Collective Robotics
Part 4: Local Sampling

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Warm Up

What did we learn last time?

3 minutes of thinking

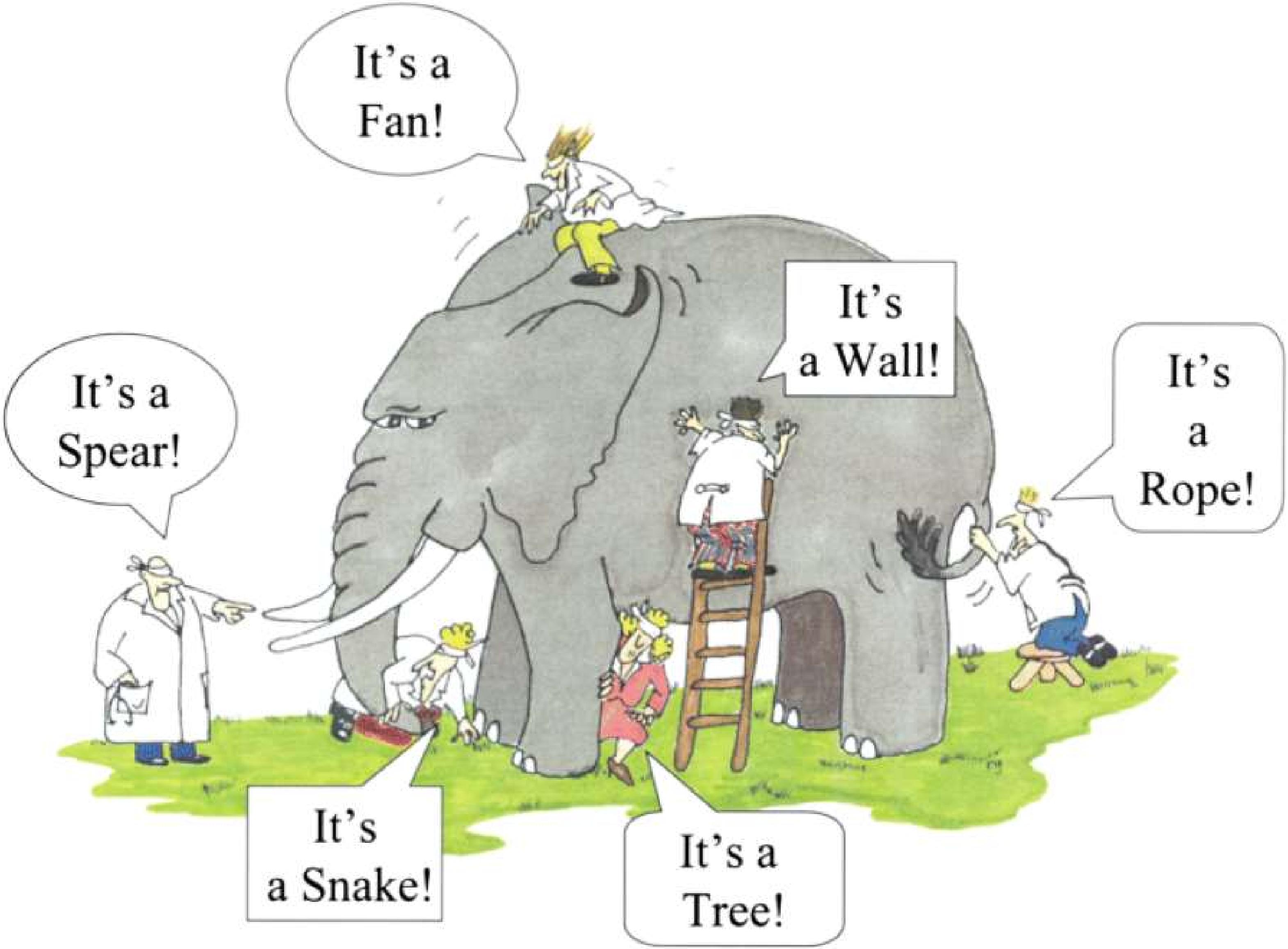
- What do you understand from Local Sampling
- Why Local Sampling is important in Collective Robotics?
- How can we implement Local Sampling? Do you have some ideas from real world examples?

Challenge

It would help to know about the global picture
but you have only local perceptions.

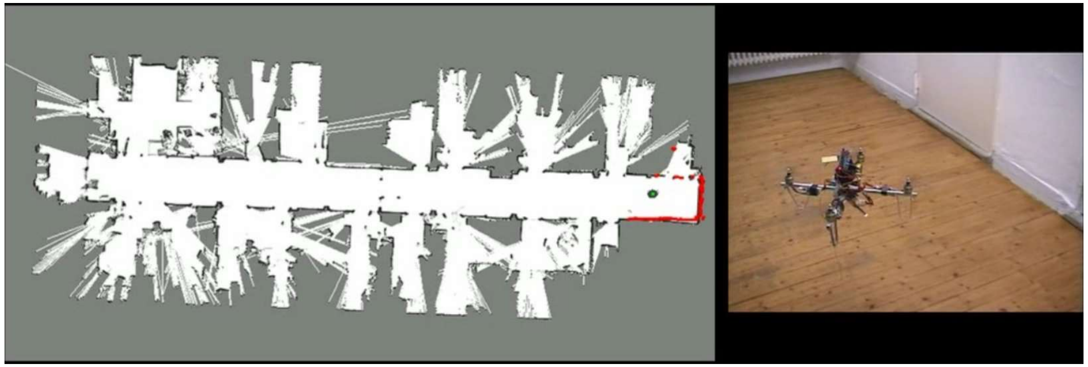
Examples:

- you have lost your way (& no map)
- voter survey
- market research
- Astronomy in 16th century
- . . . or a robot with local perception

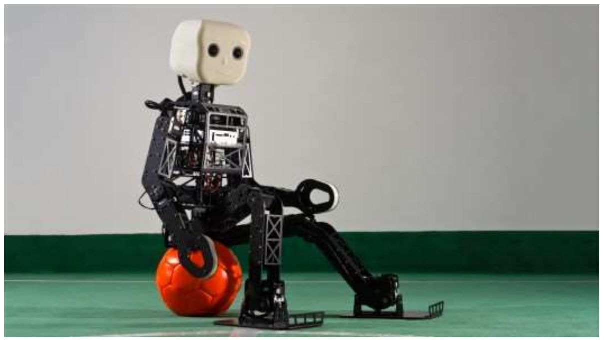

It's a Fan!
It's a Wall!
It's a Spear!
It's a Rope!
It's a Snake!
It's a Tree!

Global picture: Standard solutions in robotics

SLAM (Simultaneous Localization and Mapping)
⇒ create a global map of the environment 'on the fly'



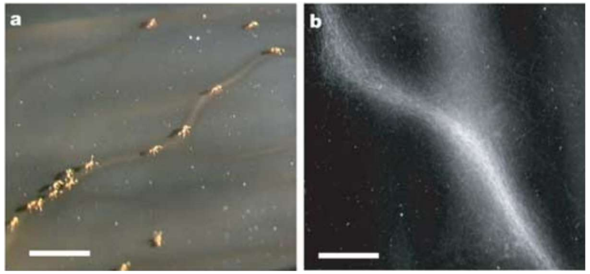
RoboCup: merge each robot's local perceptions of the ball into a global ball estimate (multi-robot sensor fusion)
⇒ global communication



Option in a swarm: Local sampling

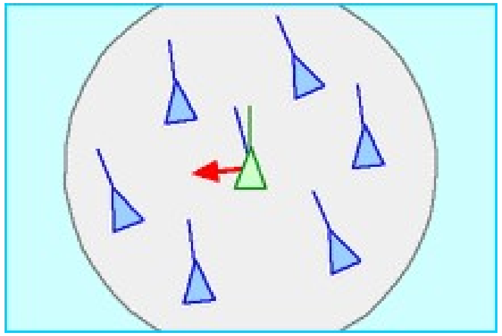
Stigmergy (e.g., cue-based navigation by pheromone trails)

⇒ follow a trail basically without knowing where it goes



check your neighbors

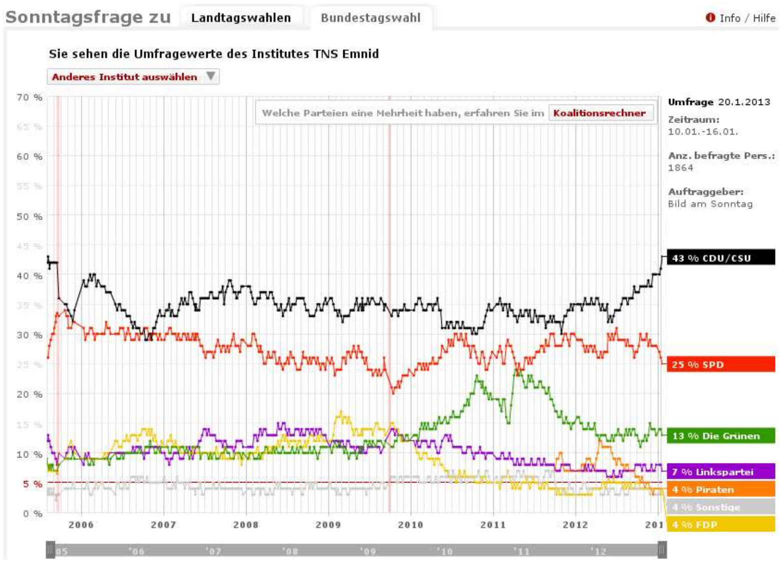
and take them as a credible sample of the global picture



Local sampling in humans

Pedestrian flow

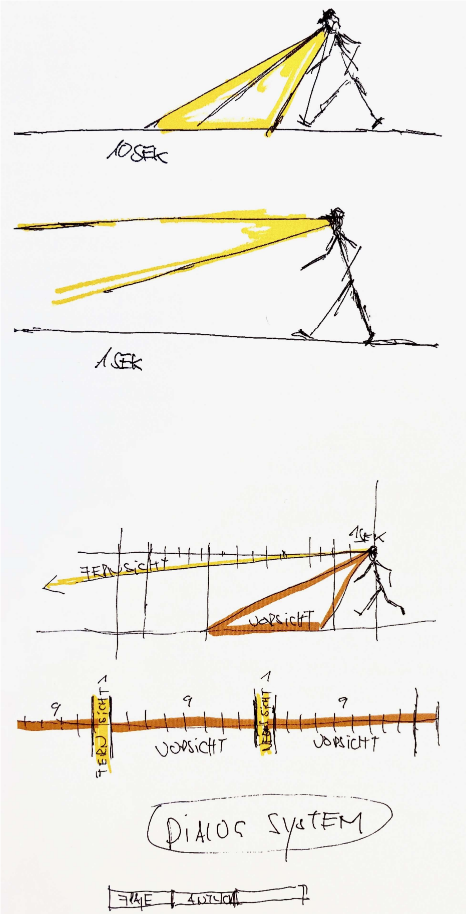
trail formation (Helbing et al., 1997)

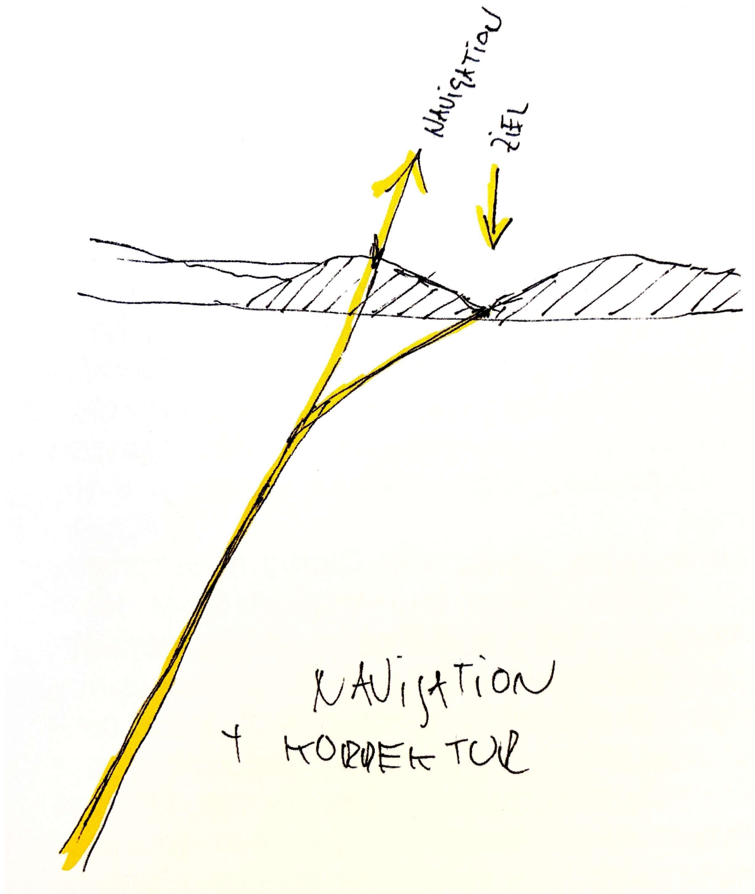


voter survey

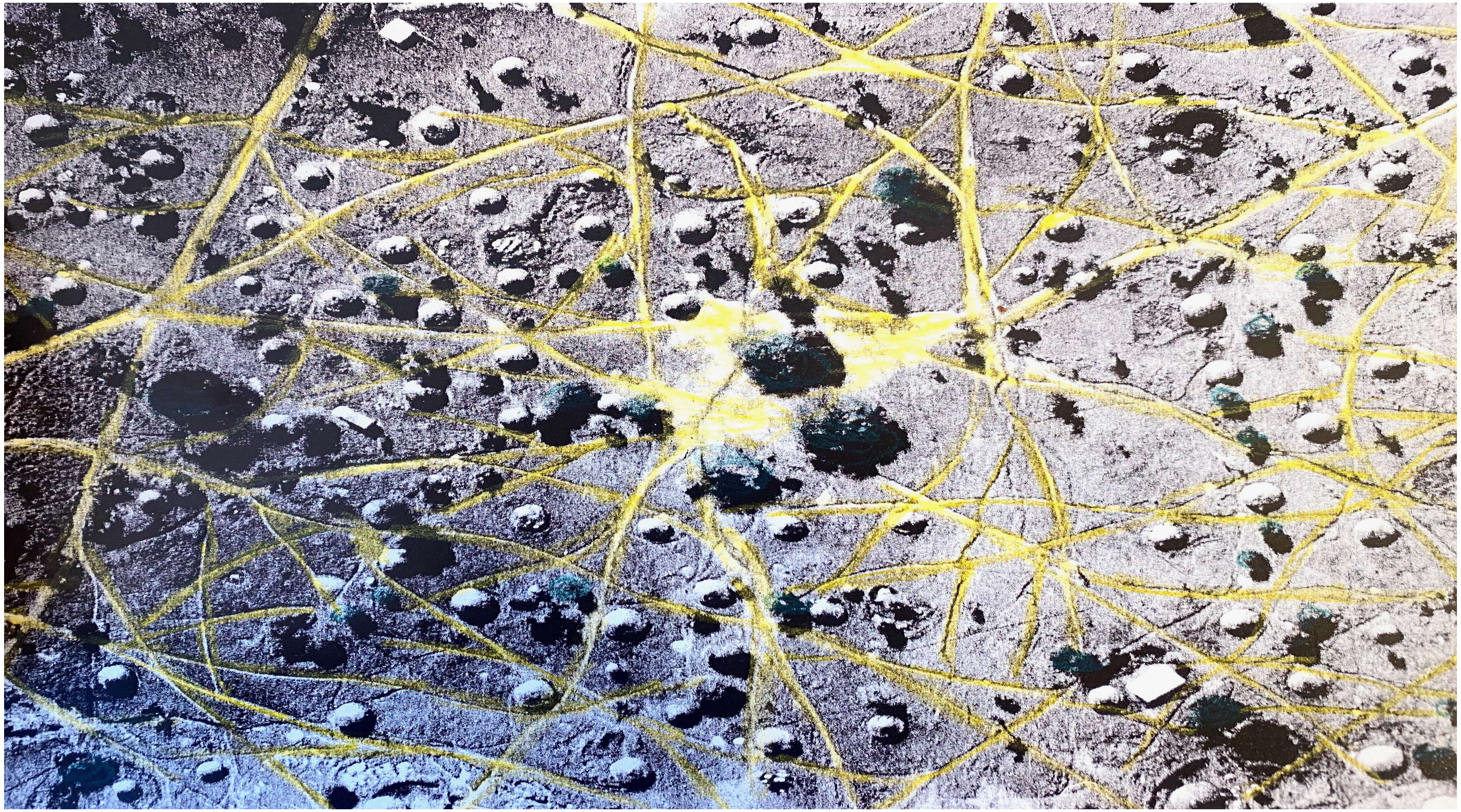
market research

Path formation – K. Humpert, Lauf-Spuren, 2007

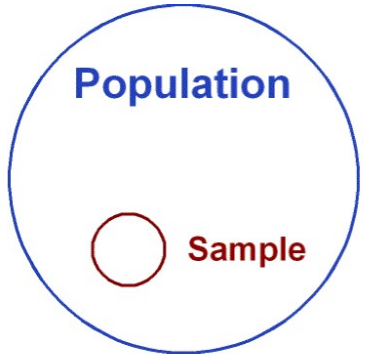




Path formation – K. Humpert, African village



Sampling in statistics



Statistical population:

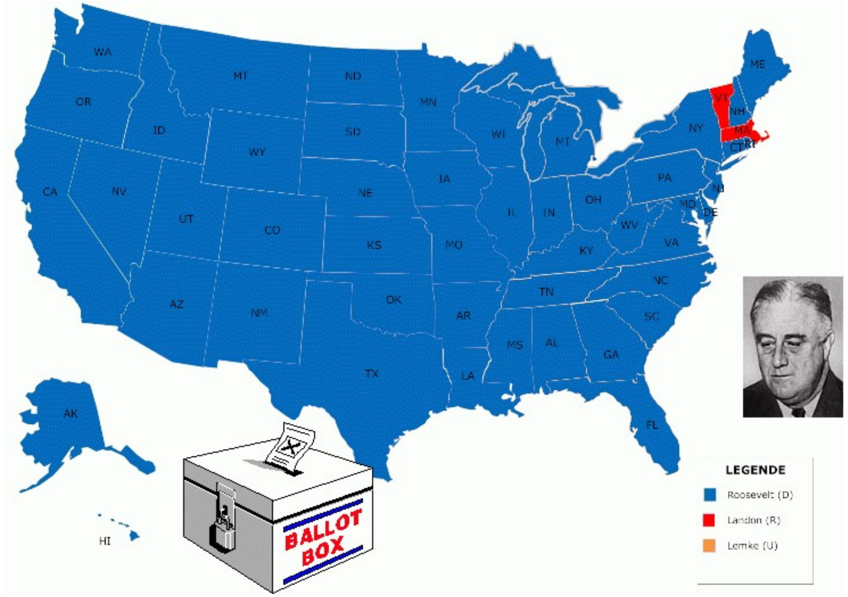
set of potential measurements

Sampling: select a subset of elements from a statistical population

- nonprobability sampling: some elements of the population have no chance of selection
- cluster sampling: elements are selected in groups (e.g., households in a street, a class of pupils)
- accidental sampling: selected elements are ‘close at hand’
- representativeness: If the selected subpopulation has ‘similar properties’ as the full population, the sample is representative.

Literary Digest Disaster (1/2)

Straw poll for US presidential election 1936
(Alf Landon vs. Franklin D. Roosevelt)



10 million people polled (mail and phone), 2.4 million answered
60 % for Alf Landon, prediction: 370 of 531 electors for Landon

Literary Digest Disaster (2/2)

Results of the election
Franklin D. Roosevelt 60%,
Alf Landon won only Vermont and Maine, that is only 8 electors!

Problem:
nonprobability sampling,
sample was registered car&phone owners and subscribers of the magazine
⇒ well-off households, typically republican (Landon),
mostly interested voters answered
and anti-Roosevelt voters felt more strongly about the election

Sampling in swarms

The sample has to be local, hence it is:

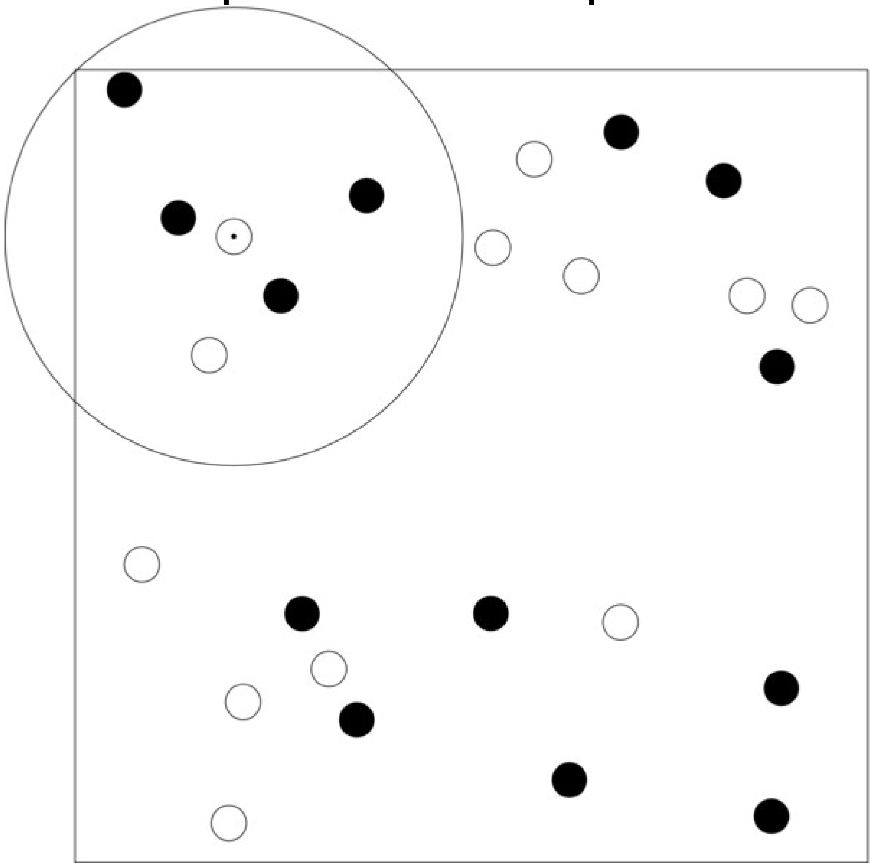
- nonprobability sampling
- accidental sampling

The sample's representativeness is at least questionable.

Difficulties:

- robot might be part of a non-representative cluster
- neighborhood might be correlated with the robot's own state
- swarm density might be too low (too small sample)

Simple example of local sampling



global:

13 black marbles (52%)

12 white marbles (48%)

local sample:

4 black, 2 white (66.6%, 33.3%)

More complex example: Estimating an area (1/2)

Different kind of local sampling:

A robot of limited capabilities (no laser scanner, no camera, etc.) has to estimate the size of a room.

How to do it?

Options:

- ?

More complex example: Estimating an area (1/2)

Different kind of local sampling:

A robot of limited capabilities (no laser scanner,

no camera, etc.) has to estimate the size of a room.

How to do it?

Options:

- measure length (e.g., measure time while moving in straight line with constant speed)
- mean free-path-length (e.g., average over times between collision avoidance behaviors)
- ?

More complex example: Estimating an area (2/2)

Observations of a certain ant species and their search for nest sites.

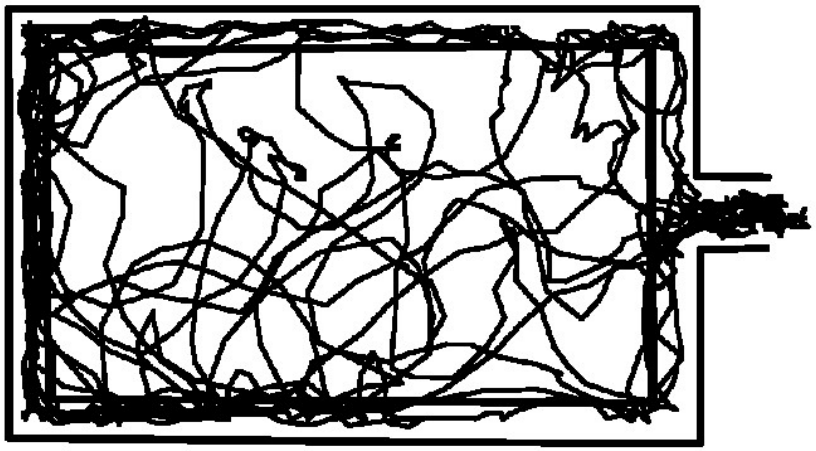
Ants estimate area using Buffon's needle

Eamonn B. Mallon* **and Nigel R. Franks**

Centre for Mathematical Biology, and Department of Biology and Biochemistry, University of Bath, Bath BA2 7AY, UK

We show for the first time, to our knowledge, that ants can measure the size of potential nest sites. Nest size assessment is by individual scouts. Such scouts always make more than one visit to a potential nest before initiating an emigration of their nest mates and they deploy individual-specific trails within the potential new nest on their first visit. We test three alternative hypotheses for the way in which scouts might measure nests. Experiments indicated that individual scouts use the intersection frequency between their own paths to assess nest areas. These results are consistent with ants using a 'Buffon's needle algorithm' to assess nest areas.

Keywords: ants; colony emigration; individual-specific pheromones; *Leptothorax*; nest sites; rules of thumb



Mallon and Franks (2000)

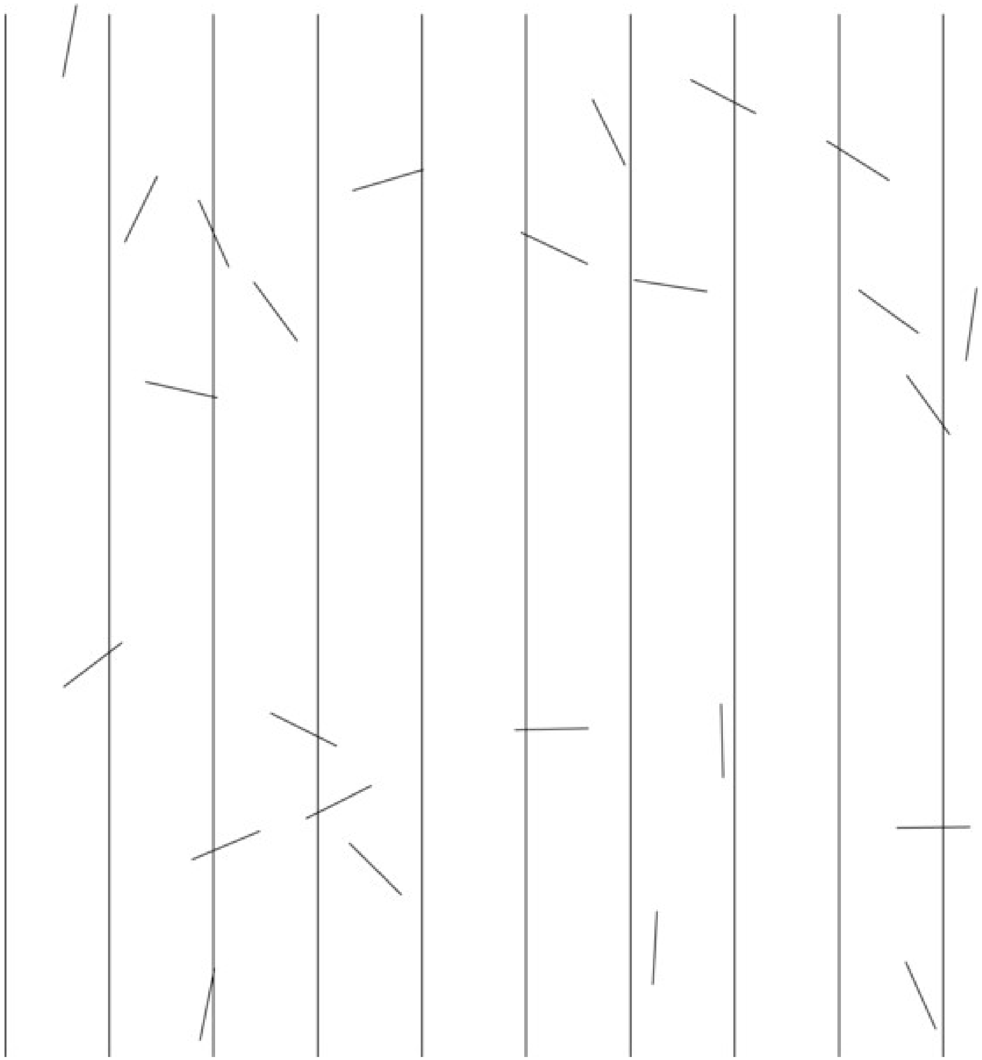
Buffon's needle

a needle of length b dropped randomly onto a plane with inscribed parallel straight lines, s units apart (where $b < s$) has probability

$$P = 2b/(s\pi)$$

of intersecting a line

also see Ramaley (1969)



length $b = 7$,
line spacing $s = 10$

sample:
14 intersections
11 non-inter-sections

probability according to this sample:
$$\hat{P} = 14/25 = 0.56$$

theory:
$$P = (2 \cdot 7)/(10\pi) \approx 0.446$$

Estimating the sampling error

Binomial proportion confidence interval

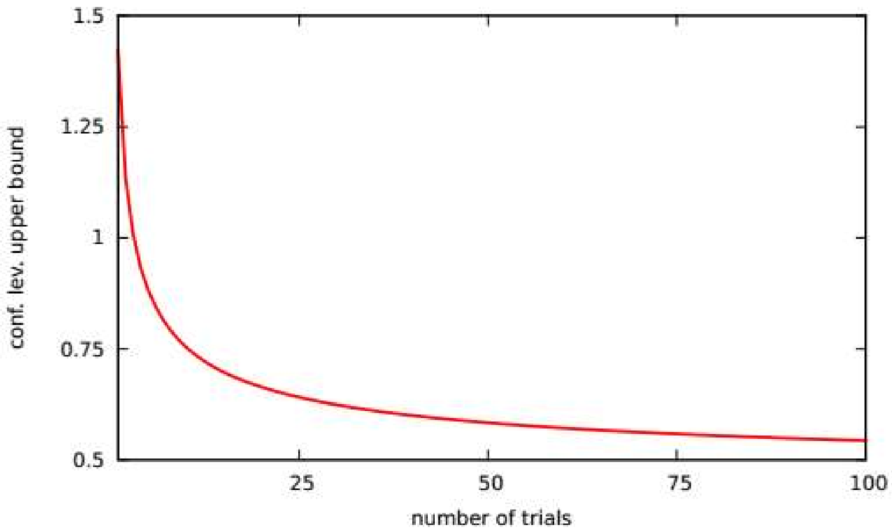
approximating binomial distribution with a normal distribution for a 95% confidence level we get:

$$\hat{P} \pm 1.96 \sqrt{\frac{1}{n}\hat{P}(1-\hat{P})},$$

$\hat{P}$ is the estimated probability (here: of crossing),

n is number of trials,

1.96 is the appropriate percentile of the standard normal distribution



(estimated upper bound of conf. interval for an assumed correct $\hat{P} = 0.446$)

Estimate area based on randomly scattered lines

a variant of Buffon's needle

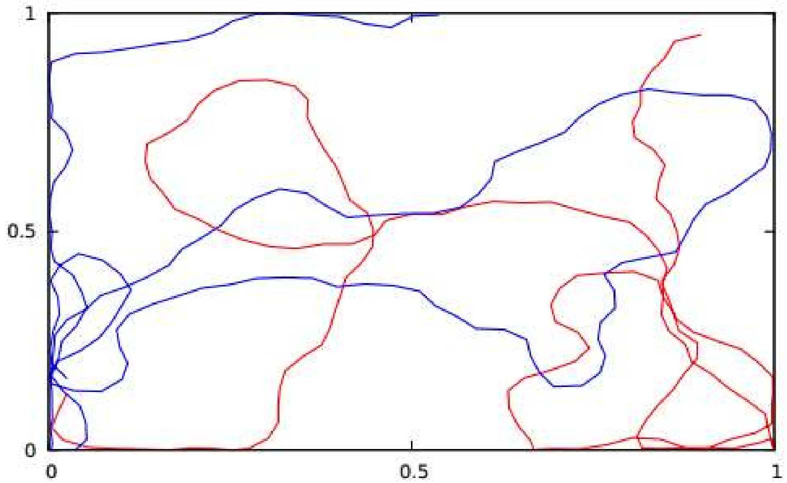
number of intersections n between two sets of lines,

first set of lines with total length L_1

and second set of lines with total length L_2,

estimated area A is

$$A = 2L_1L_2/(n\pi)$$



Ants estimate area

When their old nest is destroyed single ants (scouts) are sent out to explore a region to find potential nest sites (flat crevices in rocks) of appropriate size.

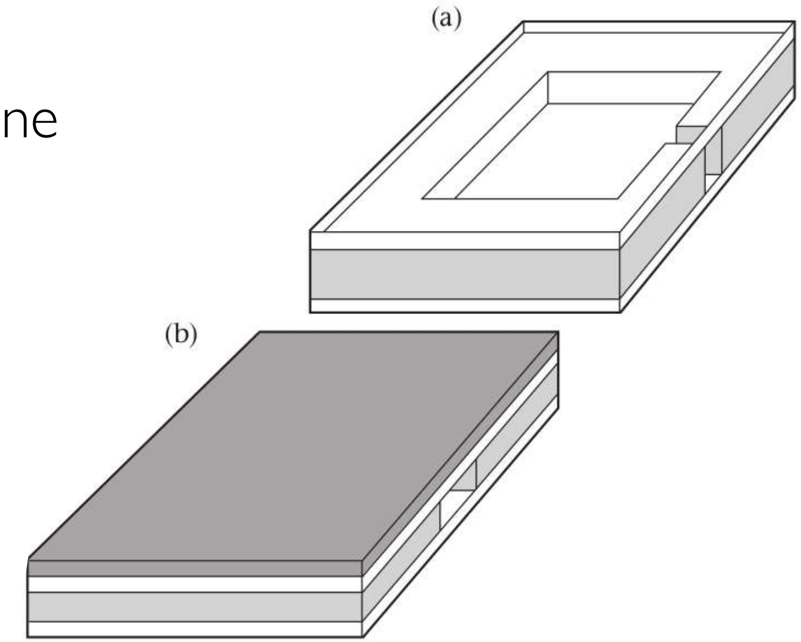
a potential nest site is visited at least twice:

a) on the first visit the scout deploys a pheromone

b) but not on the second visit

the pheromone trail of the first visit defines set of lines L_1

the scout's trajectory on the second visit defines set of lines L_2



Group Task

Estimating Room Size Using Local Sampling Principles

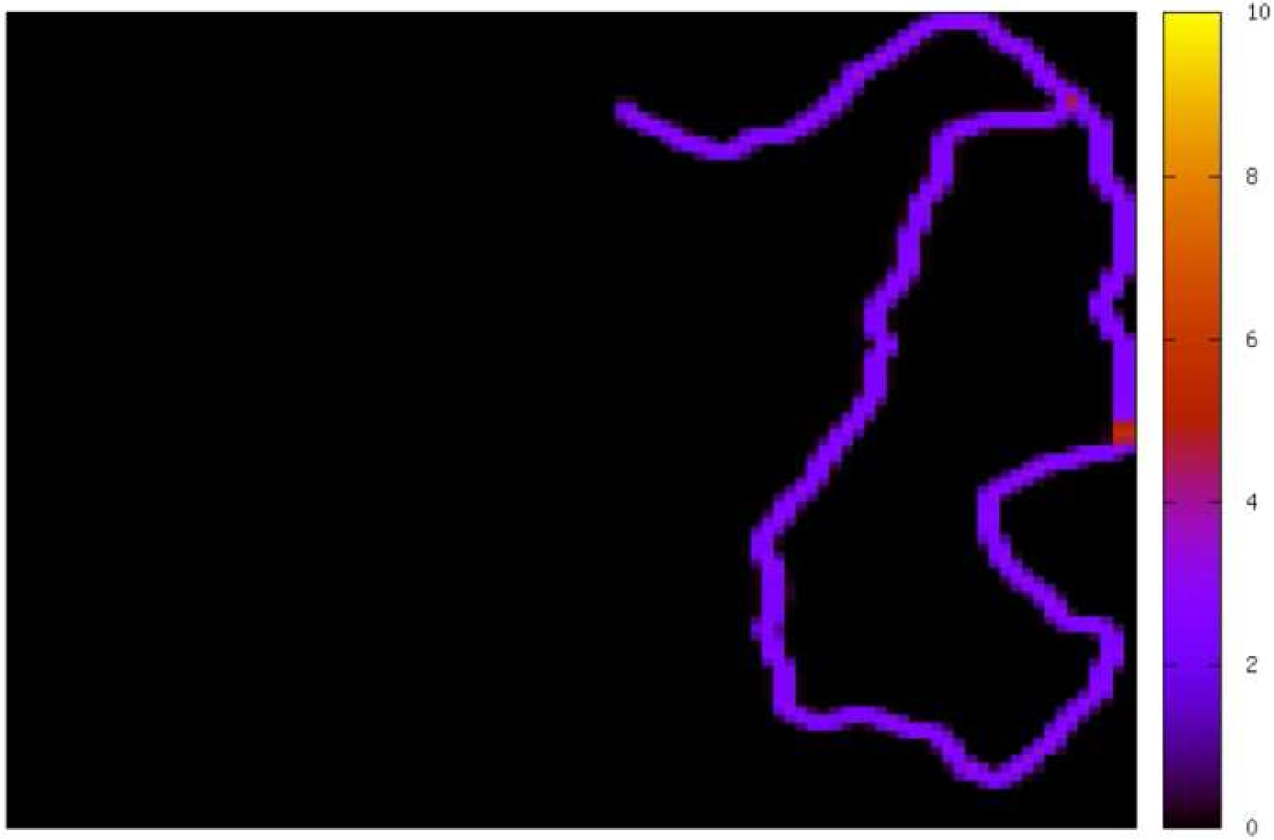
Each group simulates:

- First pass: Lay down a simulated pheromone trail (lines on the grid).
- Second pass: Trace another path across the room.
- Task: Estimate area using the Buffon-like formula

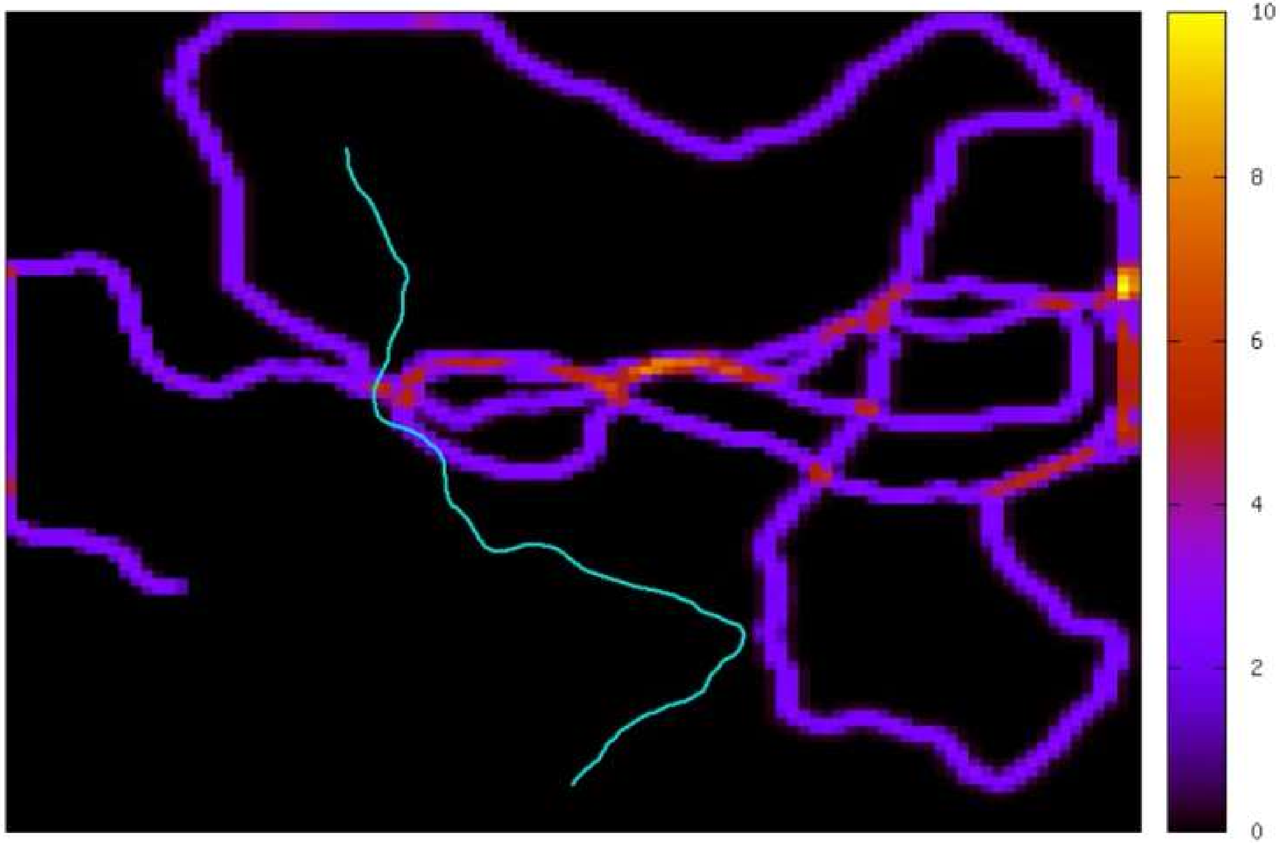
Each group shares:

- Their estimated area.
- Challenges faced in sampling (e.g., sample bias, accuracy).

Ants estimate area – 1st visit



Ants estimate area – 2nd visit



Ants estimate area – Conclusion

In an experiment an ant colony was given the choice between 2 nest sites:

- one of ‘standard size’
- and one of 5/8th (62.5%) standard size

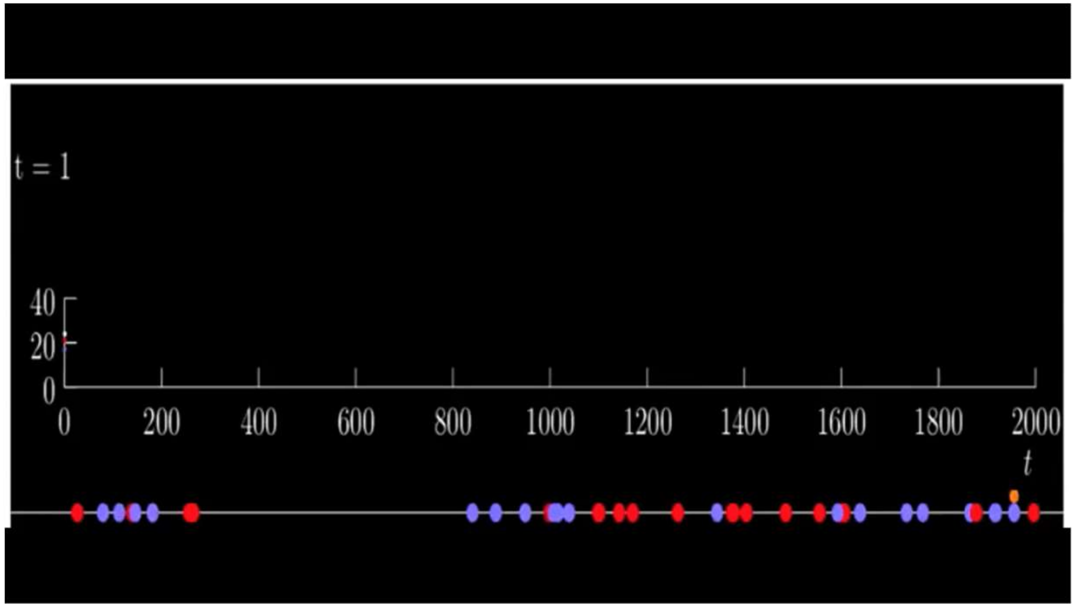
They chose the standard size nest site
15 times out 15 (smaller nest site was never chosen)
(Mallon and Franks, 2000)

good example of

- low-tech approach
- flexibility: no special hardware for measurement
- non-intuitive problem solving (in contrast to engineering)

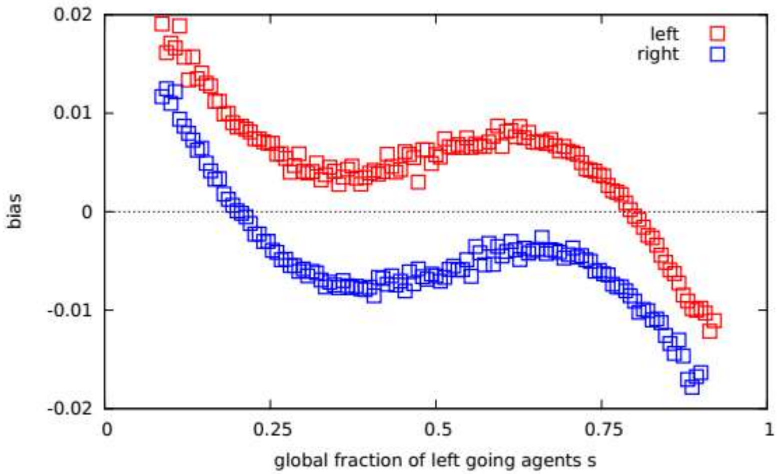
Systematic bias in local sampling (1/2)

example: collective motion in locusts



clusters with agents of the same state form
consequently agents will (in average) overestimate the number of agents of their own state

Systematic bias in local sampling (2/2)



s is global fraction of left going agents

left-going agents overestimate the number of left-going agents for $s < 0.8$

right-going agents overestimate the number of right-going agents for $s > 0.2$

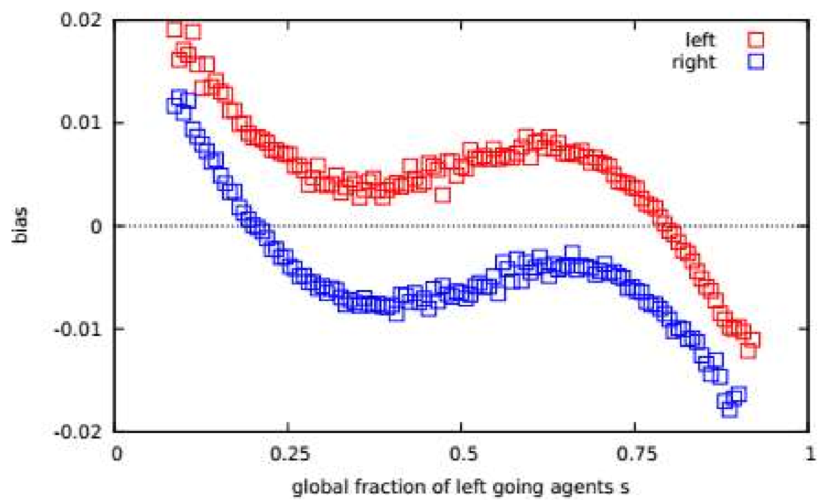
Strategies against bias

bias cannot easily be corrected because global state s is unknown to an agent

approximation possible by incorporating a model, for example:

if a left-going agent samples a local fraction of $\hat{s} < 0.8$

then correct it to $\hat{s}` = \hat{s} - 0.01$



2 Minutes of Note

- Take one minute to think: what did you learn today. Write the highlight as one sentence

- Take another one minute to think: what was hard to unterstand today? Note it in one sentence

References

Dirk Helbing, Joachim Keltsch, and Peter Moln ´ ar. Modelling the evolution of human trail systems. ´ *Nature*, 388:47–50, July 1997.

Eamonn B. Mallon and Nigel R. Franks. Ants estimate area using Buffon’s needle. *Proc. R. Soc. Lond. B*, 267(1445):765–770, April 2000.

J. F. Ramaley. Buffon’s noodle problem. *The American Mathematical Monthly*, 76(8):916–918, 1969. URL http://www.jstor.org/stable/2317945.