Patterns in Nature 4
Animal swarm behaviour

Stephan Matthiesen
Tuesdays, 10:00-12:00am

Social waves in Giant Honeybees Repel Hornets

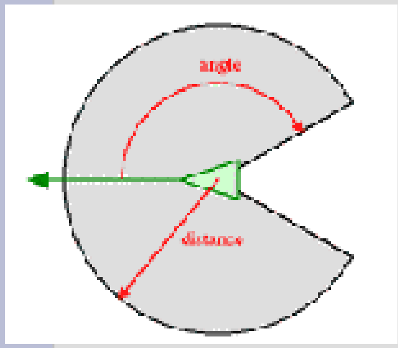
Free access article with videos:

Kastberger G, Schmelzer E, Kranner I (2008): Social Waves in Giant Honeybees Repel Hornets. PLoS ONE 3(9): e3141. doi:10.1371/journal.pone.0003141

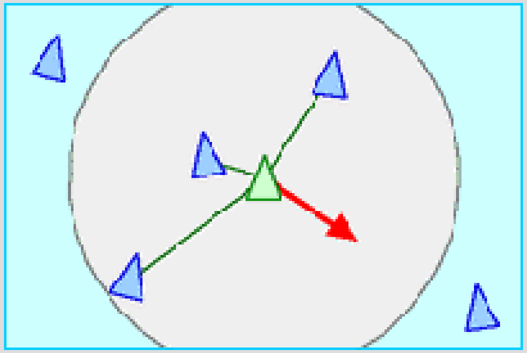
Video also at: http://www.youtube.com/watch?v=X7I75XUQ8-M

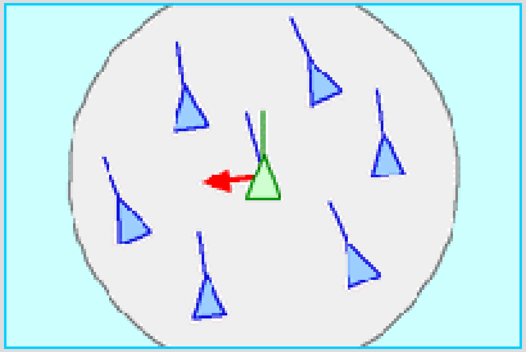
Understanding swarm behaviour

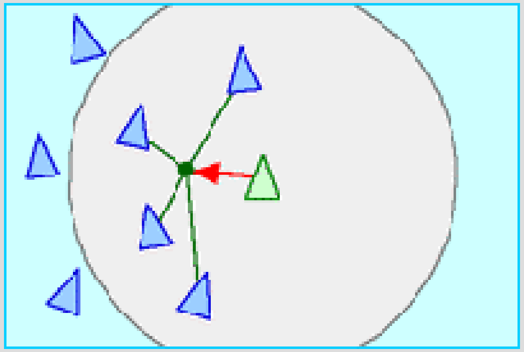
- individual-based model developed by Craig Reynolds (1986)
- "Boids" (elementary "animals"):
  - they react only to their local neighbourhood
  - neighbourhood characterised by distance & angle
  - they follow 3 simple behaviour rules



A Boid's neighbourhood


Separation
steer to avoid crowding local flockmates

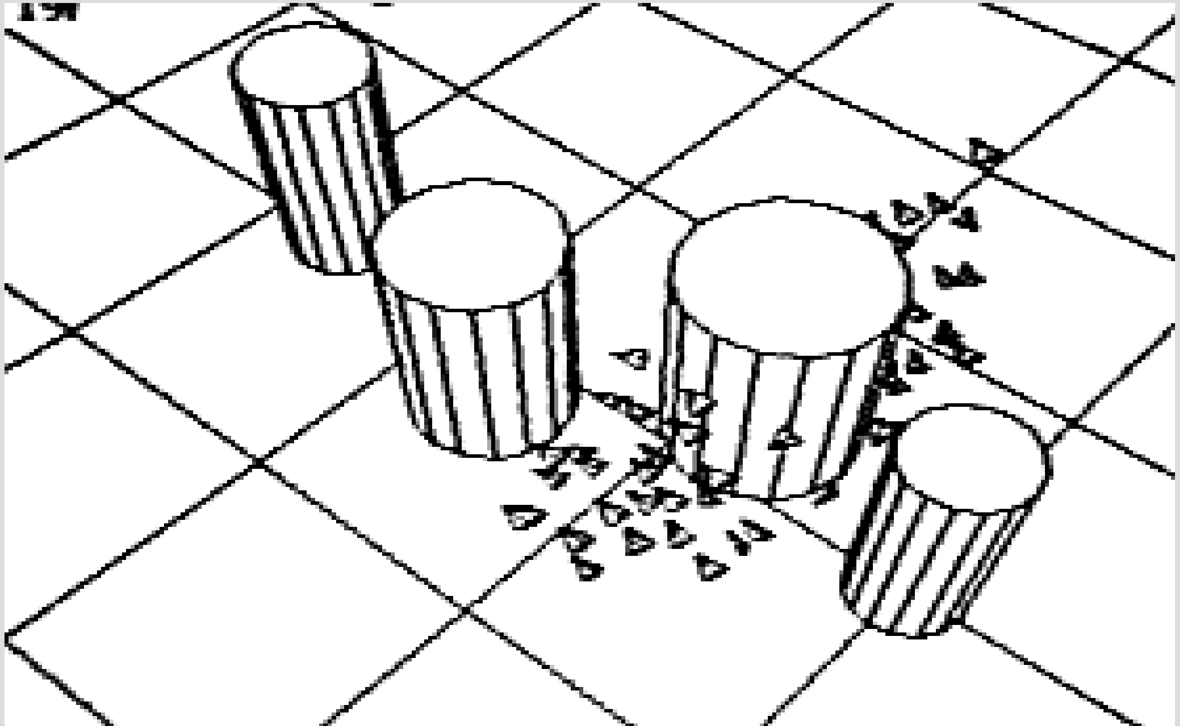

Alignment
steer towards the average heading of local flockmates


Cohesion
steer to move toward the average position of local flockmates

Modelling swarm behaviour

Watch the video from Craig Reynold's Website
http://www.red3d.com/cwr/boids/

Observe the behaviour of the swarm



Emergent behaviour in swarms

- orderly behaviour
- “chaotic” behaviour
  - wild behaviour
  - splitting groups
- splitting around obstacles and reuniting

Modifications (these rules get low priority):

- predictive obstacle avoidance
- goal seeking

PNAS, 29 Jan. 2008

Interaction ruling animal collective behavior depends on topological rather than metric distance: Evidence from a field study

M. Ballerini*[†], N. Cabibbo[‡§], R. Candelier[†¶], A. Cavagna*[∥]**, E. Cisbani[†], I. Giardina*[∥], V. Lecomte[††‡‡], A. Orlandi*, G. Parisi*[‡§]**, A. Procaccini*[‡], and M. Viale[‡§§], and V. Zdravkovic*

*Centre for Statistical Mechanics and Complexity (SMC), Consiglio Nazionale delle Ricerche-Istituto Nazionale per la Fisica della Materia, [‡]Dipartimento di Fisica, and [§]Sezione Instituto Nazionale di Fisica Nucleare, Universita' di Roma "La Sapienza," Piazzale Aldo Moro 2, 00185 Roma, Italy; [†]Istituto Superiore di Sanita', viale Regina Elena 299, 00161 Roma, Italy; [∥]Istituto dei Sistemi Complessi (ISC), Consiglio Nazionale delle Ricerche, via dei Taurini 19, 00185 Roma, Italy; and [††]Laboratoire Matière et Systèmes Complexes, (Centre National de la Recherche Scientifique Unite Mixte de Recherche 7057), Université Paris VII, 10 rue Alice Domon et Léonie Duquet, 75205 Paris Cedex 13, France

Contributed by G. Parisi, December 4, 2007 (sent for review September 25, 200

Numerical models indicate that collective animal behavior may emerge from simple local rules of interaction among the individuals. However, very little is known about the nature of such interaction, so that models and theories mostly rely on aprioristic assumptions. By reconstructing the three-dimensional positions of individual birds in airborne flocks of a few thousand members, we show that the interaction does not depend on the metric distance, as most current models and theories assume, but rather on the topological distance. In fact, we discovered that each bird interacts on average with a fixed number of neighbors (six to seven), rather than with all neighbors within a fixed metric distance. We argue that a topological interaction is indispensable to maintain a flock's cohesion against the large density changes caused by external perturbations, typically predation. We support this hypothesis by numerical simulations, showing that a topological interaction grants significantly higher cohesion of the aggregation compared with a standard metric one.

animal groups | behavioral rules | flocking | self-organization

Collective behavior of large aggregations of animals is a truly

"Metric distance":

what we usually understand as distance

"Topological distance" between two birds:

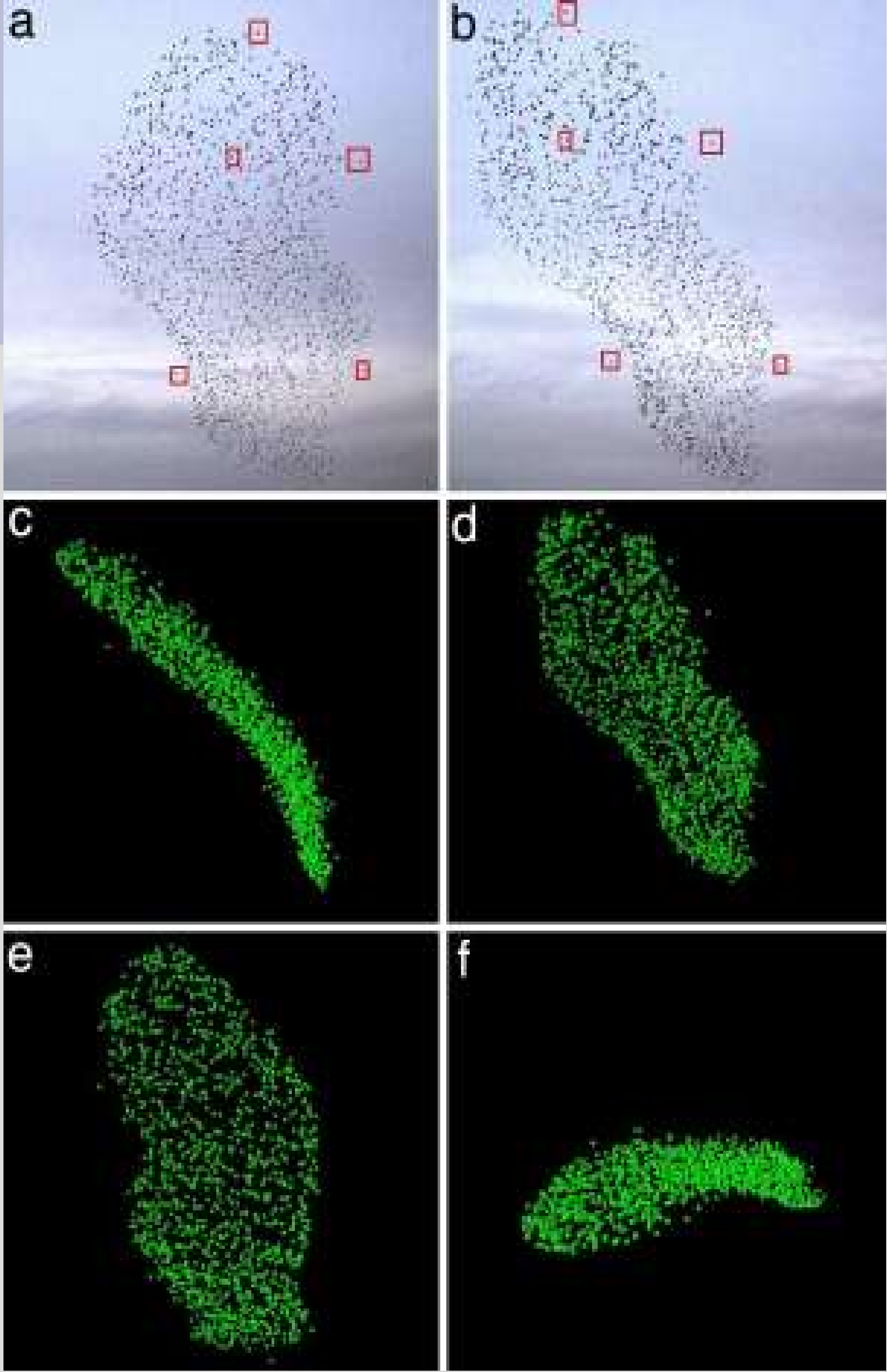
How many other birds are between them?

Real birds

Ballerini et al. (2008):

- Observed starlings in Rome with stereo camera and had computer calculate positions of all birds

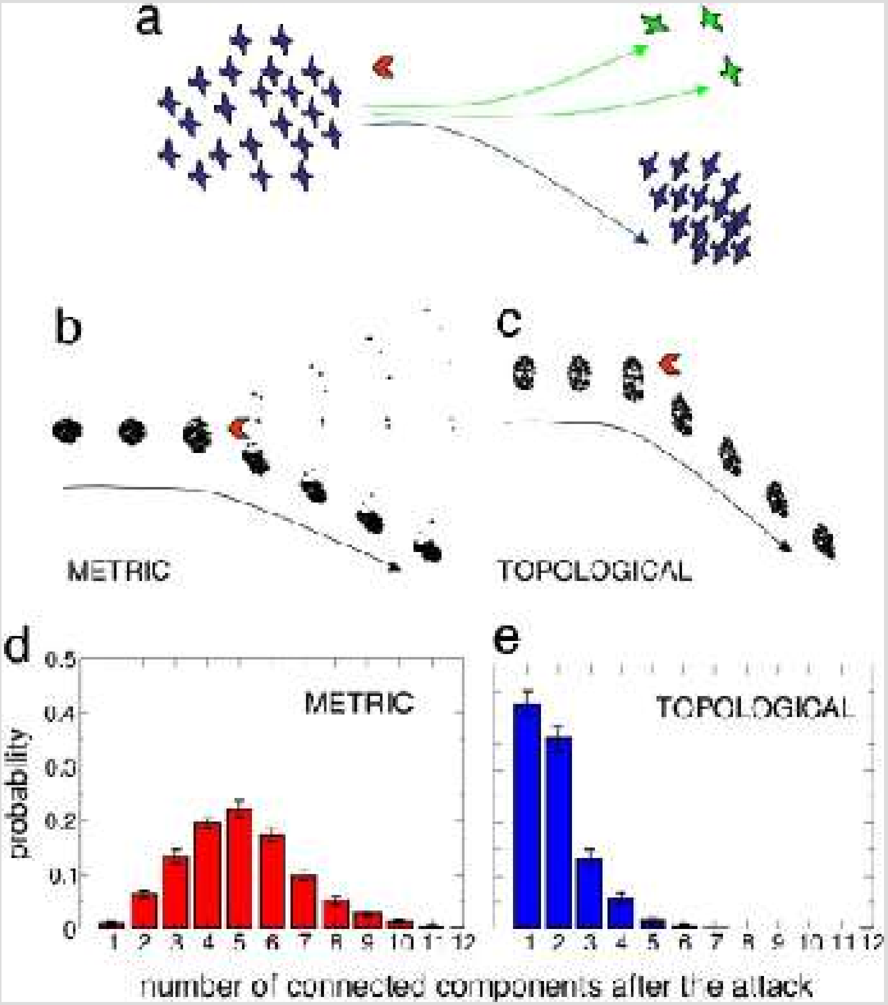
=> each bird always reacts to 6-7 nearest neighbours, independent of their (metric) distance



Does it make a difference?

Models using metric versus topological distance:

- With metric distance, flock disintegrates when attacked (a, b) (stragglers are lost)
- with topological distance, flock usually remains connected (c)



Ballerini et al. (2008)

http://dx.doi.org/10.1073/pnas.1007102108

Stop press:

Fast and accurate decisions through collective vigilance in fish shoals

Ashley J. W. Ward[a,1], James E. Herbert-Read[a], David J. T. Sumpter[b], and Jens Krause[c,d]

[a]School of Biological Sciences, University of Sydney, Sydney, NSW 2006, Australia; [b]Mathematics Department, Uppsala University, 751 06 Uppsala, Sweden; [c]Leibniz-Institute of Freshwater Ecology and Inland Fisheries, 12587 Berlin, Germany; and [d]Department for Crop and Animal Sciences, Humboldt University, 10115 Berlin, Germany

Edited by Giorgio Parisi, University of Rome, Rome, Italy, and approved December 27, 2010 (received for review May 21, 2010)

Although it has been suggested that large animal groups should make better decisions than smaller groups, there are few empirical demonstrations of this phenomenon and still fewer explanations of the how these improvements may be made. Here we show that both speed and accuracy of decision making increase with group size in fish shoals under predation threat. We examined two plausible mechanisms for this improvement: first, that groups are guided by a small proportion of high-quality decision makers and, second, that group members use self-organized division of vigilance. Repeated testing of individuals showed no evidence of different decision-making abilities between individual fish. Instead, we suggest that shoals achieve greater decision-making efficiencies through division of labor combined with social information transfer. Our results should prompt reconsideration of how we view cooperation in animal groups with fluid membership.

swarm intelligence | collective decision-making | sociality

their own as well as in groups of different sizes under simulated predation risk, predicting that, because animals should optimize both speed and accuracy in their decision-making process, larger groups would make faster as well as more accurate decisions than smaller groups or singletons.

Results

In a simple decision-making task (Fig. 1), solitary fish performed relatively poorly, avoiding a replica predator in 60 of 108 trials (55.6%). The proportion of fish making an accurate decision increased with group size with focal individuals in groups of 8 fish and of 16 fish being significantly more likely to make accurate decisions (i.e., to avoid the replica predator) than solitary ones (binomial test: group of 8, $P = 0.02$; group of 16, $P = 0.02$; Fig. 2*A*).

The theoretical "perfect many eyes" case, where the probability of all individuals avoiding the predator is equal to that of just one or more individuals detecting the predator, can be cal-

ECOLOGY

Experiment with humans

Experiment by a German TV Science Programme:
http://www.wdr.de/tv/quarks/sendungsbeitraege/2007/0410/002_schwarm.jsp

- 300 volunteers
- Rule: keep at arm's length to neighbours, and don't say anything
- Swarm behaviour
- 5% can steer the whole swarm

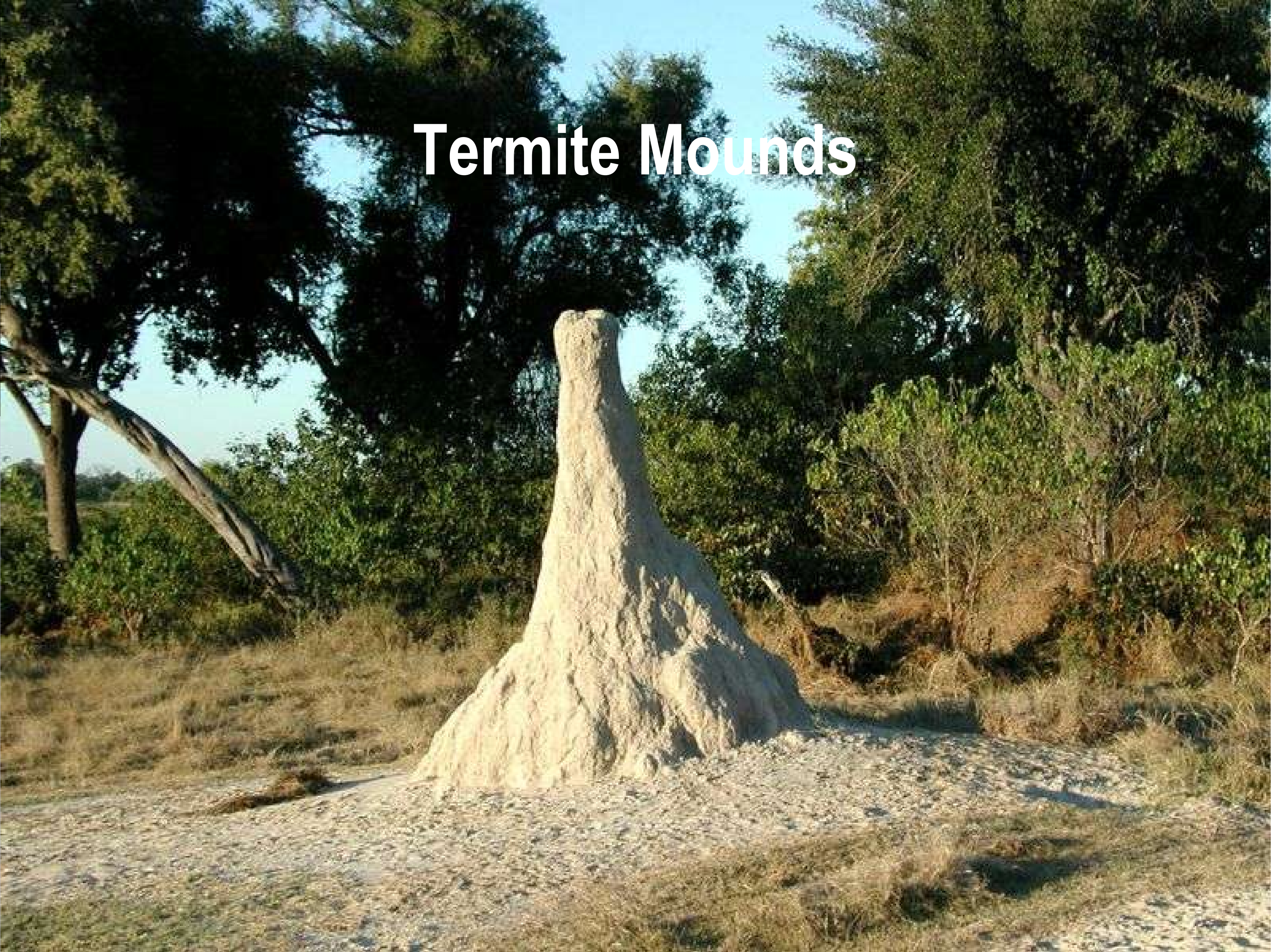
Mass panics and what to do about them

15/8/1989 Hillsborough: 96 dead, 766 injured

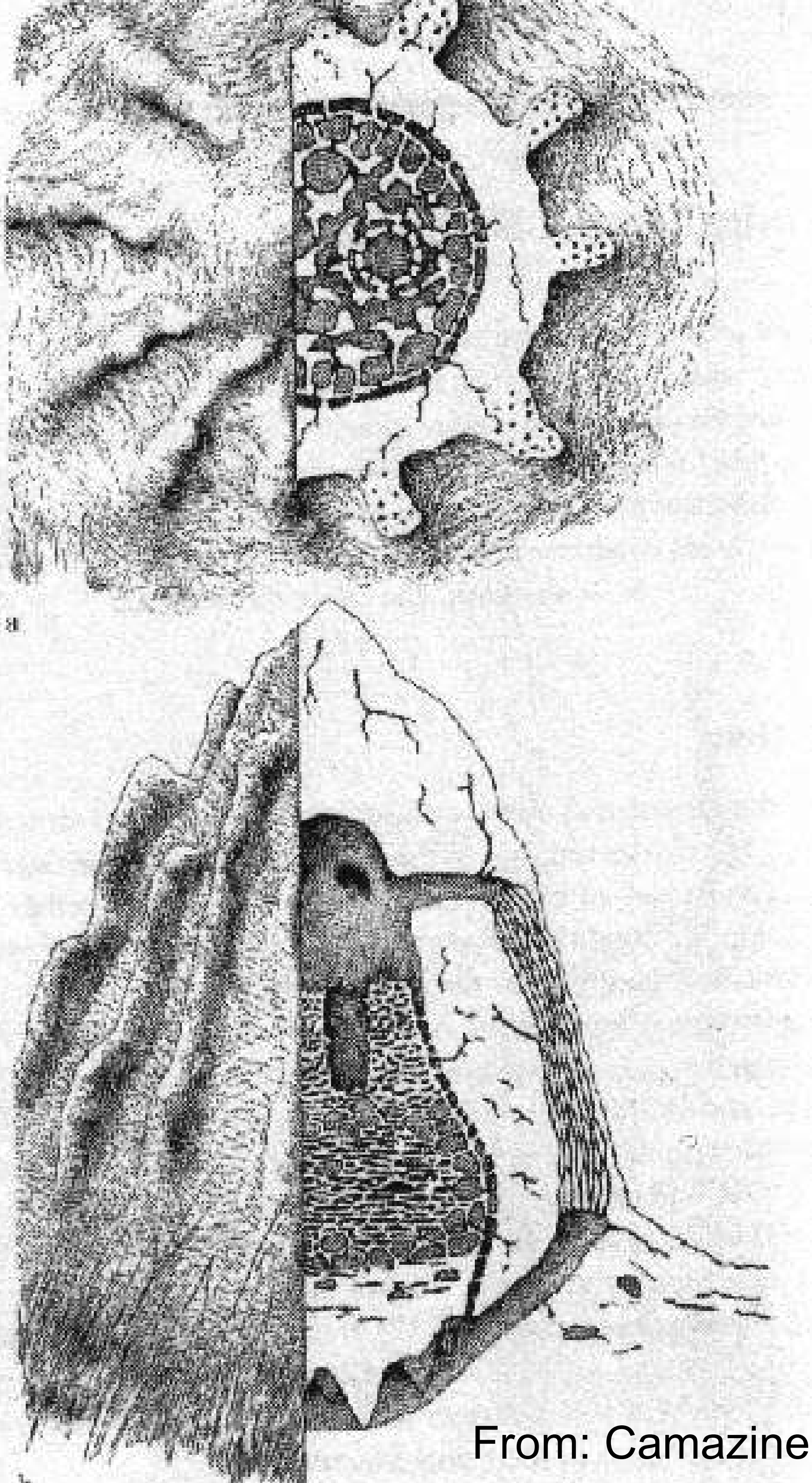
12/1/2006 Mecca: 362 dead;
3 million pilgrims within 24 hours

24/7/2010 Duisburg, Loveparade: 21 dead,
>500 injured, ca. 485000 participants

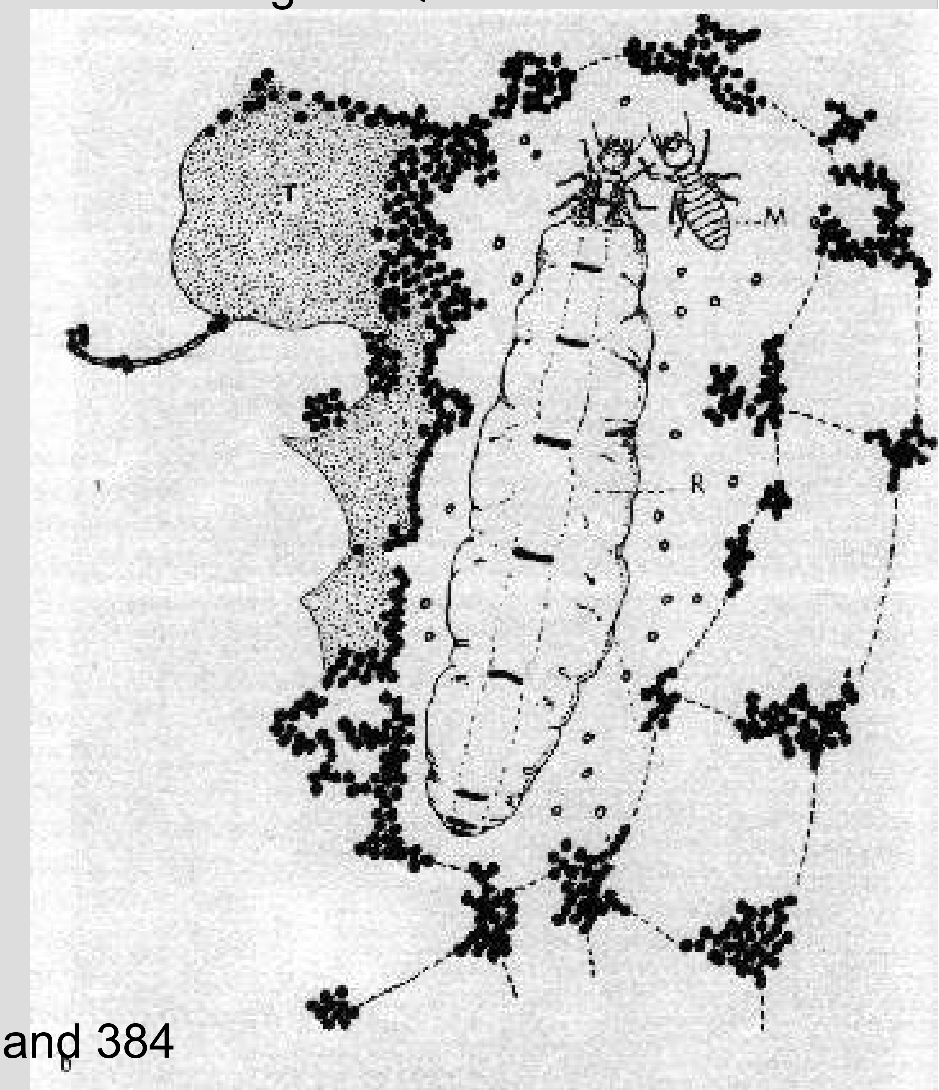
Video (German): Research on panic in Mecca
http://www.wdr.de/tv/quarks/sendungsbeitraege/2007/0410/001_schwarm.jsp


Termite Mounds

Termite mounds



Building the Queen' Chamber



From: Camazine et al., p 378 and 384

An evolutionary thought

Classically, aggregation has been viewed as an evolutionarily advantageous state (...) Complexity theory indicates that large populations of units can self-organize into aggregations that generate pattern, store information, and engage in collective decision-making. This begs the question, are all emergent properties of animal aggregations functional or are some simply pattern?

Julia Parrish, Leah Edelstein-Kashet (1999): Complexity, Pattern, and Evolutionary Trade-Offs in Animal Aggregation, Science 284 (5411); 99—101

Patterns in Nature
Outline

1. Introduction
2. Waves and oscillations
3. Regularity and chaos
4. Animal cooperation
5. Spatial patterns
6. Aggregation and growth processes
7. Cellular automata
8. Fractals
9. Miscellaneous topics
10. Concluding session