UNIVERSITAT DE BARCELONA

AI from and for Complex Systems

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INTEL·LIGÈNCIA ARTIFICIAL (IA):
RECERCA I SOCIETAT
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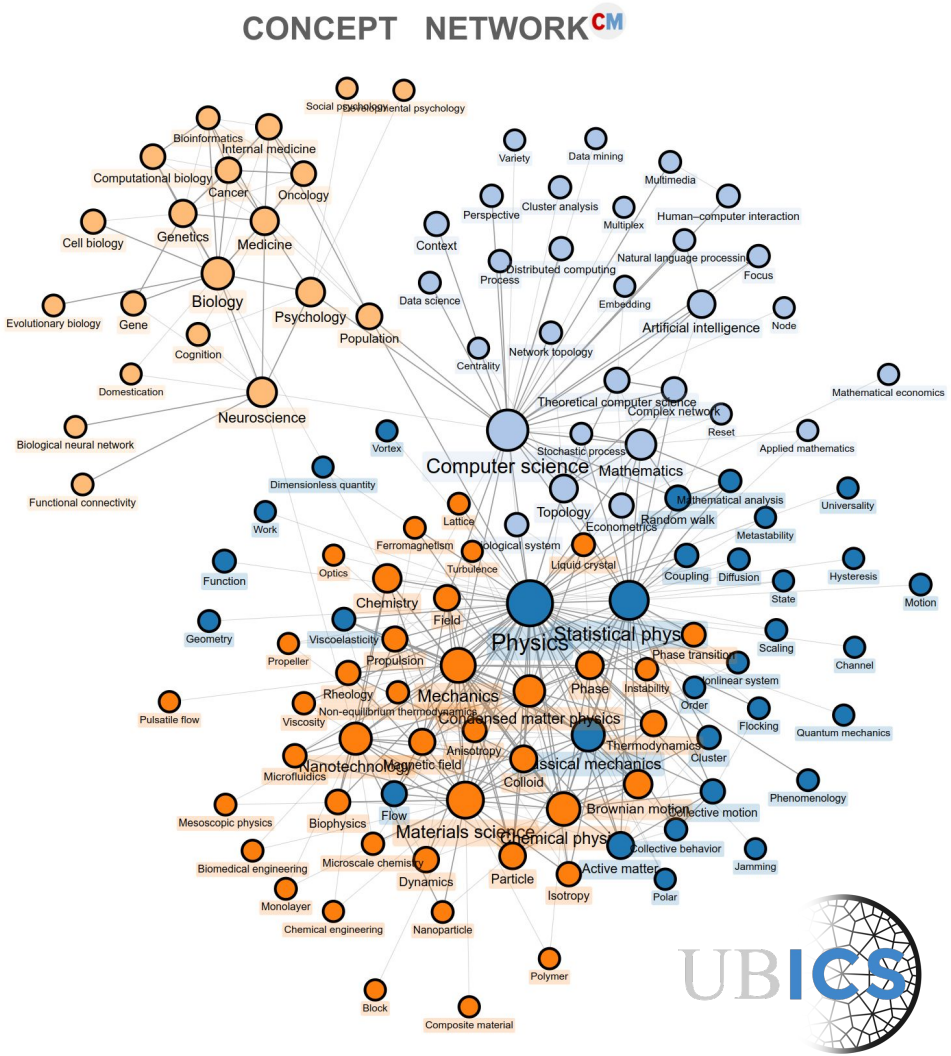
UBICS

UBICS, a truly multidisciplinary institute

The map of the most frequent topics covered by our publications shows the interdisciplinarity of the research.

Not appearing yet here but also present: Archeology, Climate Science, Economy and Linguistics.



http://complemetrix.net/html/ubics-ror.html

AI and ML research from Complex Systems

Many aspects of AI research grew in parallel with the Complex System research.

E.g. Intelligence as an **emergent phenomenon** of the dynamics of a (complex) network of interconnected neurons.

- Hopfield and Tank (1986) In “Computing with Neural Circuits: A Model”

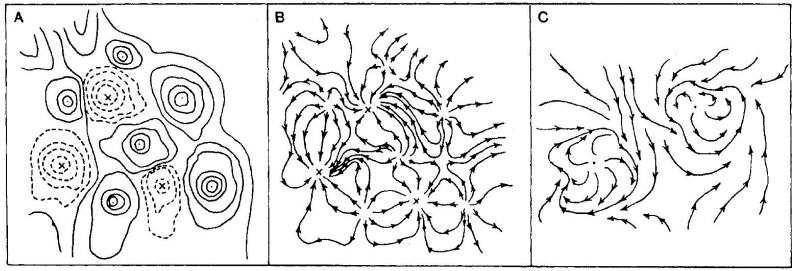


Fig. 4. (A) Energy-terrain contour map for the flow map shown in (B). (B) Typical flow map of neural dynamics for the circuit of Fig. 3 for symmetric connections ($T_{ij} = T_{ji}$). (C) More complicated dynamics that can occur for unrestricted (T_{ij}). Limit cycles are possible.

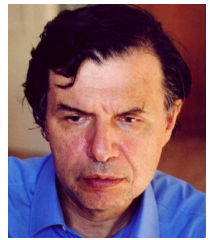
Another example is the origin of Reinforcement learning, Klopf (1972), inspired by **adaptive systems.**

AI and ML research from Complex Systems

Neural networks learn by optimizing their parameters W

E.g. minimizing $$\mathcal{L} = \frac{1}{m}\sum_{i=1}^{m}\left(\boldsymbol{y}^{(i)} - \hat{\boldsymbol{y}}\left(\boldsymbol{x}^{(i)}; \boldsymbol{W}\right)\right)^2$$

Many insights in the study of the landscape come from the analogy with **Spin-glasses**.
The models of disordered complex materials are helping understand why NNs challenge the theory of ML and generalization.



"Our world is full of complex systems characterised by randomness and disorder. Around 1980, Giorgio Parisi discovered hidden patterns in disordered complex materials. His discoveries are among the most important contributions to the theory of complex systems. They make it possible to understand and describe many different and apparently entirely random materials and phenomena, not only in physics but also in other, very different areas, such as mathematics, biology, neuroscience and machine learning."
[Giorgio Parisi – Facts – 2021. NobelPrize.org. Nobel Prize Outreach AB 2024. Mon. 12 Feb 2024. <https://www.nobelprize.org/prizes/physics/2021/parisi/facts/>]

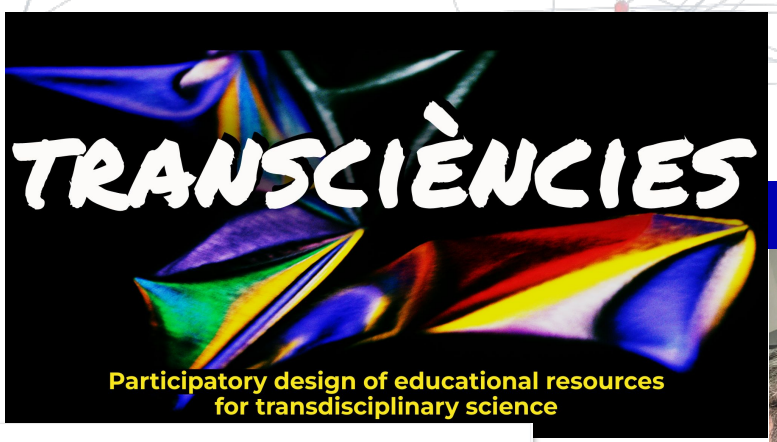
Choromanska, A., Henaff, M., Mathieu, M., Arous, G. B., & LeCun, Y. (2015, February). The loss surfaces of multilayer networks. In Artificial intelligence and statistics (pp. 192-204). PMLR

AI and ML research for Complex Systems

Complex System Science is a strongly data driven discipline.
For UBICS research, ML is an essential tool:

- Supervised learning
- Unsupervised learning
  (e.g. community detection)
- Generative models:
  - Simulation of physical systems
  - Large language models for data integration and ABM for social dynamics
- Embedding models (e.g. network embedding)
- xAI: Explainable AI and machine learning explanations

ML for social science experiments
the Schelling model



EL JOC DE

from simulation to human playing

SCHELLING

Luce Prignano

Aleix Nicolás

Irene Ferri

Emanuele Cozzo

https://transciencies.wixsite.com

HEURÍSTICA

UBICS

ICUB Institut de Cultura

Ajuntament de Barcelona

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The Schelling model of segregation

Schelling 1971

A model demonstrating how, within a two-group society, a mere preference to *avoid being in the minority* can drive **segregation**, absent any regulatory mechanisms.

The model:

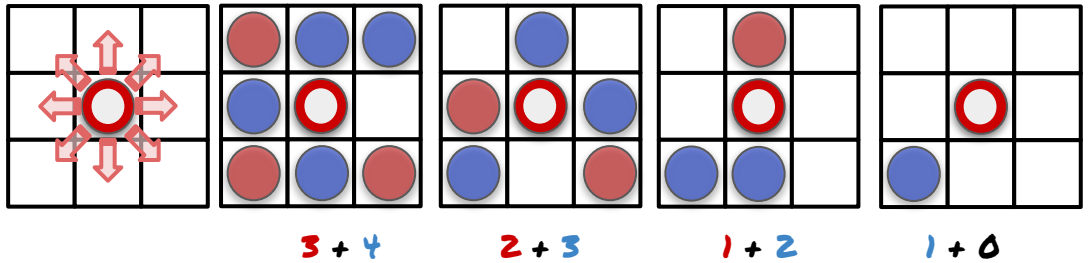
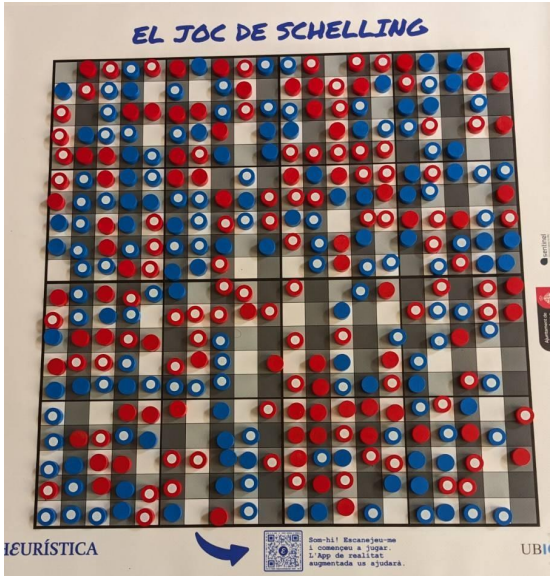


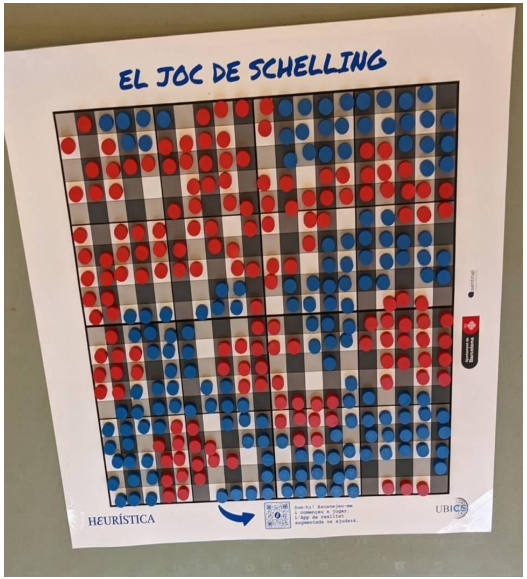
Image credits to:
Luce Prignano

- Each agent occupies a random position in a grid.
- If the number of neighbors belonging to the other group exceeds the neighbors of its own group, the agent is dissatisfied (or unhappy)
- At each step, an unhappy agent moves to any other cell in the grid where it will be satisfied (happy)
- The dynamics end when all the agents are happy.

How does the game look like?

Initial state: random positions





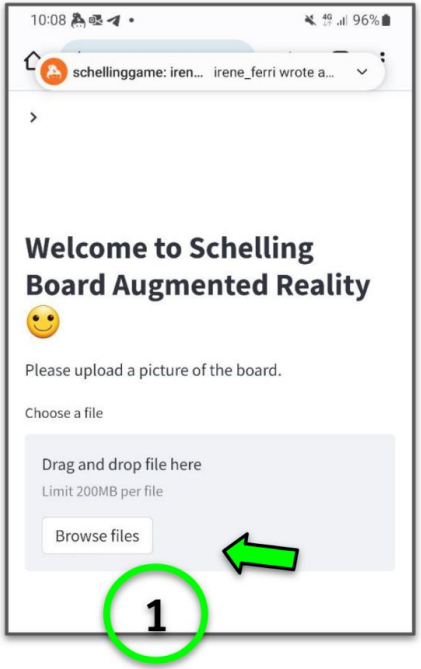
Final state: All the agents are happy.

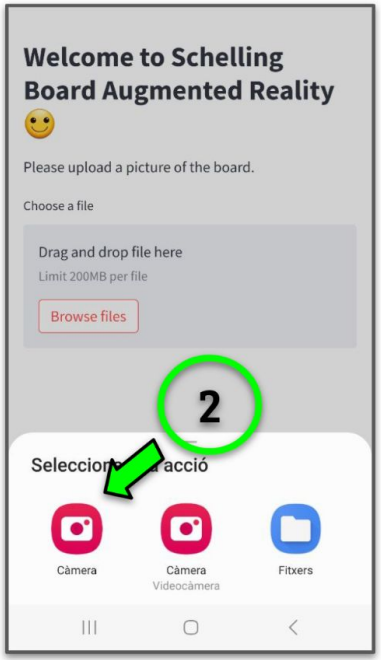
Checking that at each step all the rules of the models are correctly applied is challenging and time-consuming.

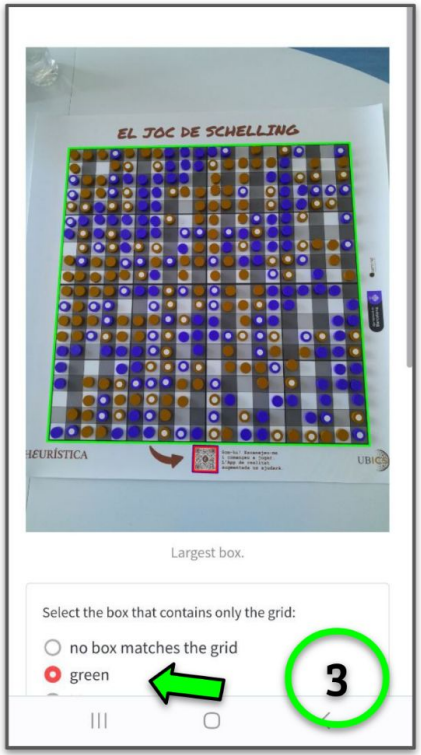
A neural network app that augments reality can be of help!

COM FER SERVIR L'APP

ESCANEJA EL CODI QR I COMENÇA A FER FOTOS







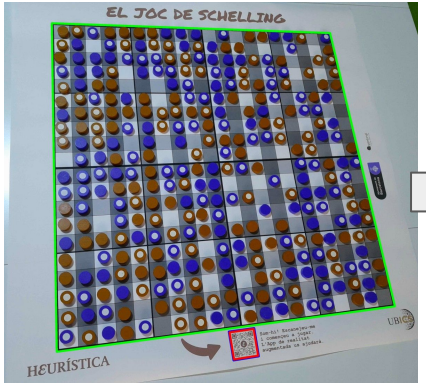
https://github.com/dimitri-mar/SchellingBoardAR

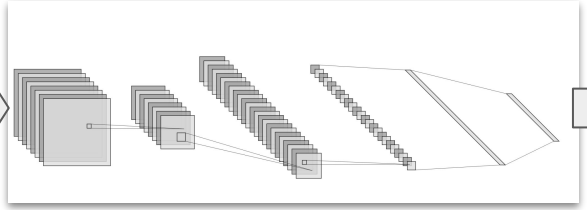
Image credits: Luce Prignano

How the App works: Some Computer Vision

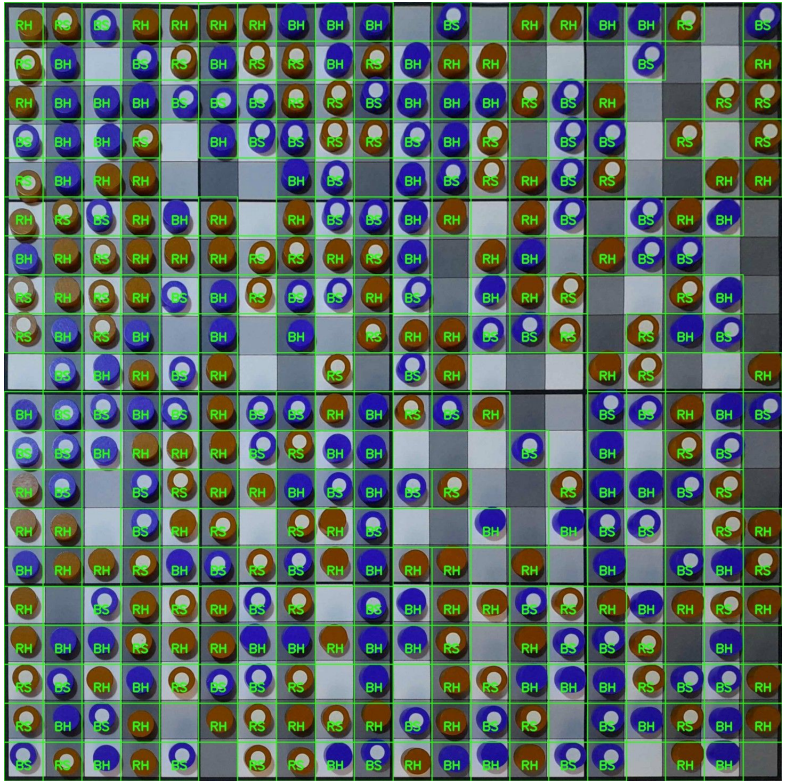
Two computer vision algorithms, combined with a convolutional neural network:

- First, it looks for all the quadrangles in a preprocessed image (Black and white with noise reduction)
- Then, it shows you the three quadrangles with the largest area.
- From the box, it corrects the perspective.





A convolutional NN classifies the agents and their state.

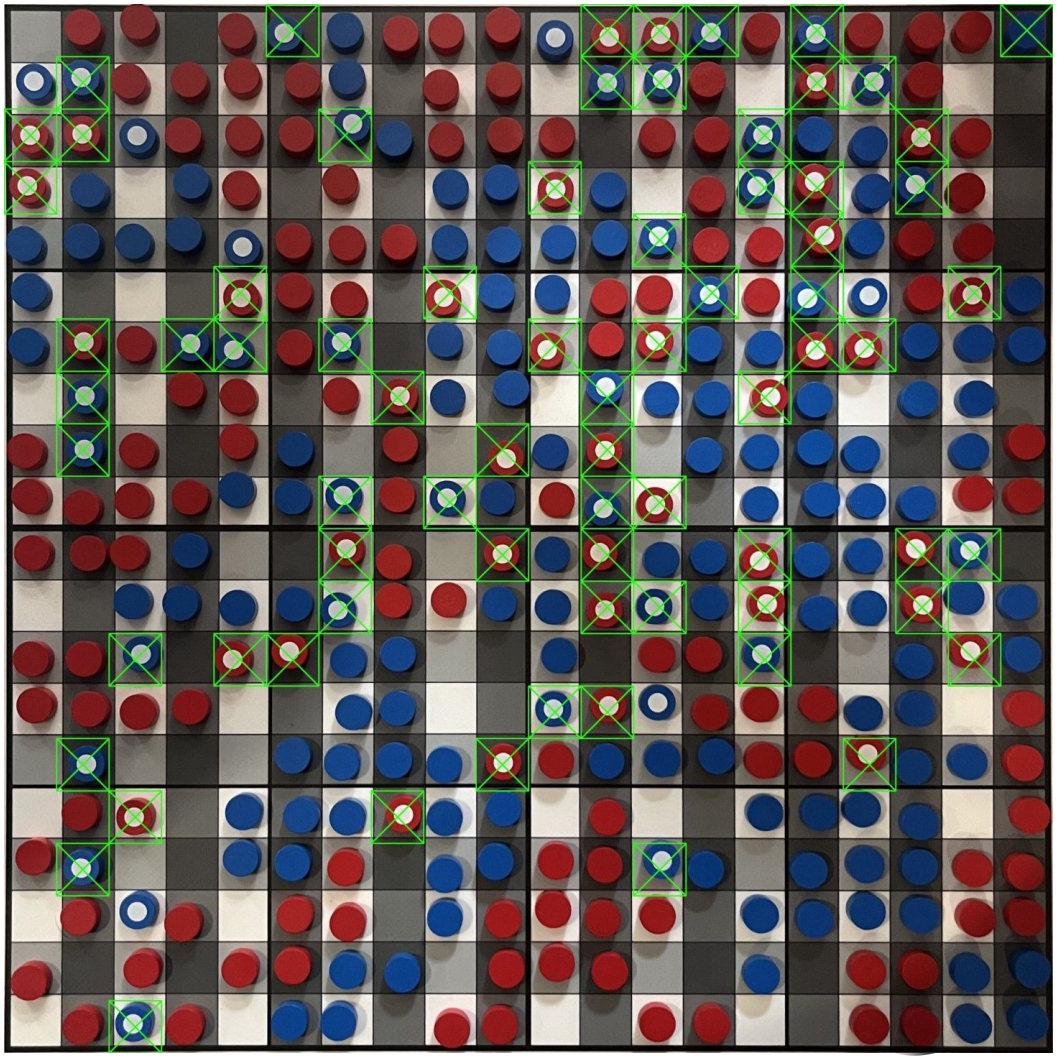


https://github.com/dimitri-mar/SchellingBoardAR

It *informs you* on which agents you need to flip from happy to sad or from sad to happy.

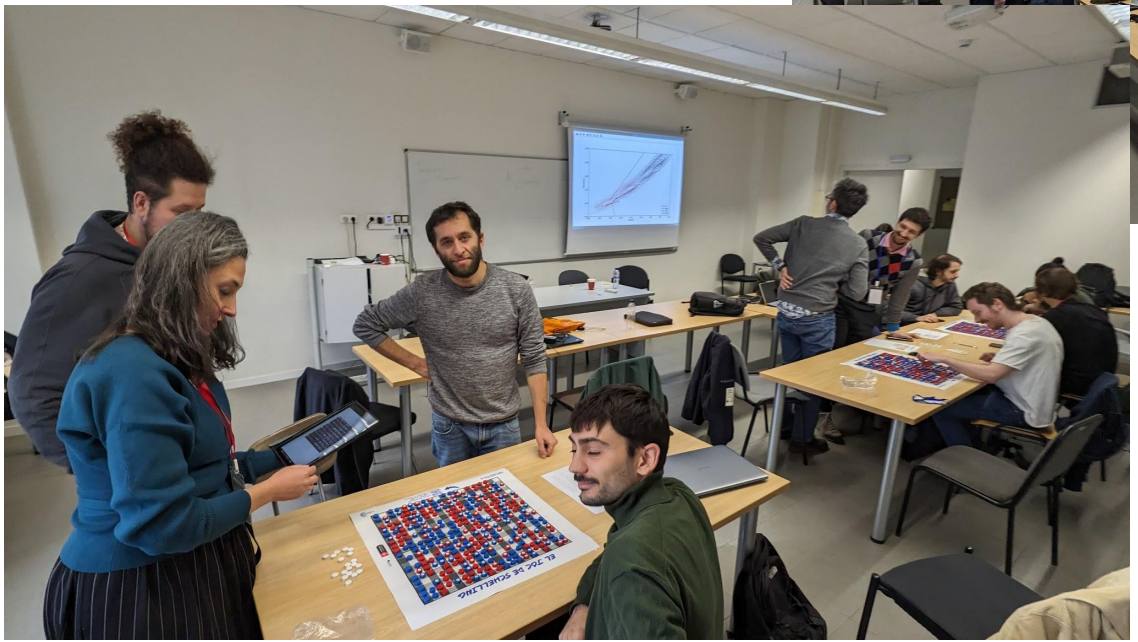
Moreover, it computes the percentage of happy agents and the degree of segregation in the board.

Now we can measure the game's progress and store the data in a centralized database.



SMS-Social Modelling and Simulations

4 tables. ~20-30 participants



We asked:
Can you beat simulations and reduce the segregation?

End with all agent happy

Complexitat day 2023 - Complexitat.cat

10 tables. ~60-80 participants

We asked:
Can you beat simulations and reduce the segregation?

Fixed time.

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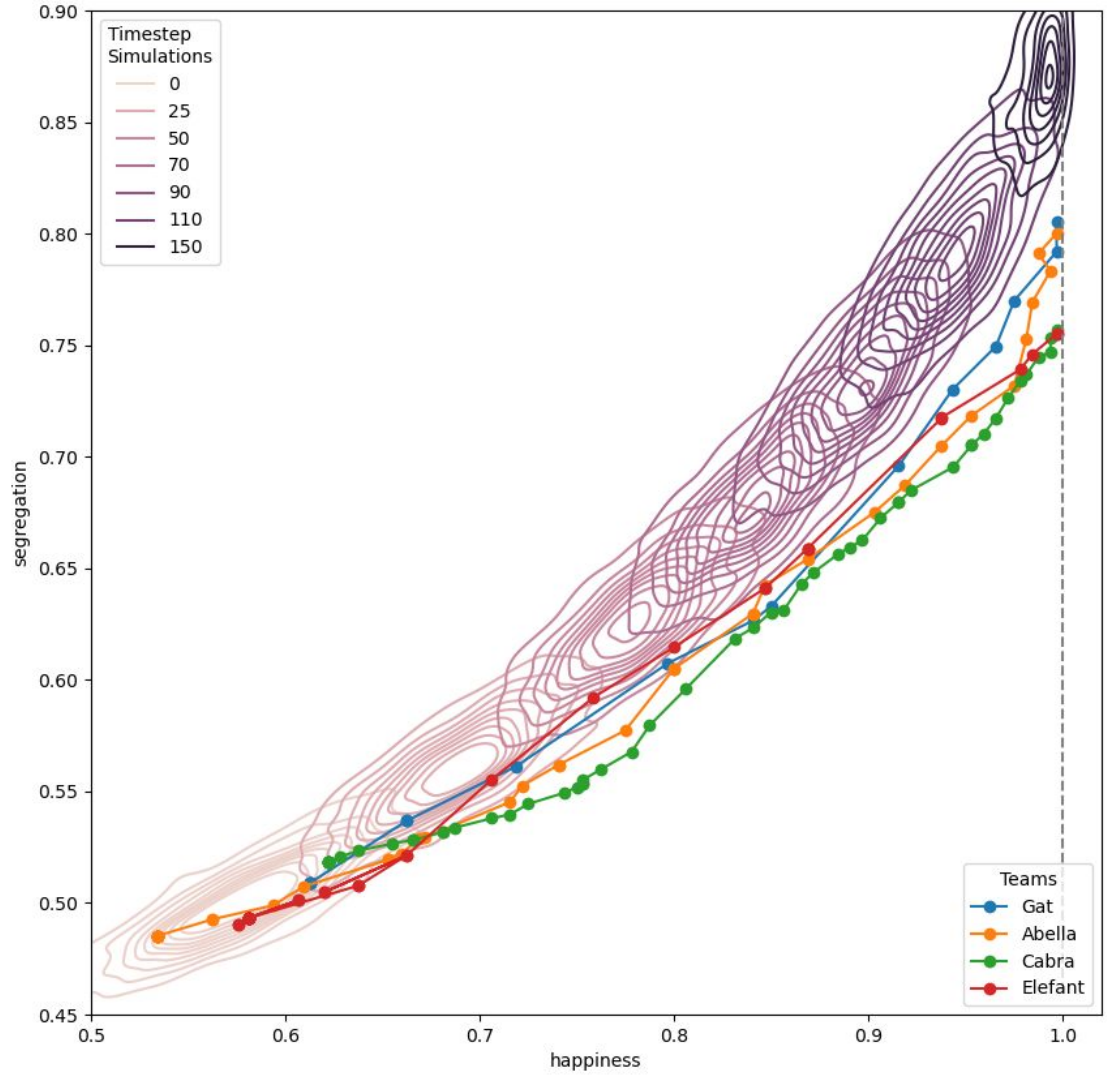

Trajectories vs Simulations for each table

We asked:
Can you beat simulations and reduce the segregation?

Data from the *SMS-Social Modelling and Simulations*
December 2023

Simulations by E. Cozzo

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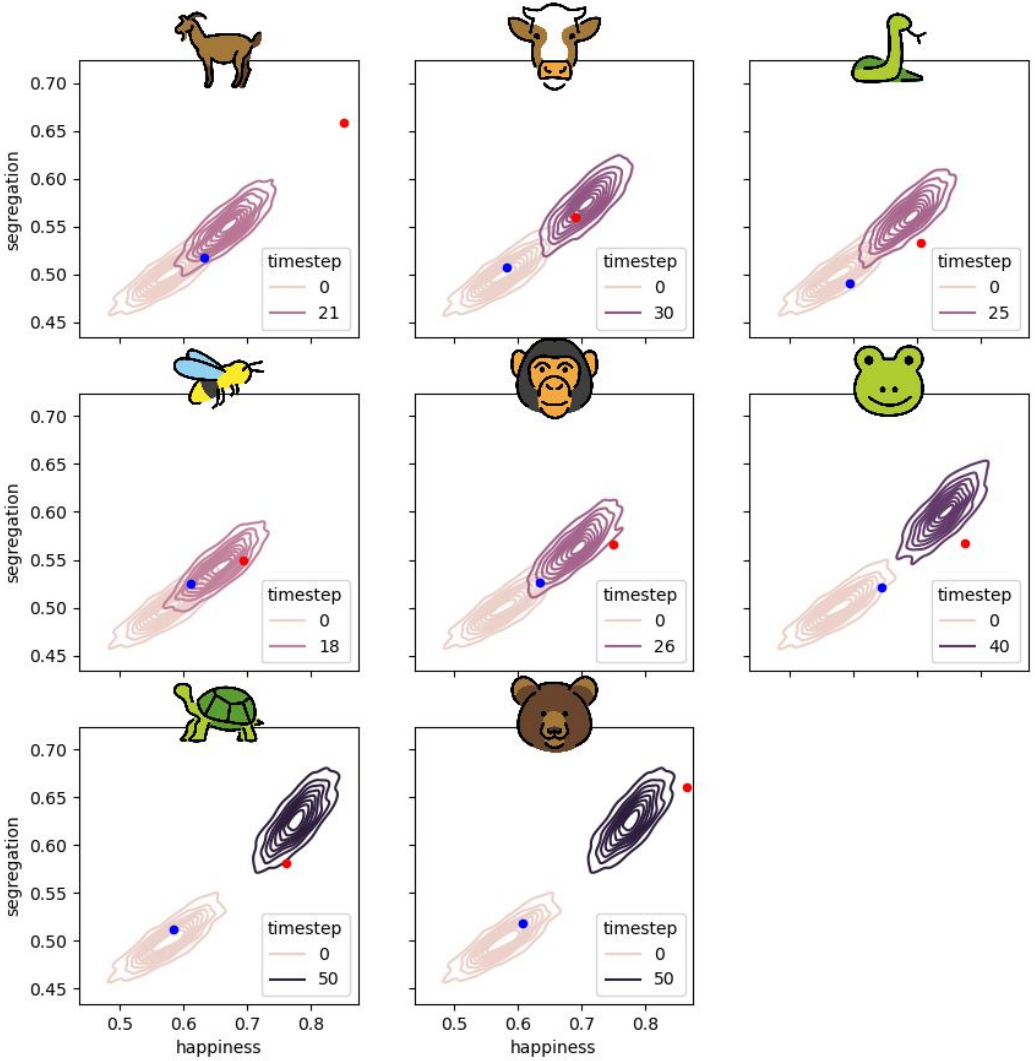

Trajectories vs Simulations for each table

Blue: initial point
Red: final point

N. steps information from the players.

Data from the
Complexity day 2023
June 2023
Finite time.

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Recommendation Systems to facilitate scientific collaborations

Based on Open Data (OpenAlex dataset)

Can we facilitate the scientific collaboration among researchers in the Alliance?

University of Barcelona, Trinity College Dublin, Utrecht University, the University of Montpellier, Eötvös Loránd University Budapest, Åbo Akademi University, Julius-Maximilians-University Würzburg, Ruhr West University of Applied Sciences and the University of Bergen

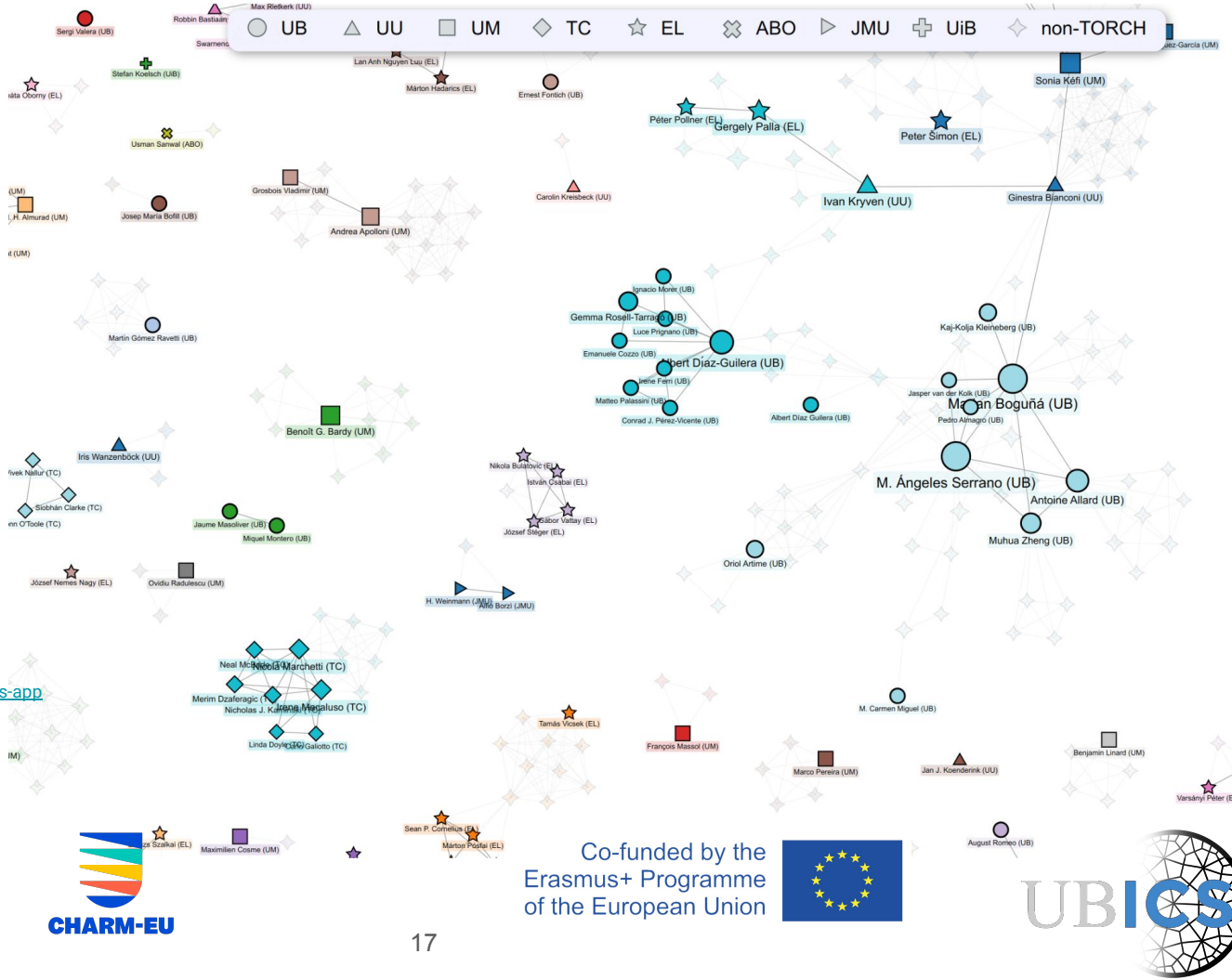
https://www.charm-eu.eu/collaboration-networks-app

Recommendation Systems to facilitate scientific collaborations

Based on paper citation network one can look for collaborators working on the same field.

(keyword:
Complex systems)

https://www.charm-eu.eu/collaboration-networks-app



Conclusions

AI is a growing part of UBICS research:

- Complex system research helps understand AI models and their limits, studying intelligence as an emergent phenomenon.

- AI opens new opportunities in studying complex systems:
  - on **the model** side of the research,
  - on the **data-driven** (experiments and data science) side.

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Thank you!