Sistemas Complexos e o Prêmio Nobel de Física 2021

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The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics 2021

"for groundbreaking contributions to our understanding of complex physical systems"

with one half jointly to

SYUKURO MANABE
Born 1931 in Shingu, Japan. Ph.D. 1957 from University of Tokyo, Japan. Senior Meteorologist at Princeton University, USA.

KLAUS HASSELMANN
Born 1931 in Hamburg, Germany. Ph.D. 1957 from University of Göttingen, Germany. Professor, Max Planck Institute for Meteorology, Hamburg, Germany.

"for the physical modelling of Earth's climate, quantifying variability and reliably predicting global warming"

and the other half to

GIORGIO PARISI
Born 1948 in Rome, Italy. Ph.D. 1970 from Sapienza University of Rome, Italy. Professor at Sapienza University of Rome, Italy.

"for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales"

Sistemas Complexos

Ingredientes básicos e propriedades emergentes

Complex systems is a relatively new and broadly interdisciplinary field that deals with systems composed of many interacting units, often called "agents." The foundational elements of the field predate the current surge of interest in it, which started in the 1980s, but substantial recent advances in the area, coupled with increasing interest both in academia and industry, have created new momentum for the study and teaching of the science of complex systems.

There is no precise technical definition of a "complex system," but most researchers in the field would probably agree that it is a system composed of many interacting parts, such that the collective behavior of those parts together is more than the sum of their individual behaviors. The collective behaviors are sometimes also called "emergent" behaviors, and a complex system can thus be said to be a system of interacting parts that displays emergent behavior.

M. Newman, Am. J. Phys. **79**, 800-810 (2011)

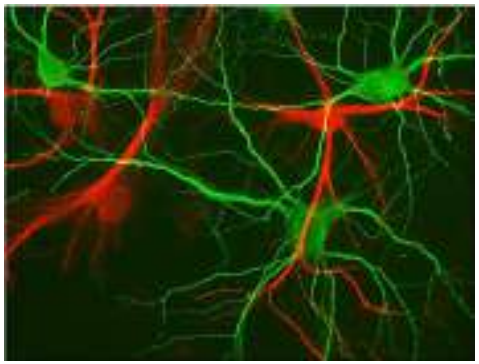
- Muitos "agentes"
- Relações entre agentes: interações $\rightarrow$ rede de conexões.
- Vínculos conflitantes: interações competitivas (frustração).
- Comportamento emergente: auto-organização.
- Múltiplas escalas: estrutura hierárquica.
- Complexidade: muitos equilíbrios possíveis.

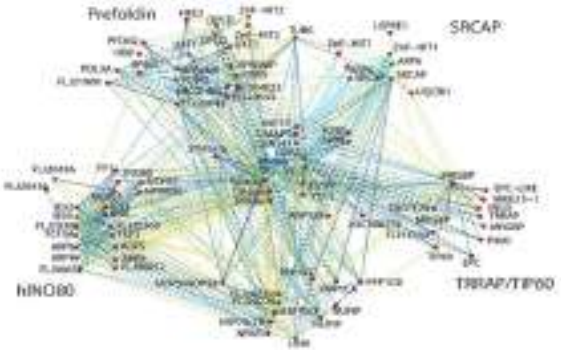
Sistemas Complexos

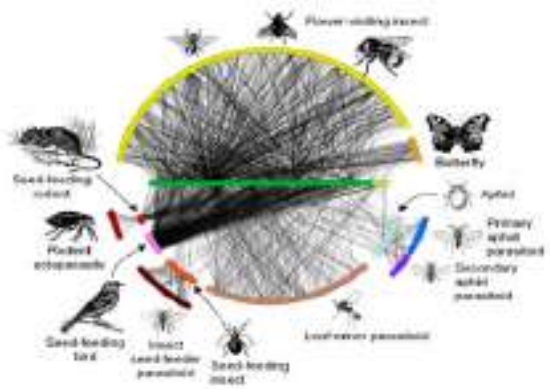
Como funcionam ?

Qual a relação entre estrutura e “observáveis” ?

Como evoluem no tempo ?







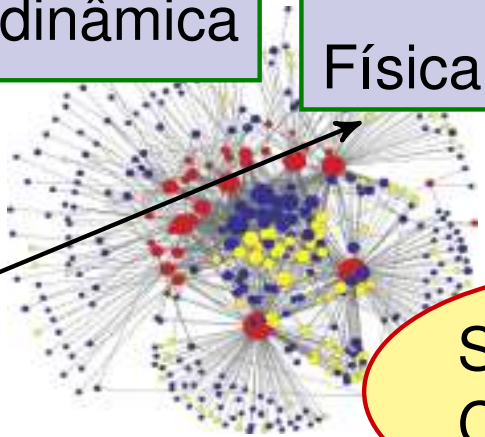
Os Sistemas Complexos e as áreas da Física

Mecânica Clássica

MECÂNICA

Termodinâmica

Física Estatística



Mecânica Quântica

Sistemas Complexos

Giorgio Parisi

"for groundbreaking contributions to our understanding of complex physical systems"

vidros de spin
vidros estruturais
problemas de otimização combinatória
redes neuronais

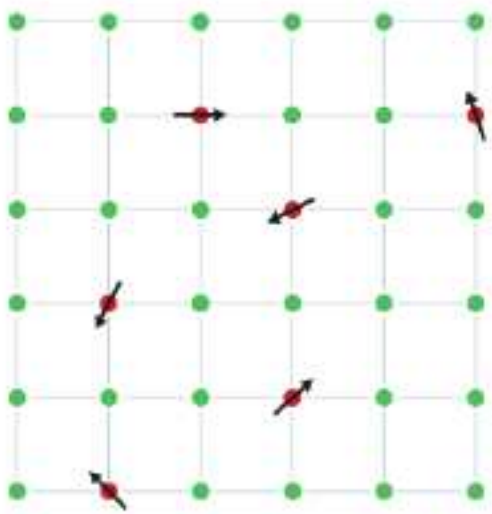
...

"for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales"

Vidros de spin

Ligas de dois metais, um deles magnético

Desordem:

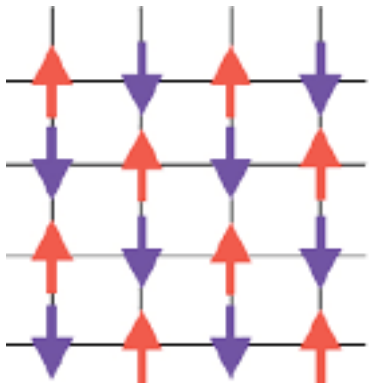


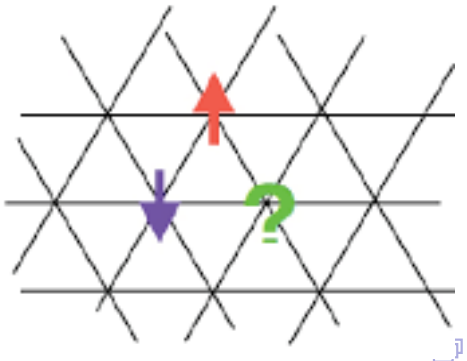
$$Energia = -\frac{1}{2}\sum_{i,j=1}^{N} J_{ij} S_i S_j$$

Quais os estados de menor energia ?

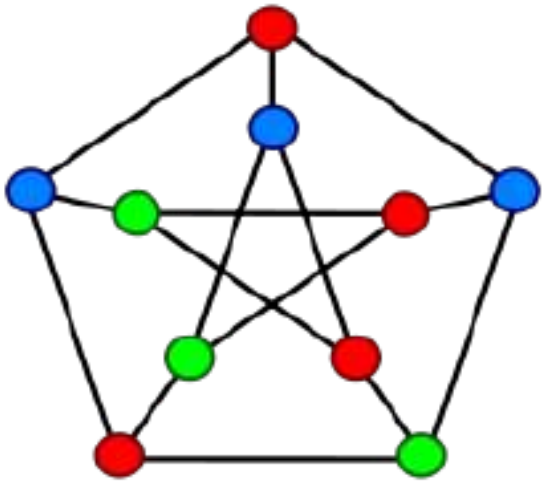
Frustração: impossível satisfazer todos os vínculos simultaneamente !

Muitos arranjos possíveis, com energias parecidas ...





Problemas de otimização



Otimização: problema do Caixeiro Viajante (TSP)

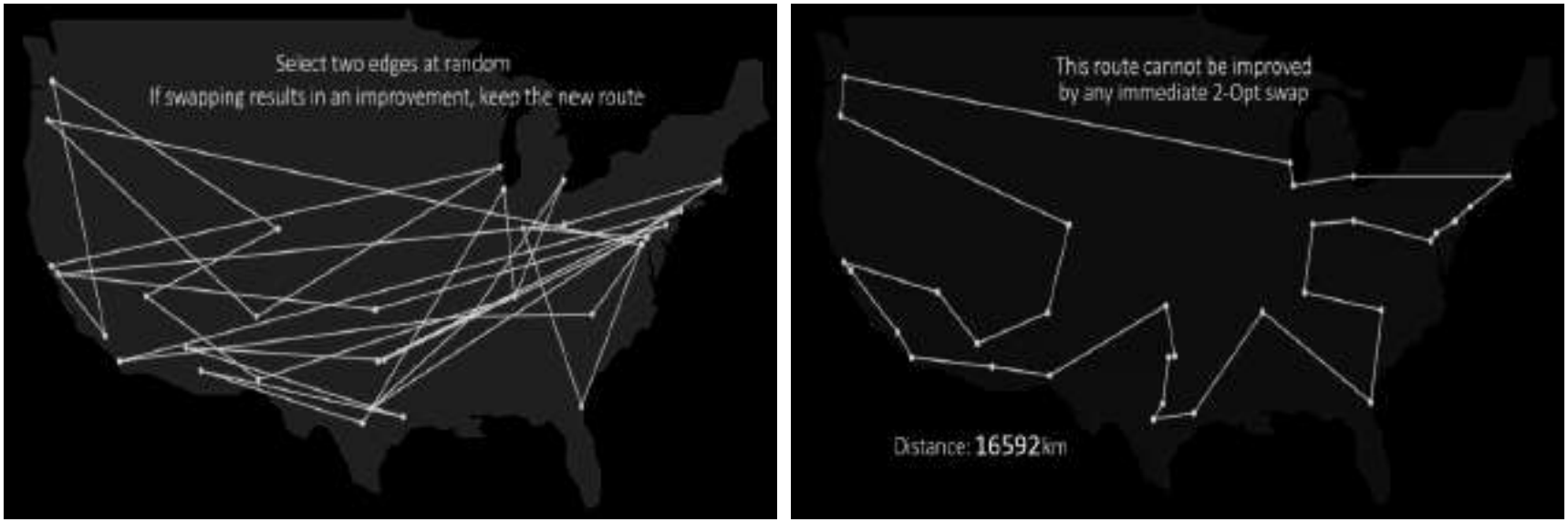
Problema: *Dada uma lista de cidades (agentes) e as distâncias entre elas (relações) , achar o caminho mais curto que passe por todas as cidades apenas uma vez (vínculo).*

$$
\begin{aligned}
i &= 1, 2, \ldots N \text{ cidades} \\
d_{ij} &: \text{distância entre as cidades “i” e “j”} \\
D &: \text{extensão de um dado caminho} \\
c_i &= 0, 1
\end{aligned}
$$

Um caminho: $D = d_{12} c_1 c_2 + d_{23} c_2 c_3 + \ldots + d_{N-1\,N} c_{N-1} c_N$

Em geral: $D = \sum_{i,j=1}^{N} d_{ij} c_i c_j$ + vínculo

Desordem, frustração e dinâmica no TSP

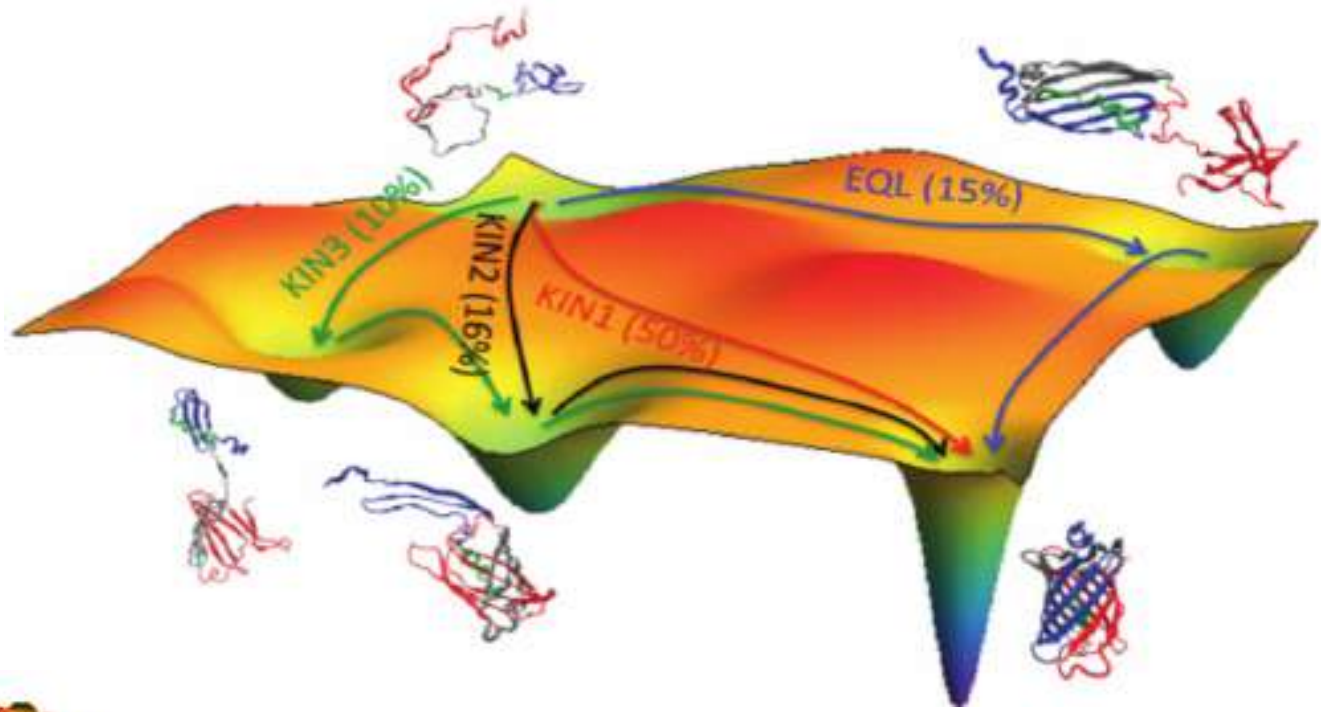


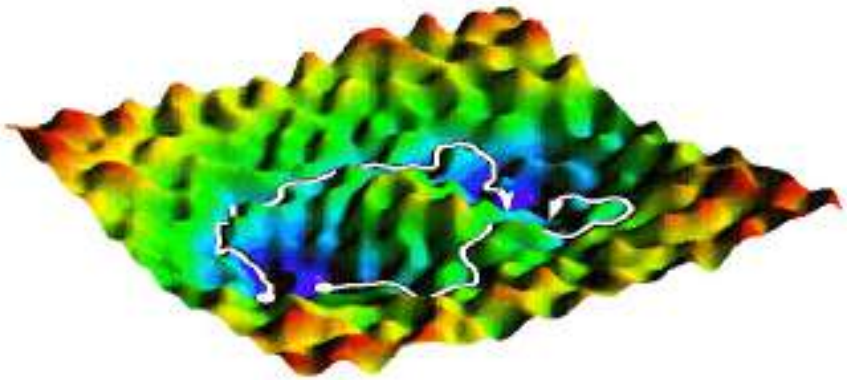
Desordem: nos interessa o comportamento de um conjunto de mapas definidos pelas distâncias $\{d_{ij}\} \rightarrow$ propriedades estatísticas.

Frustração: minimizar as distâncias de uma cidade até as vizinhas não sempre ajuda a minimizar o caminho total (propriedade local versus global).

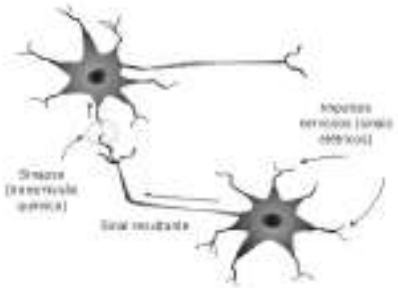
Propriedades emergentes: a paisagem de energia

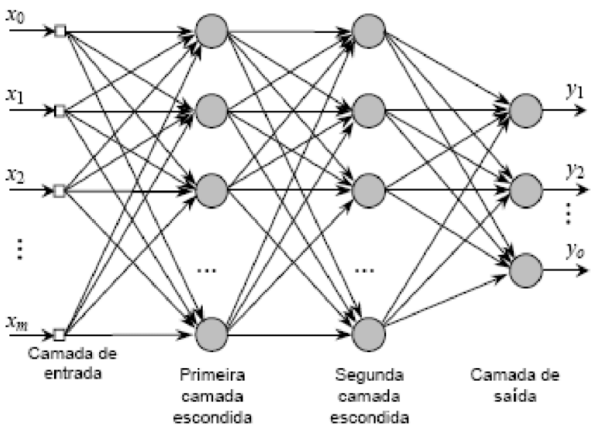
Complexidade: muitos estados estáveis possíveis





Neurônio Biológico





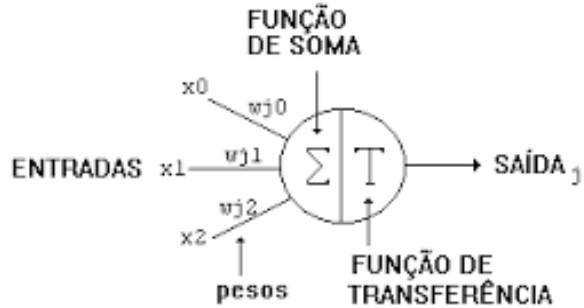
O modelo de Hopfield

É possível fixar as conexões (W_{ij}) para armazenar um conjunto dado de memórias ? (problema inverso)

$$E = -\frac{1}{2}\sum_{j=1}^{N} X_j \left(\sum_{k=1}^{N} W_{jk} X_k \right)$$

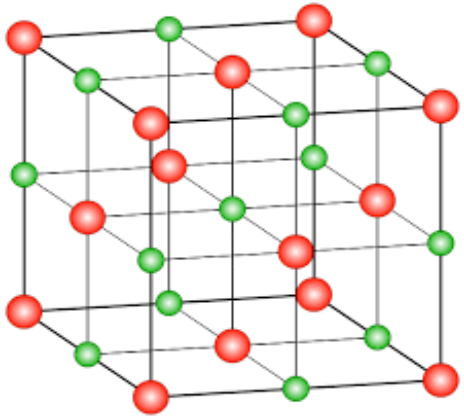
Regra de Hebb: $W_{ij} = \sum_{\mu=1}^{p} \xi_i^\mu \xi_j^\mu$

$$p = \alpha\, N$$

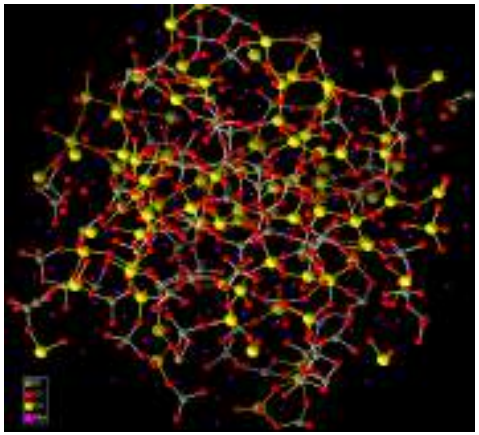


Muito obrigado pela atenção !

Vidros de janela



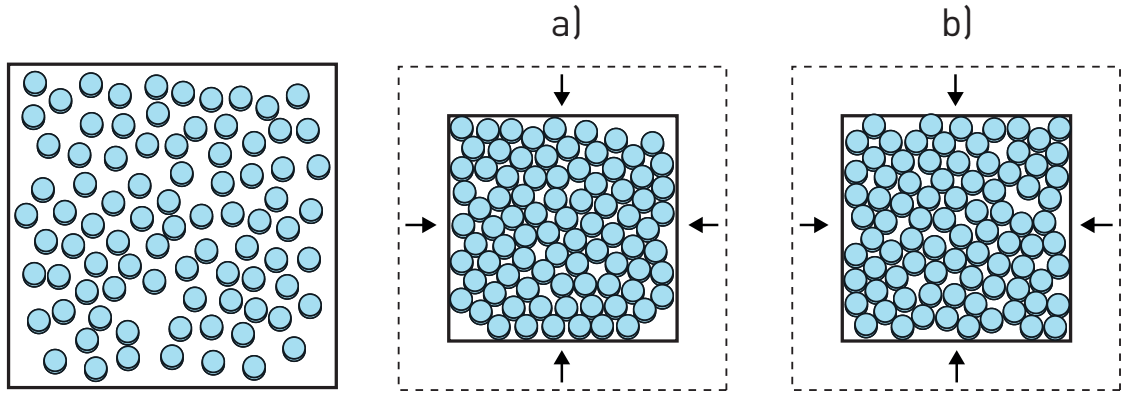
Cristal



Vidro

Mathematics for complex disordered systems

Every time many identical discs are squeezed together, a new irregular pattern is formed despite them being squeezed in exactly the same way. What governs the result? Giorgio Parisi discovered a hidden structure in such complex disordered systems, which these discs represent, and found a way of describing them mathematically.



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