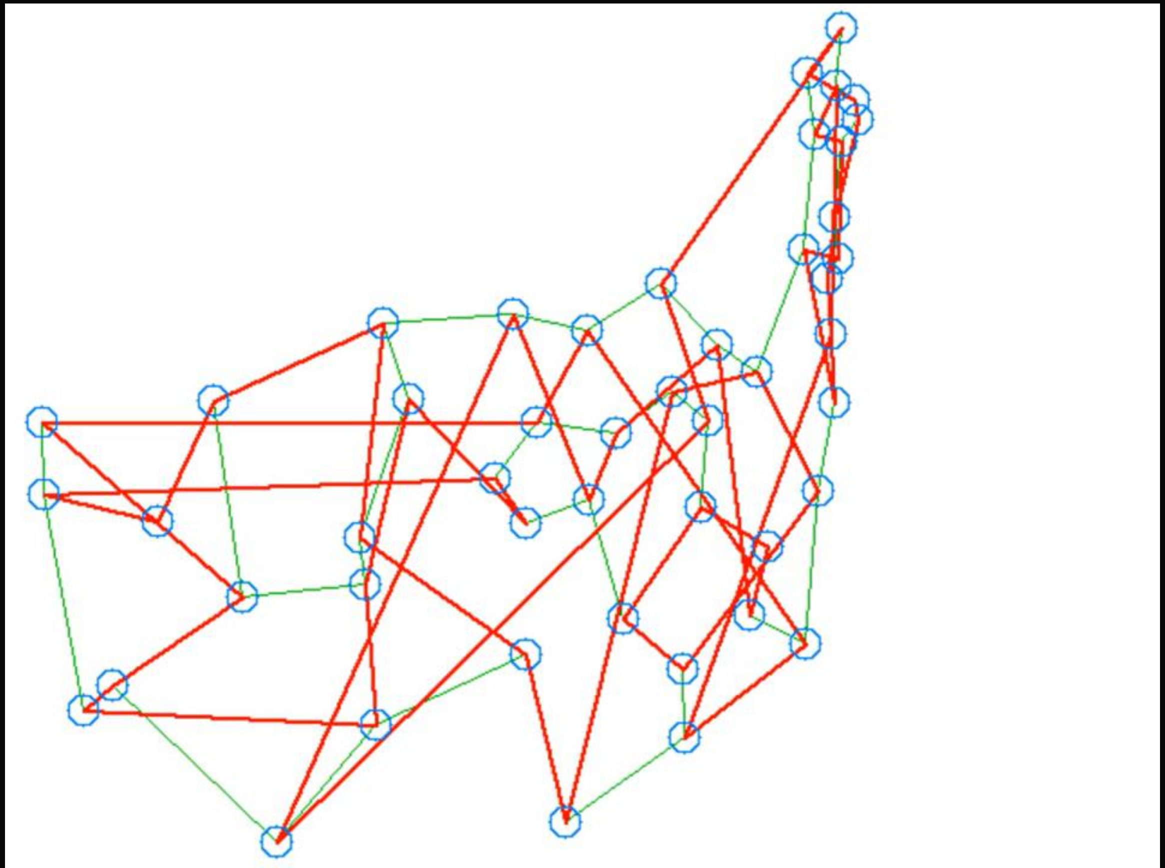


Travelling salesman problem

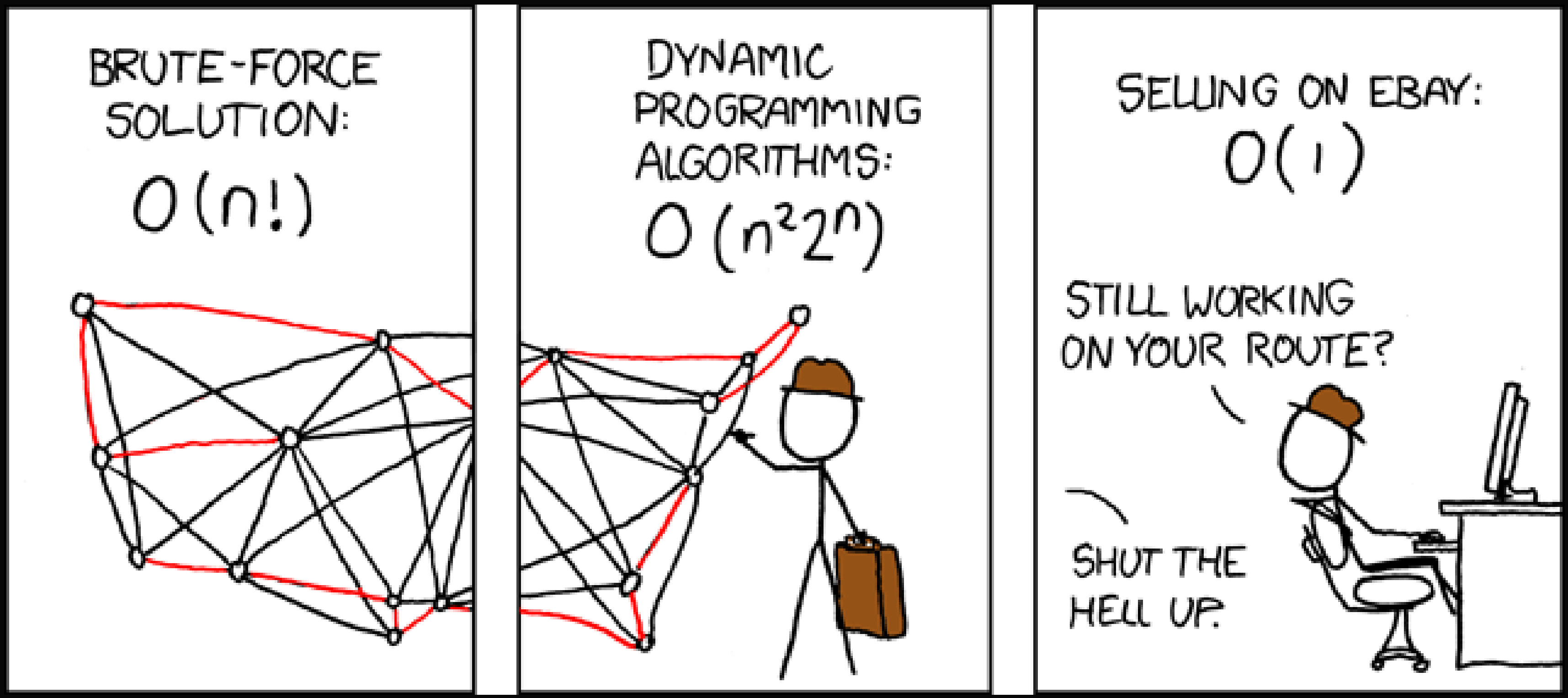
- The salesman must travel to all cities once before returning home.
- The distance between each city is given and is assumed to be the same in both directions.
- Objective – minimize the total distance to be travelled.



Travelling salesman problem (2)



Travelling salesman problem (3)



Simplicity in complexity: simple rules under complex motion.