Phase Separation in Human Groups

Understanding the emergence of collective phenomena in human groups

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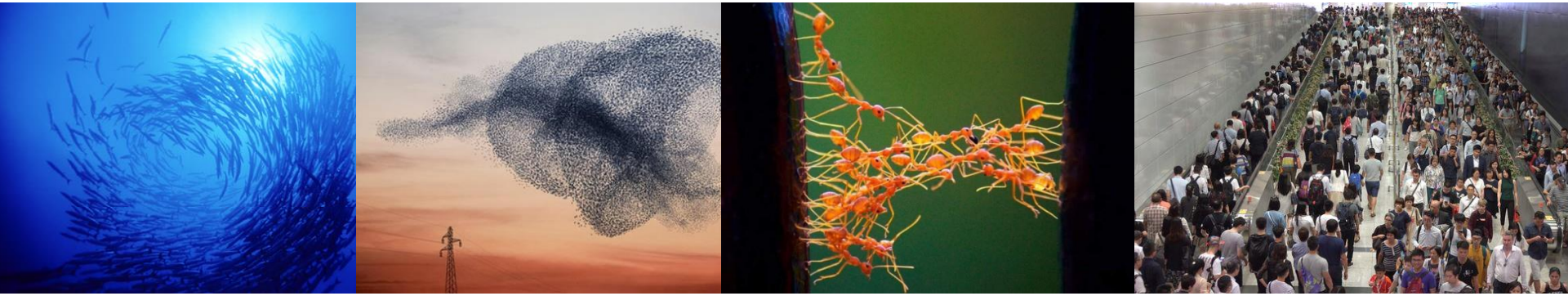
Collective phenomena



- Study of **collective phenomena emerging** from **interactions** in animal groups
- Using the **methods/tools of physics** and in an **interdisciplinary** framework
- Popularization articles in *La Recherche* (FR) and in *CNRS – Le Journal* (FR/EN)

Summary of my research in "social physics"

- **Dynamics of fish schools**
  - Measuring social interactions
  - Social interaction models – phase diagrams
  - Study of information cascades in a school
  - Effects of the ambient fluid
  - Fish and robots/VR
- **Collective phenomena in human groups**

  What is the optimal information to provide to help a human group to solve a problem?
  - Measuring social interactions
  - Social interaction models
  - Experiments and models of collective estimations
  - Experiments and models on recommender systems
  - VR behavioral Experiments and modeling

Presentation of the experimental system

- Each subject is equipped with **sensors** tracking its position in **real time**
- The sensor on the left shoulder can also **emit a "beep" controlled by the system**

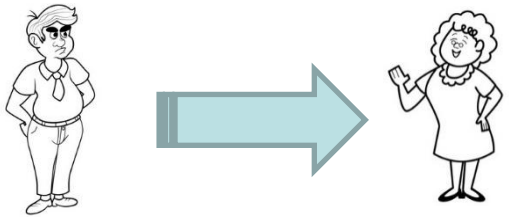
Random walk of human groups

- Recording **trajectories** of groups of 1**, 2, 5, 10, 22 subjects** walking "randomly" in one of the 3 circles marked on the ground
- This first type of experiment aims at **building a model** of walking pedestrians

Measuring social interactions

Social "forces" are mediated by **sight** (and other senses) and are generally **non-conservative**

- Newton's action-reaction law **does not apply** (and therefore no notion of "social energy")



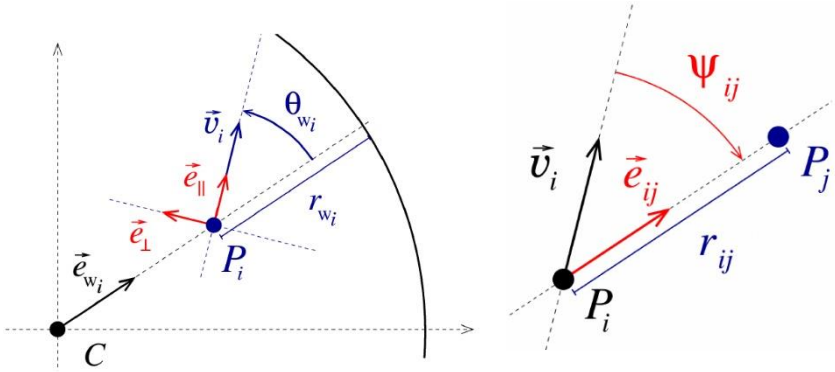
- Dependence of interactions on **velocities**
- Additivity of interactions? Notion of **most influential neighbors**
- This implies the possibility of **new collective organizations** in animal groups (compared to the physics of inert matter)

Model in the random walk phase

- **General equation of motion**

$$\frac{d\vec{v}_i}{dt} = \vec{a}_i = -A(v_i)\frac{\vec{v}_i}{v_i} + \sigma\vec{\eta}_i + \vec{F}_{w_i} + \sum_{j\neq i}\vec{F}_{h_{ij}}$$

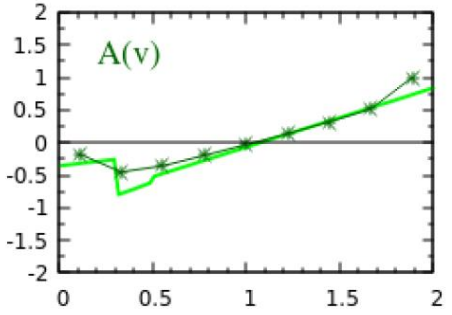
$$\frac{d\vec{x}_i}{dt} = \vec{v}_i$$



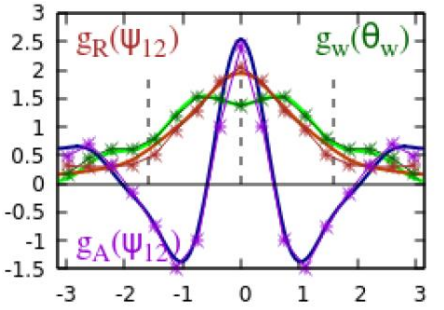
- **Minimization of the error between modeled and experimentally measured accelerations**

$$Error = \sum_{n=1}^{\#\,data} \left|\vec{a}_n - \vec{a}_{model}\right|^2$$

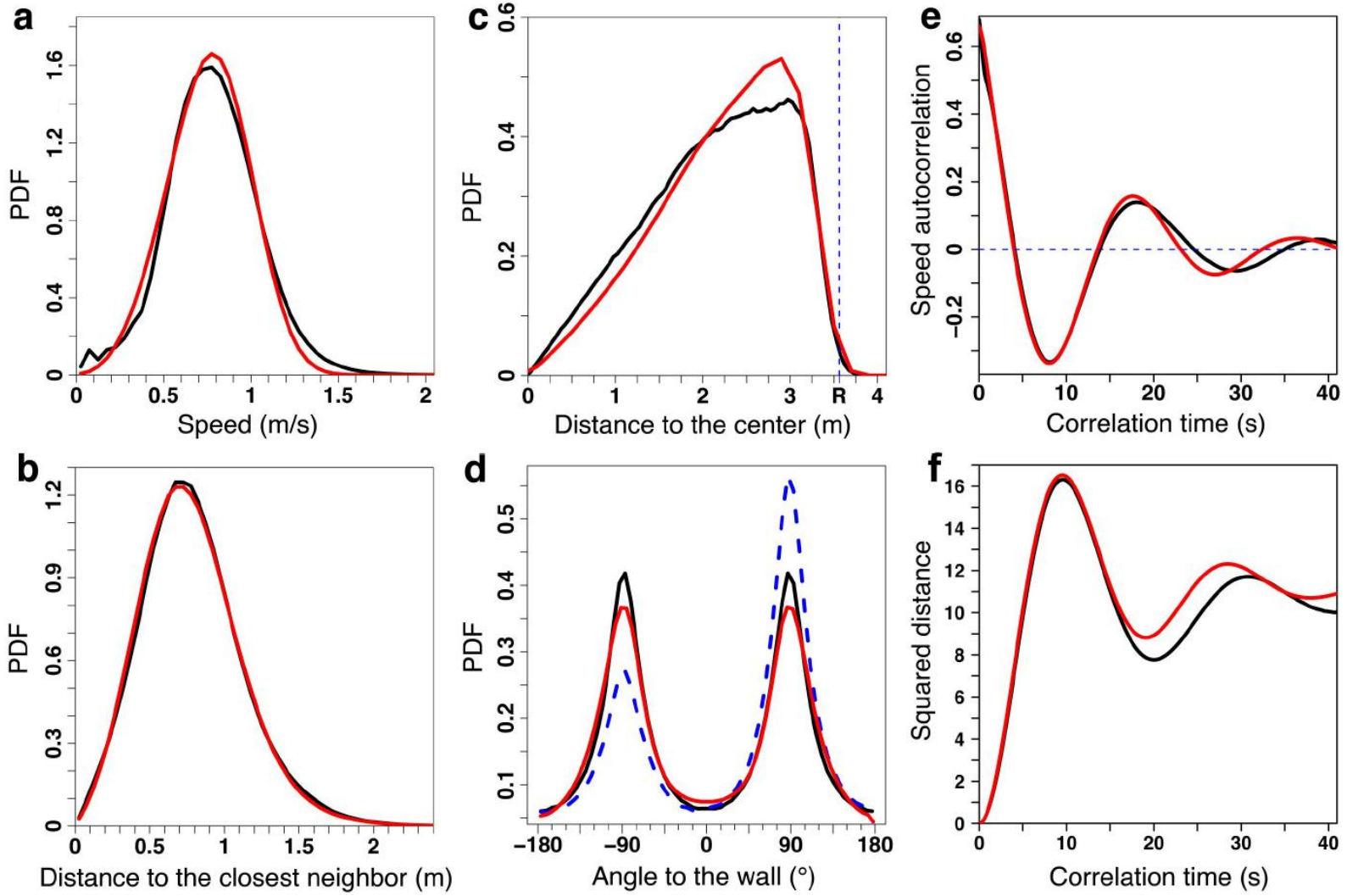
$$A(v) = \frac{v - v_0}{\tau_0}$$



$$\vec{F}_w(v, r_w, \theta_w) = -f_w(r_w)g_w(\theta_w)\vec{e}_w$$



Random walk of 22 subjects
Experiment-model comparison

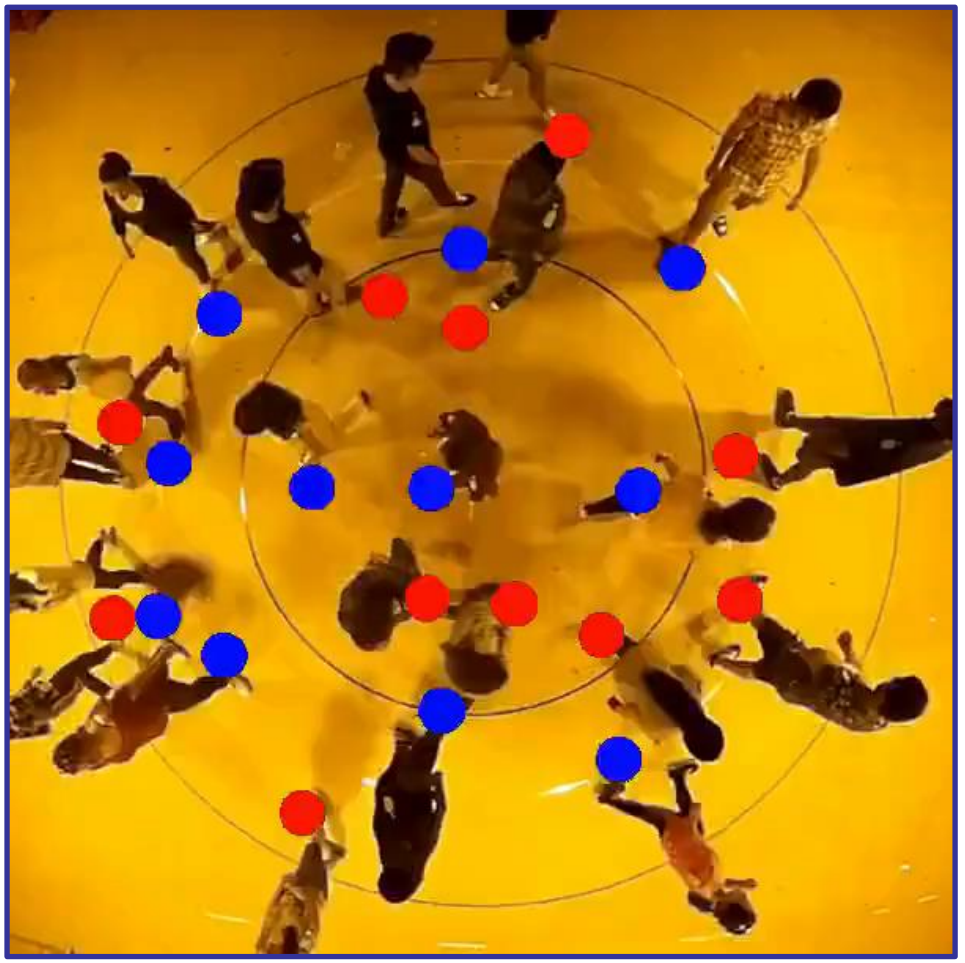


Phase separation of human groups
Overview of the experiment

- Groups of **22 individuals**
- Each subject is randomly associated with a **color** (blue/red)
- The subjects **do not know** their own color, nor that of the other subjects
- After a period of "random walking" of typically 45s (silent sensors), the left sensor of each subject **begins to "beep" when the "environment" of the subject is not of the same color as him/her**

Phase separation of human groups
Overview of the experiment

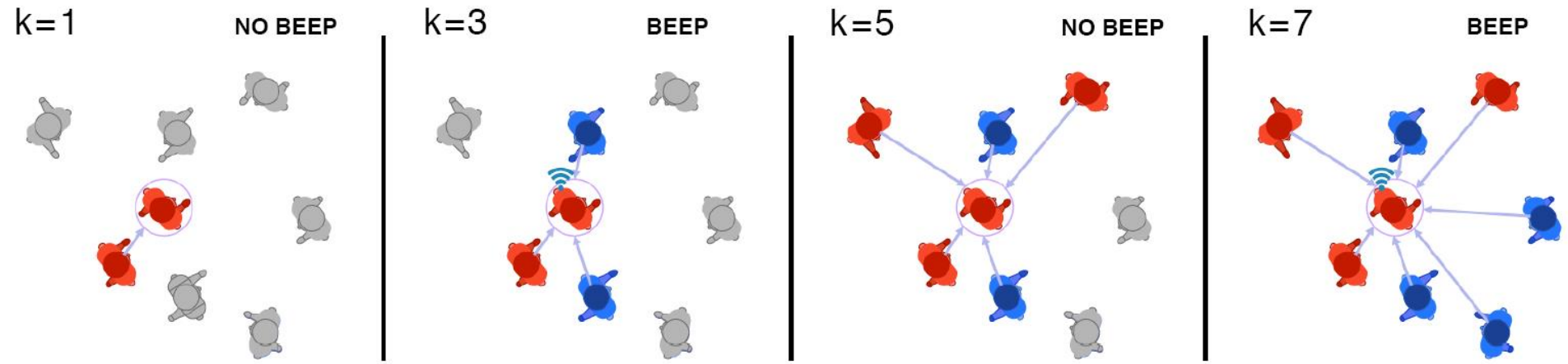
- An experimental run ends when **no more sensors beep...**



Phase separation of human groups
The "environment"

- The subjects had **no information** on the actual nature of the **"environment"** taken into account

- Without their knowledge, the environment was characterized by ***k*=1,3,5,7,9,11,13**, and a subject was beeping **if the majority of his *k* nearest neighbors were not of the same color as him/her**



Phase separation of human groups
An artificial sensory device

- For each run of the experiment, the **range *k*** was drawn "randomly" (according to a predefined protocol); **experimental control** of the value of *k*
- The "beep" constitutes an **artificial sensory device**
- Like the human eye, this device is **limited** by its **range of perception** (here, *k*), but also by a **filtering of information** (the beep, which translates a more complex information)
- This device associated to a simple binary signal does not lead to any **cognitive saturation**

Model adapted to the human phase separation experiment

- The **comfort speed** v_0 and the **cognitive noise** σ are set to zero when the agent does not beep (the agent then quickly stops)

$$\frac{d\vec{v}_i}{dt} = -\frac{v_i - v_0}{\tau_0}\frac{\vec{v}_i}{v_i} + \sigma\vec{\eta}_i + \vec{F}_{\mathrm{w}_i} + \sum_{j=1,\, j\neq i}^{N} \vec{F}_{\mathrm{h}_{ij}}$$

- v_0 and σ retake a non-zero value if the agent beeps again (the agent resumes its walk)

- In the experiment, in addition to this **simple strategy**, the subjects still beeping can also **probe preformed unicolor groups**

Human phase separation
Characterization of unicolor groups

- We define the **3-groups** recursively by connecting each individual to their neighbors of the same color among their 3 nearest neighbors

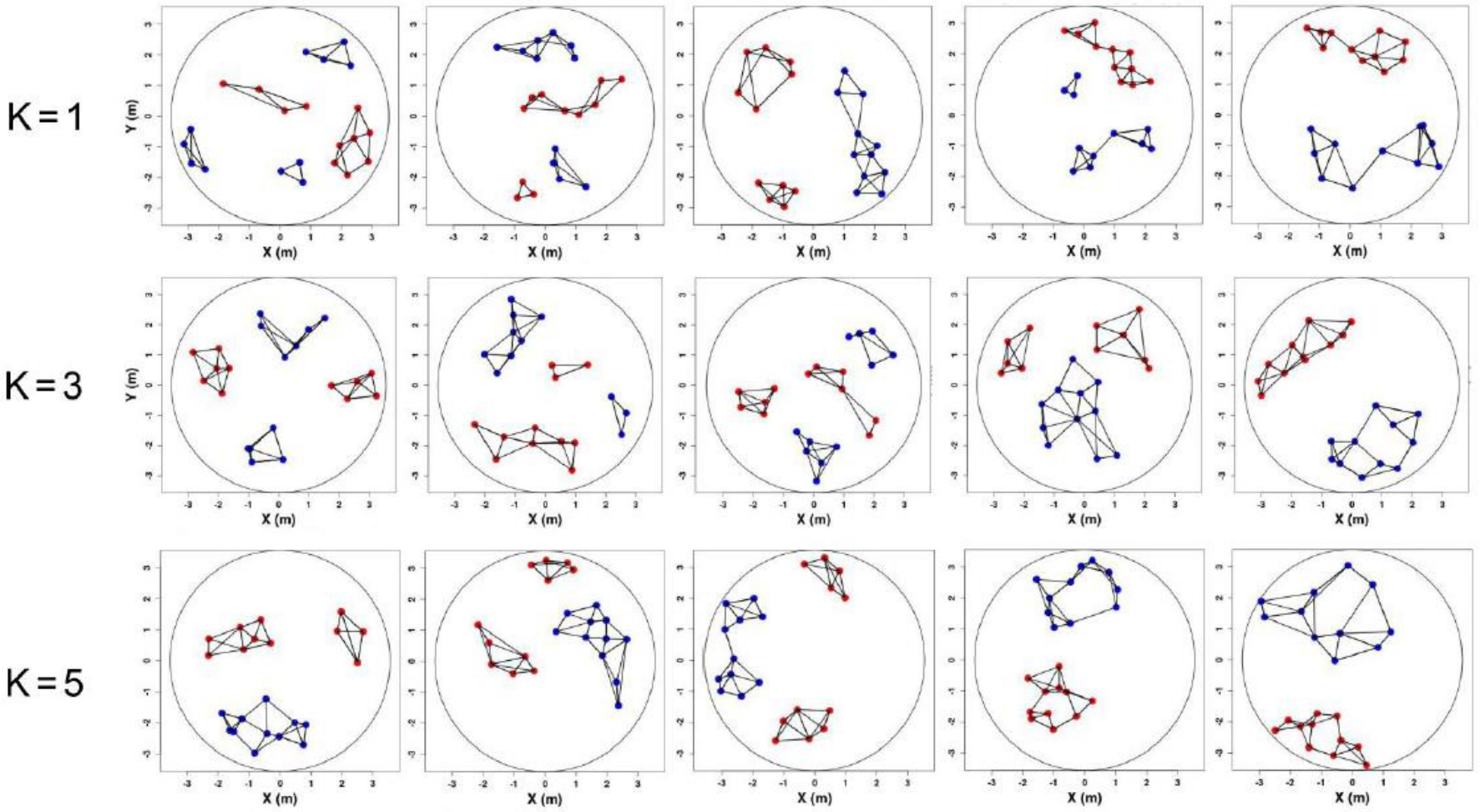
- This definition is ***k*-independent** (and consistent with the notions of Voronoi and Delaunay constructions in 2 dimensions)

- This notion of **3-groups** allows to **quantify** the **dynamics of the separation** and its **"quality"** in the final state

Human phase separation

Characterization of unicolor 3-groups in the final state

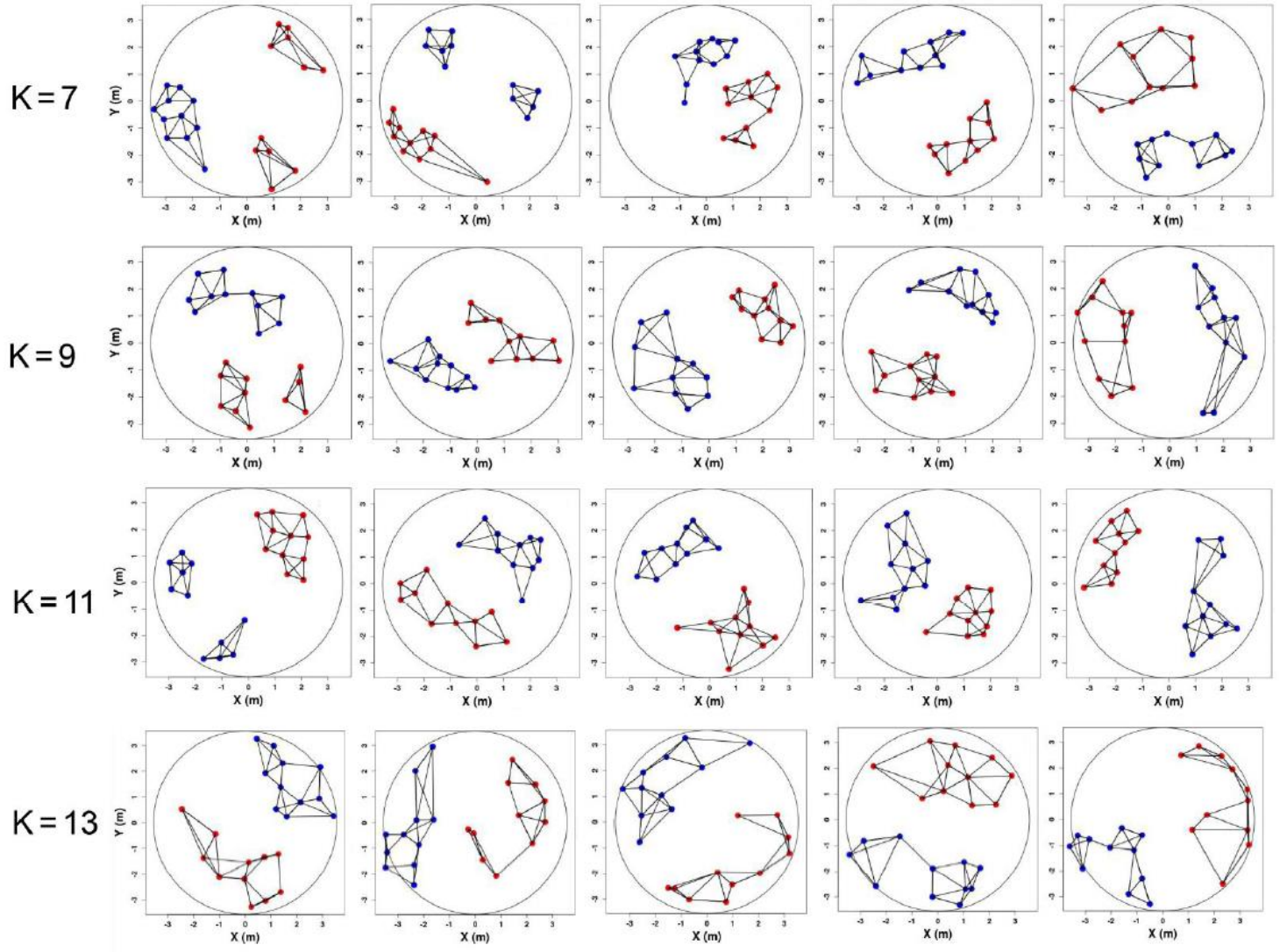
- ***k*=1,3,5 :** presence of **fragmented groups**



Human phase separation

Characterization of unicolor 3-groups in the final state

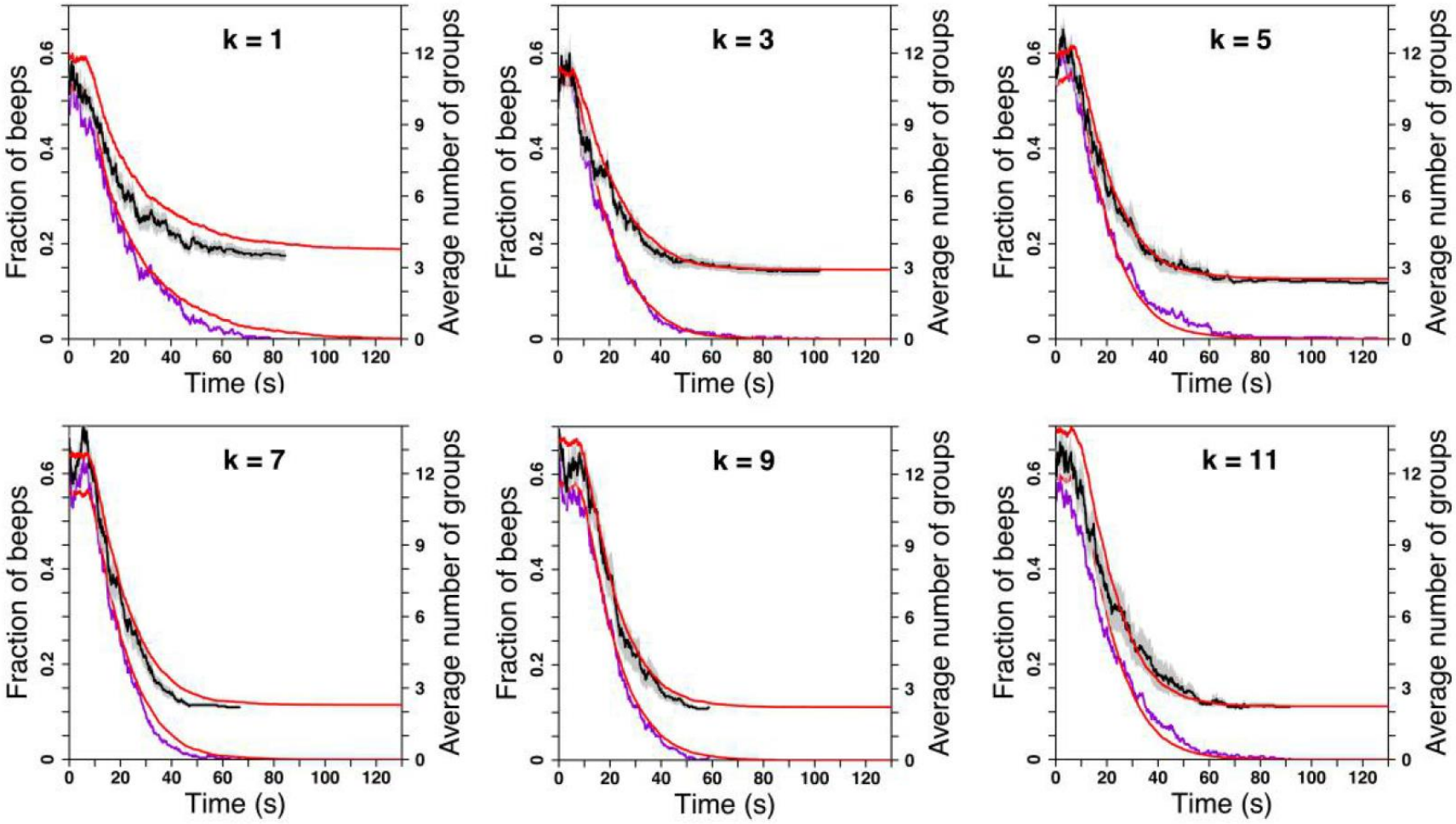
- ***k*=7,9,11,13 :** final state often **fully separated**



Human phase separation

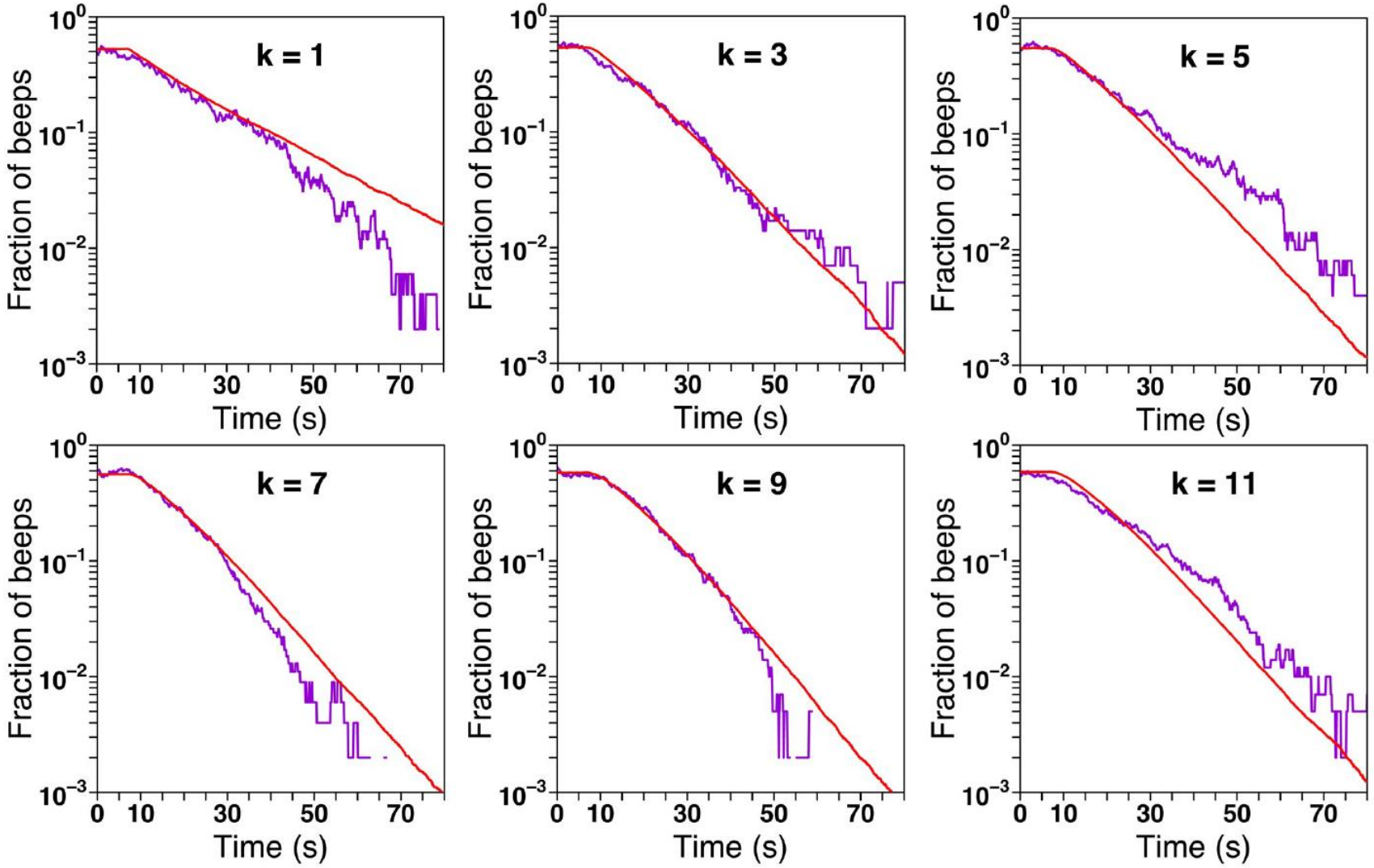
Decay of the number of beeps and groups

(model results in red)

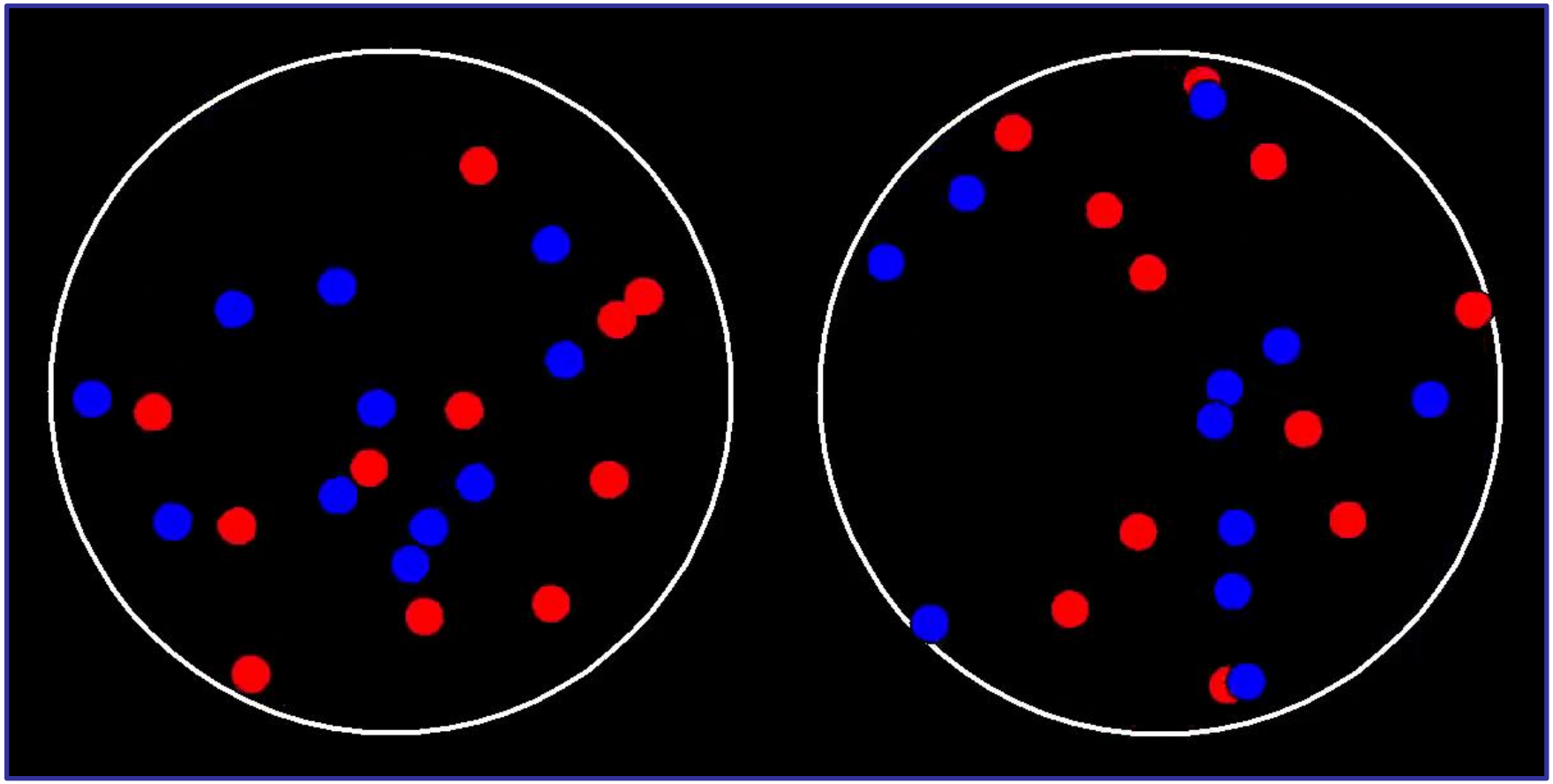


Human phase separation

Exponential decay of the number of beeps



Human phase separation (k = 3)

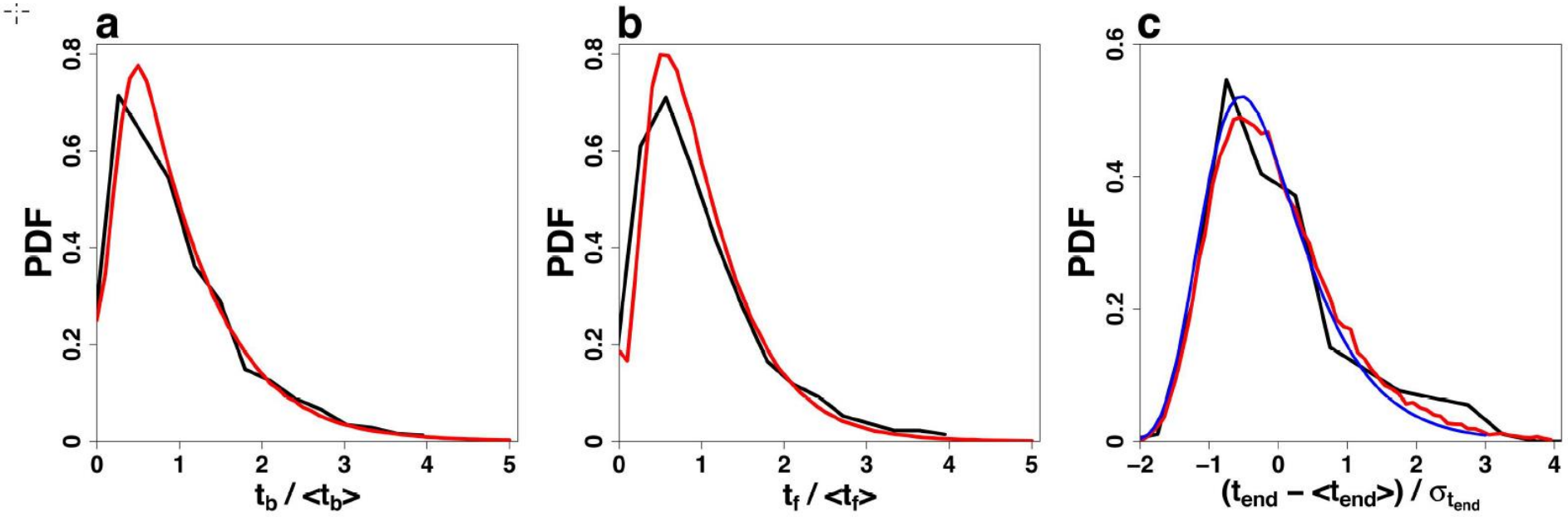


Experiment vs Simulations

Human phase separation
Duration of the beeping periods

Probability distribution functions (PDF) of

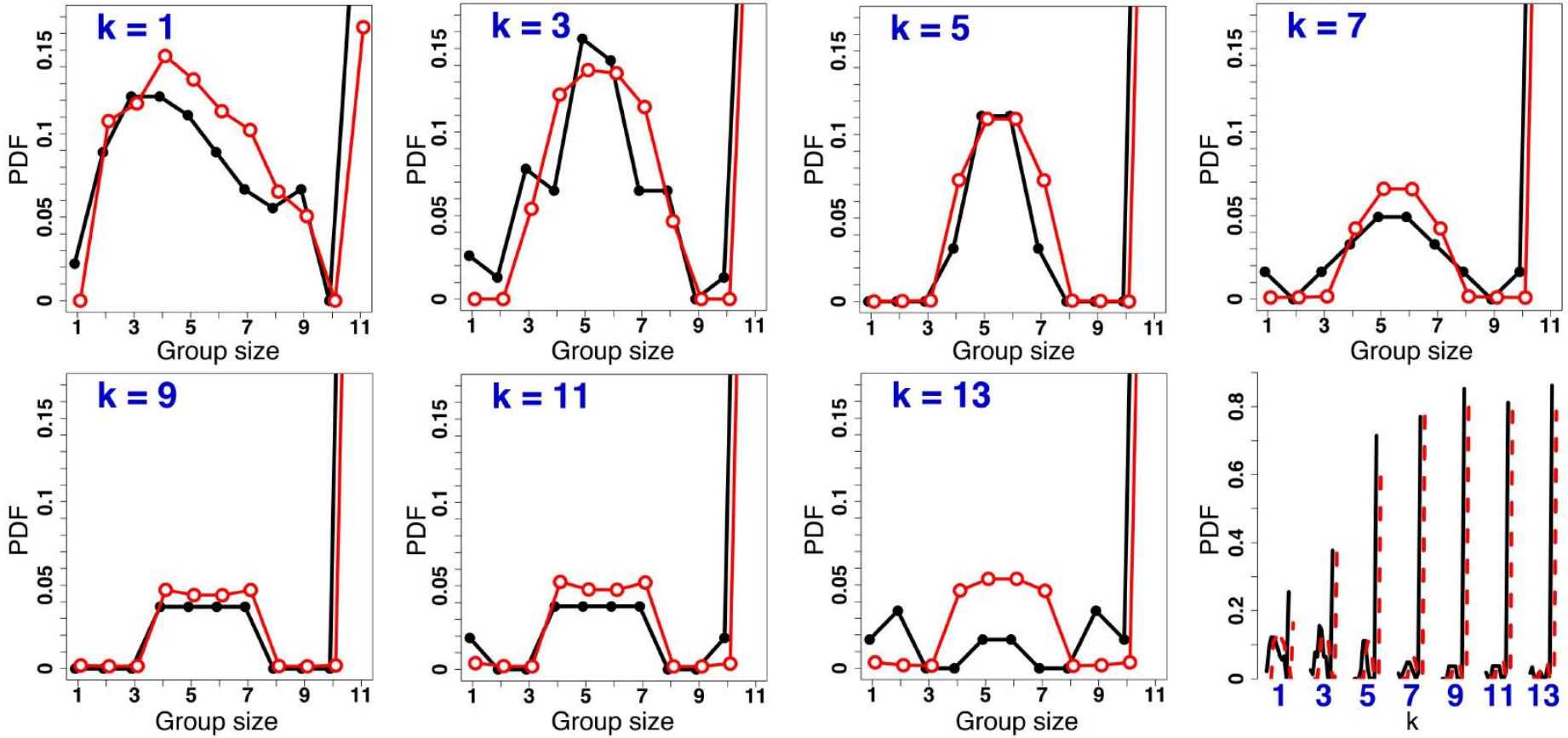
a) total duration of each subject's beeping periods
b) final time of the individual beeping period
c) total duration of an experiment (comparison with the Gumbel distribution – extreme statistics)



Human phase separation

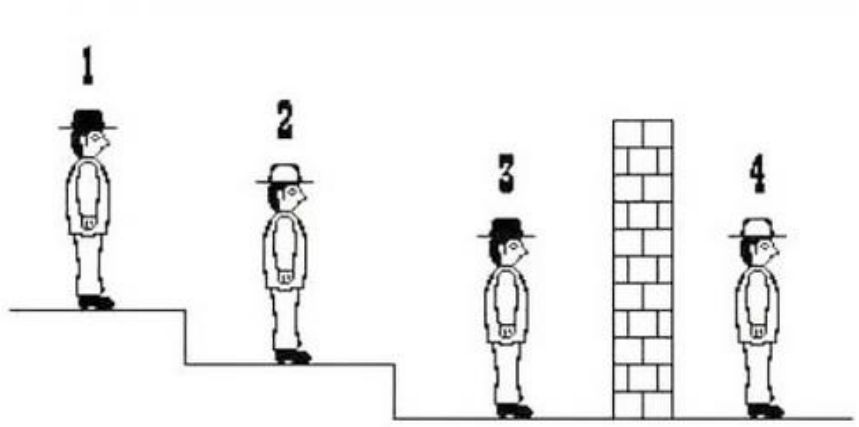
Distribution of unicolor 3-groups in the final state

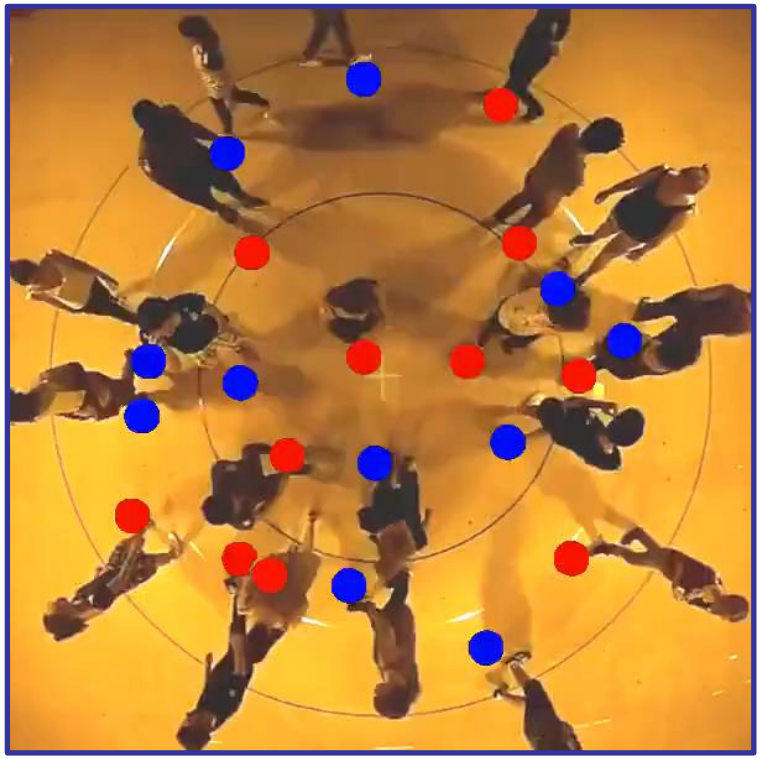
(25 to 30 experimental runs per value of k)



Human phase separation + instruction to form 2 clearly identifiable groups

- This **"strategy"** is natural, but is only effectively implemented when the **subjects know that it is shared by all**
- Analogy with **“prisoners and hats”** problems

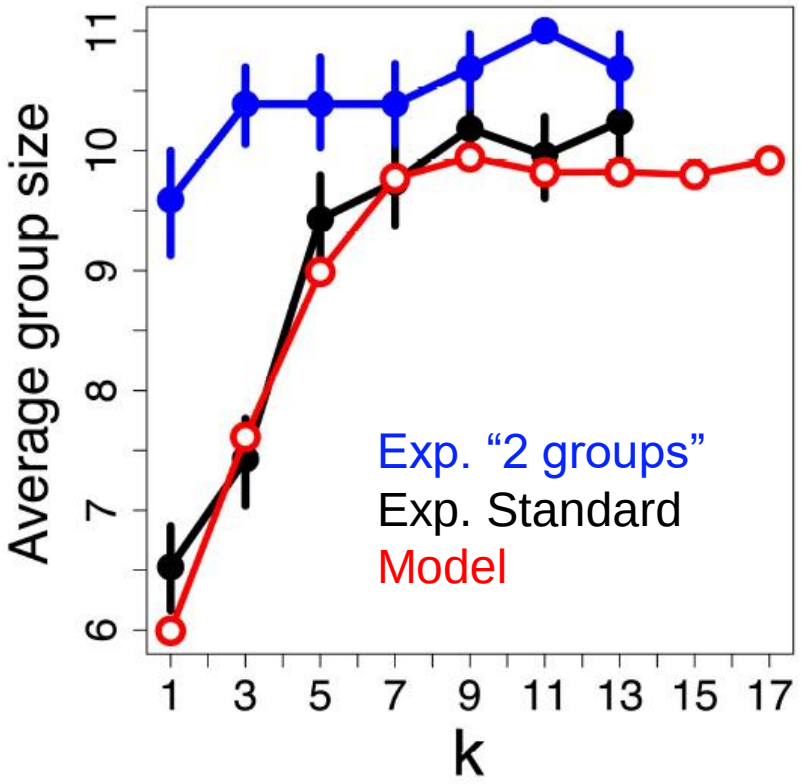


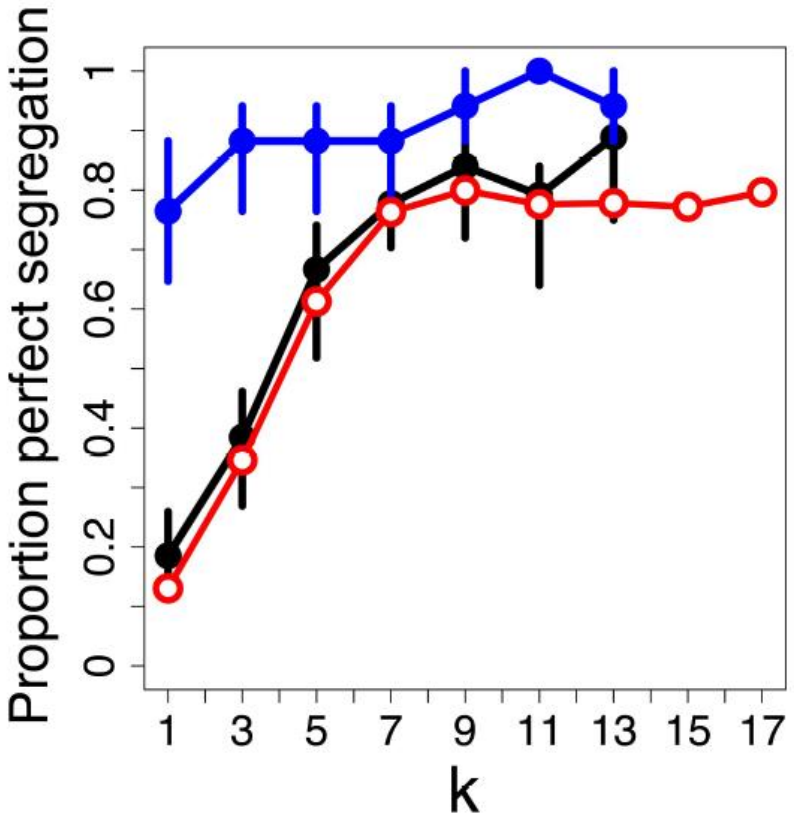


Human phase separation

Characterization of the separation in the final state

- Above $k \sim 7$ (in general, $k \sim N/3$), we observe a **saturation of the quality of the separation**

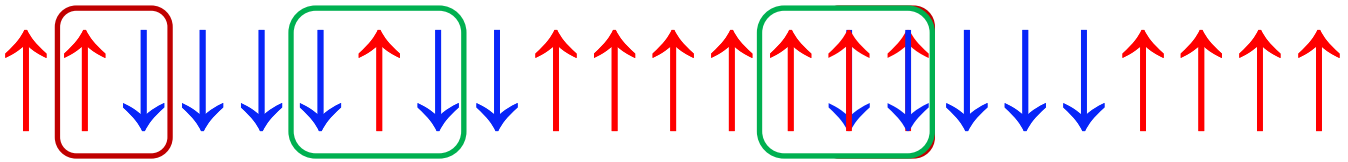




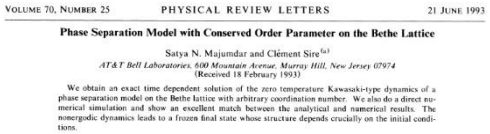
Human phase separation

Analogy with a zero-temperature physical phase separation

- **Conserved model of ferromagnetic spins in dimension 1 and at $T=0$... equivalent to $k=2$!**
  (an agent beeps and moves if it is surrounded by $k=2$ agents of opposite color)
  MC exchange dynamics (Kawasaki) at $T=0$



- With Satya Majumdar, we solved this spin model exactly … **in 1993!**



VOLUME 70, NUMBER 25 PHYSICAL REVIEW LETTERS 21 JUNE 1993

Phase Separation Model with Conserved Order Parameter on the Bethe Lattice

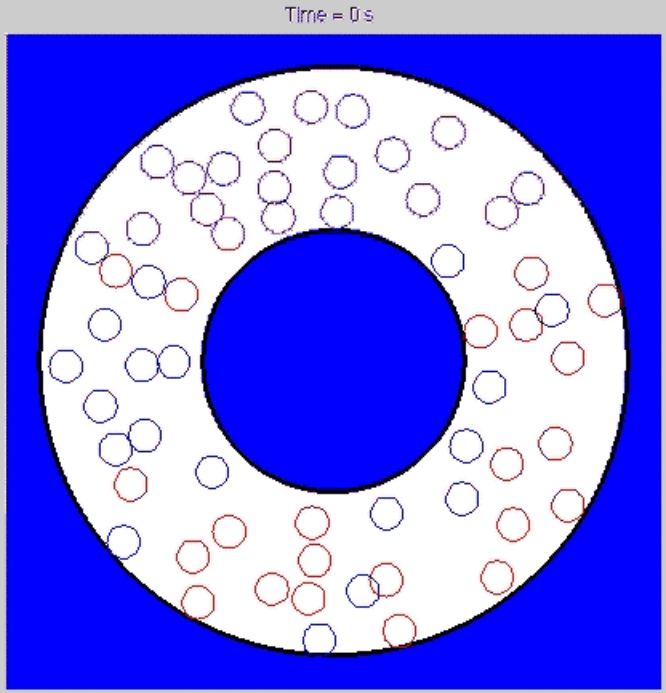
Satya N. Majumdar and Clément Sire[(a)]
AT&T Bell Laboratories, 600 Mountain Avenue, Murray Hill, New Jersey 07974
(Received 18 February 1993)

We obtain an exact time dependent solution of the zero temperature Kawasaki-type dynamics of a phase separation model on the Bethe lattice with arbitrary coordination number. We also do a direct numerical simulation and show an excellent match between the analytical and numerical results. The nonergodic dynamics leads to a frozen final state whose structure depends crucially on the initial conditions.

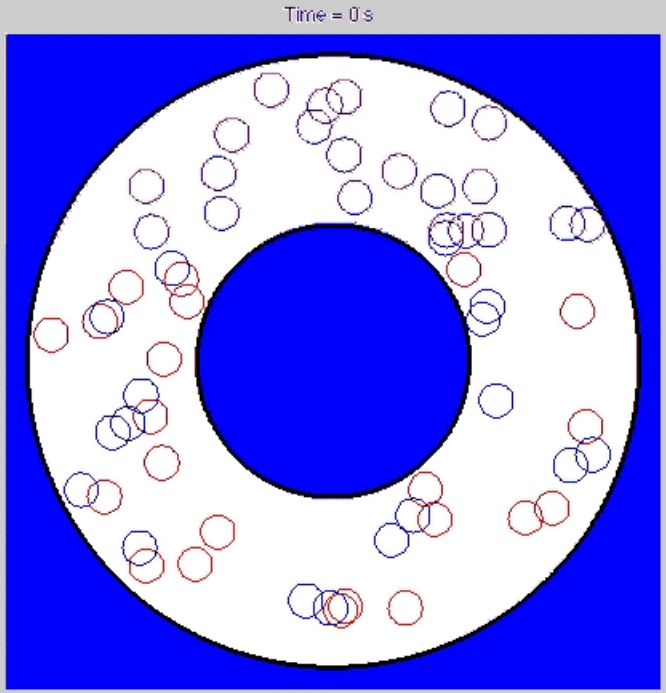
  - Exponential decay of the number of interfaces/beeps
  - Statistics of group sizes in the final state (and at all times)

Spontaneous formation of pedestrian lines (sidewalk, metro corridor...)

Experiment



Model



Cocktail dynamics

Conclusion

- Very rich **collective behaviors** can **emerge** from **social interactions** between individuals in a group
- These experiments allow us to **quantitatively measure social interactions** and implement them in a **model of pedestrian walk**
- The very simple **sensory device** that equips our subjects nevertheless allows them to **solve the problem** (with an optimal range $k \sim 7$)
- Model in **quantitative agreement** with experiments and precise analogy with a **physical phase separation**
- The understanding and control of **separation, segregation, polarization phenomena** are relevant in many **social contexts** (alerting the members of a social network when their environment becomes too polarized?)

Merci de votre attention !

Et merci à mes collaborateurs :

- ***G. Theraulaz et R. Escobedo au CRCA,***
- ***B. Jayles (LPT & CRCA),***
- ***G. Tredan, M. Roy, R. Pasqua, C. Zanon (LAAS),***
- ***A. Blanchet (TSE)***

Références :

- *Collective information processing in human phase separation*, B. Jayles, R. Escobedo, R. Pasqua, C. Zanon, A. Blanchet, M. Roy, G. Tredan, G. Theraulaz, and C. Sire, *Phil. Trans. R. Soc*., B37520190801 (2020).

- ***Article dans « CNRS – Le Journal »***

Présentation téléchargeable (avec d'autres séminaires/vidéos/textes de vulgarisation) sur ma page sur le site du LPT Toulouse