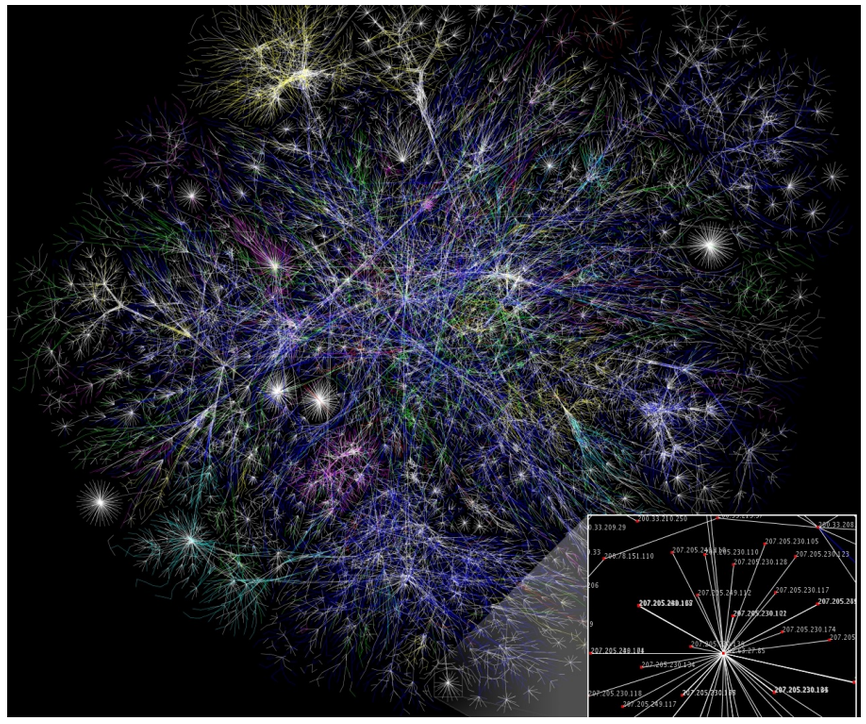
ENTROPY AND INFORMATION IN COMPLEX SYSTEMS

Karoline Wiesner
University of Bristol

GOAL OF THE TALK

- Notes on what is a complex system
- Information mathematically and conceptually
- Examples of information analysis of complex systems



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Ladyman, Lambert, Wiesner
What is a complex system
Eur J Phil Sci (2013)

“

A complex system is an ensemble of many elements which are interacting in a disordered way, resulting in robust organisation and memory.

ENTROPY

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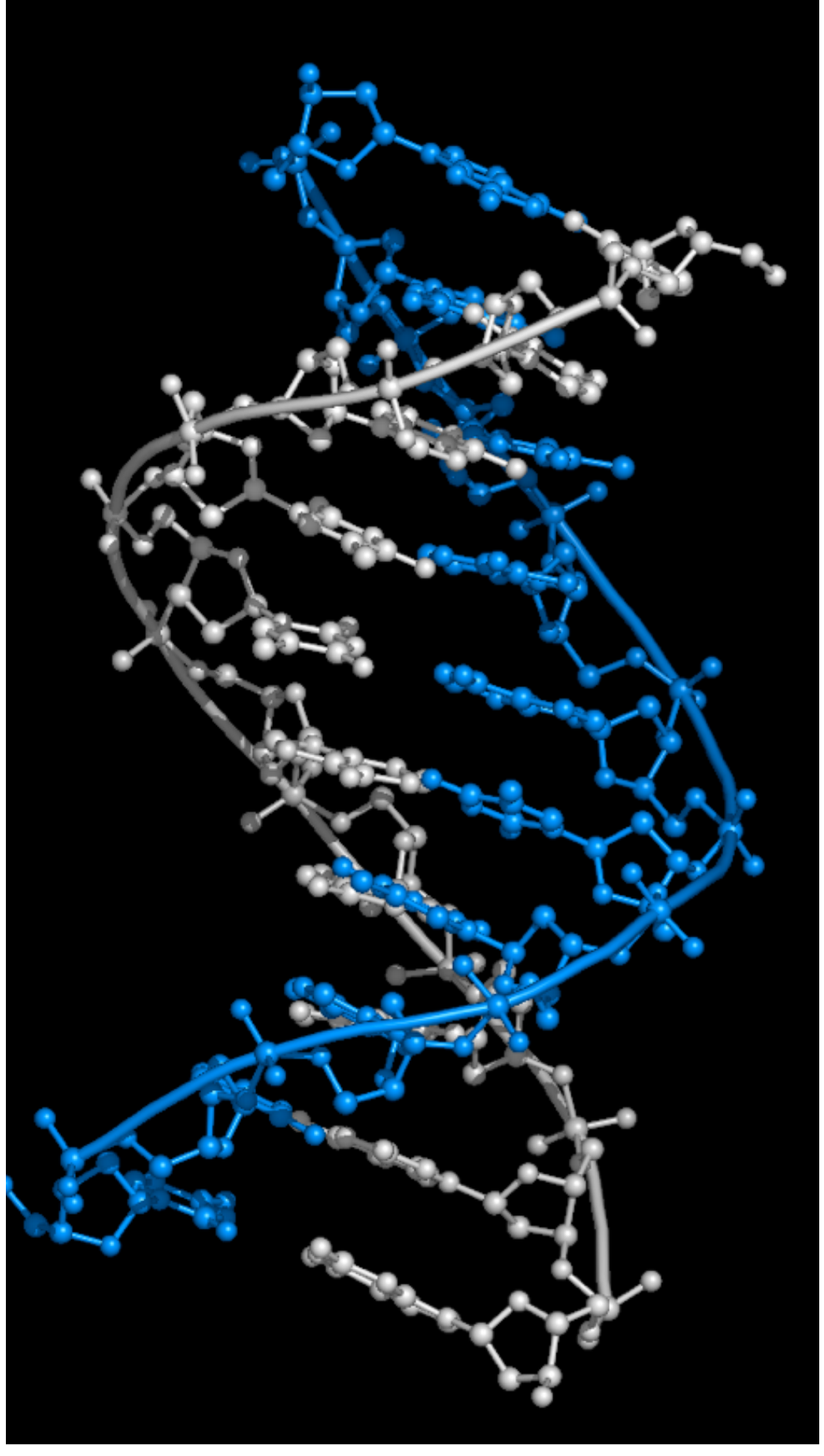

INFORMATION

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> A measure that corresponds much better to what is usually meant by complexity in ordinary conversation, as well as in scientific discourse, refers [...] to the length of a concise description of a set of the entity's regularities.

Murray Gell-Mann. What is complexity. Complexity, (1995)

COMPLEXITY IS NOT JUST REGULARITIES.

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THREE QUESTIONS I WILL ANSWER

A. Is complexity really between order and randomness?

B. Why is information relevant for complex systems?

C. What have scientists done to show this?

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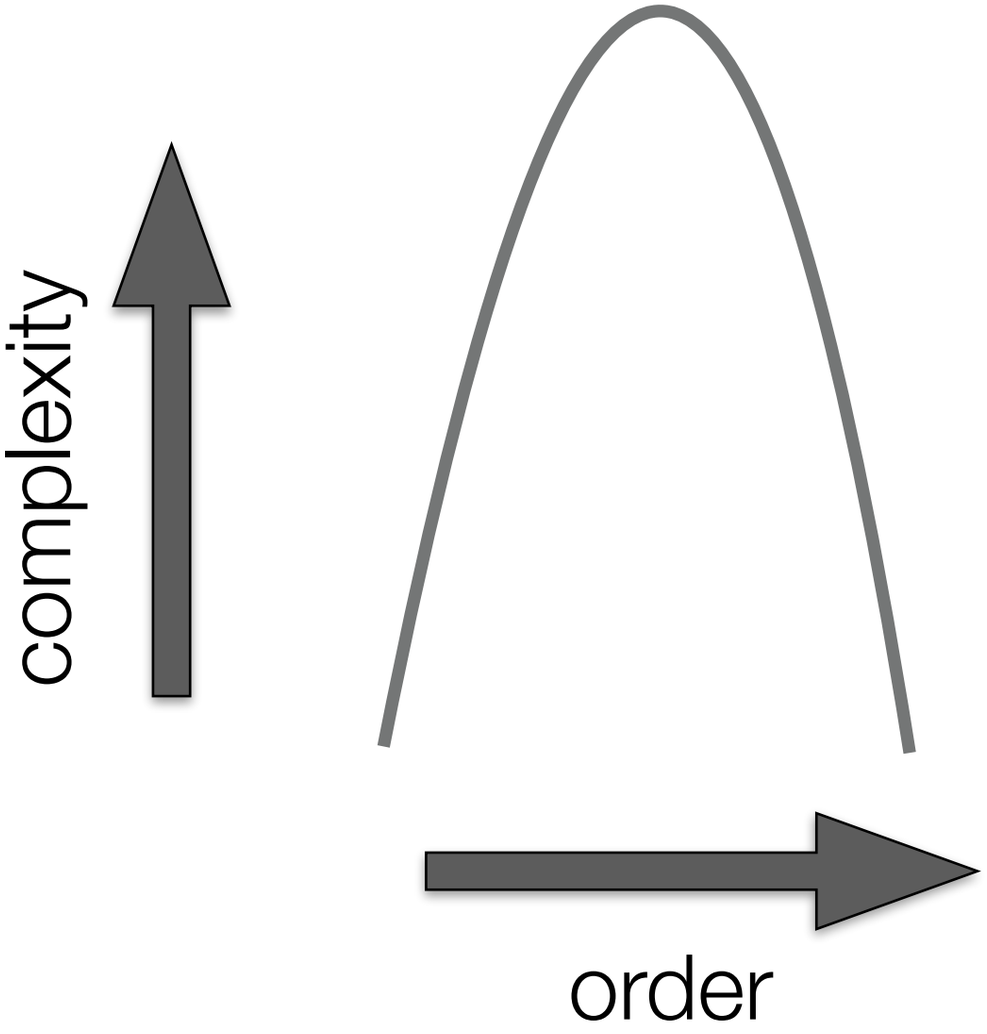
B. Why is information relevant for complex systems?

C. What have scientists done to show this?

MYTH OF THE PEAKED COMPLEXITY FUNCTION



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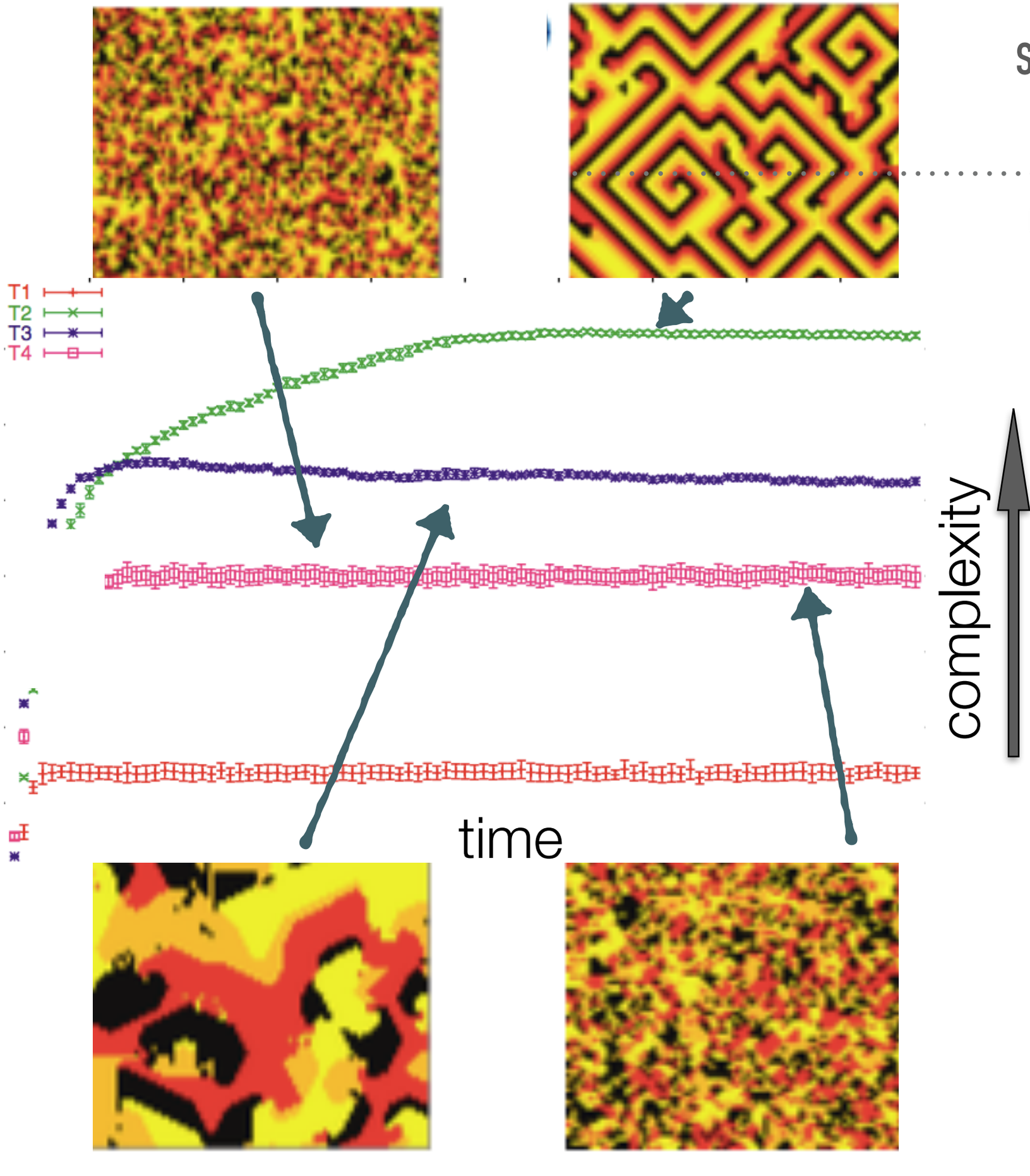

Shalizi, CR, KL Shalizi, and R Haslinger. "Quantifying Self-Organization with Optimal Predictors." Phys Rev Lett (2004)

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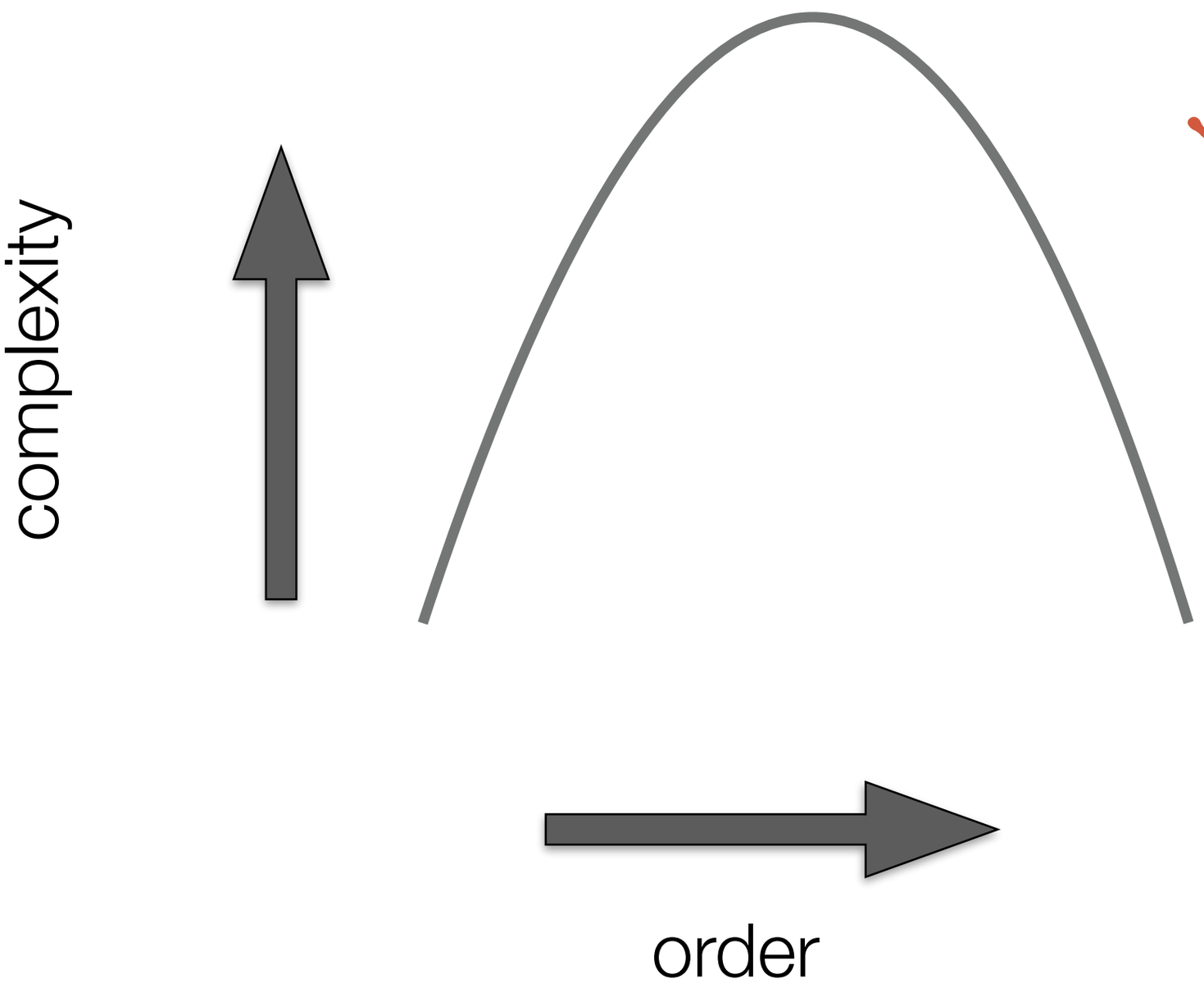
THERE IS NO FUNCTION REPRODUCING THE PEAK (YET)

Ladyman, Lambert, Wiesner
What is a complex system
Eur J Phil Sci (2013)



statistical complexity

effective complexity

effective measure complexity

logical depth

…

DISORDER VS ORDER

Ladyman and Wiesner
Princeton University Press
to be published 2017

- System vs product

2ND PART

A. Notes on what is a complex system

B. Information mathematically and conceptually

C. Examples of information analysis of complex systems

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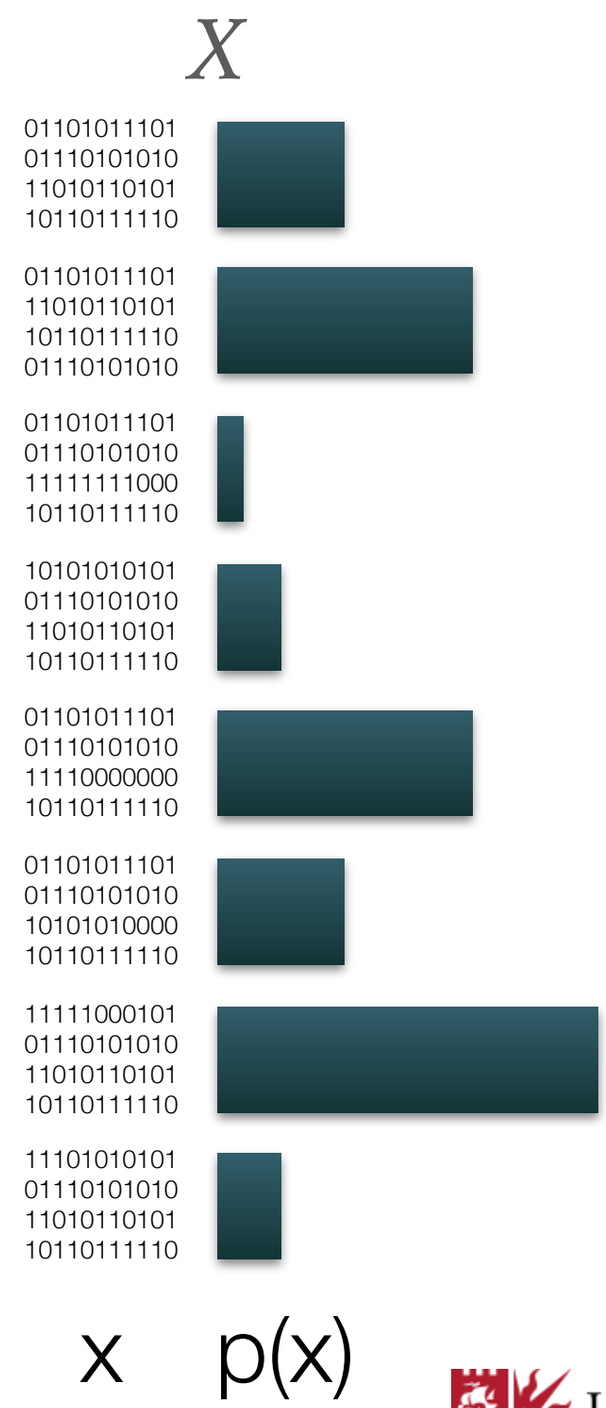
SHANNON ENTROPY MEASURES DISORDER

- Shannon entropy

$$H(X) = -\sum_x p(x) \log p(x)$$



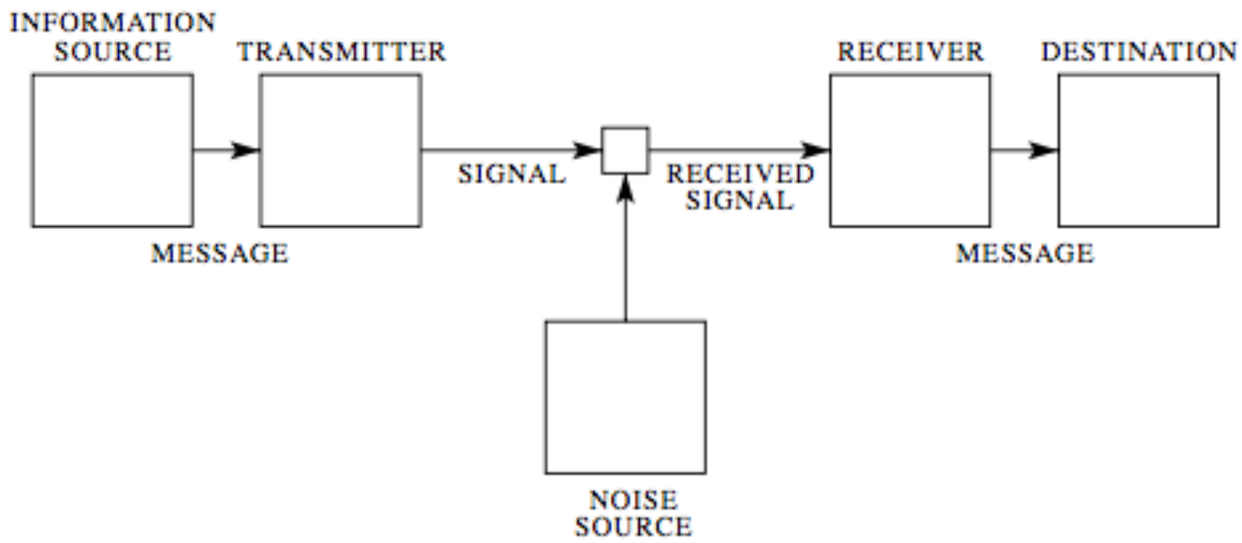
SHANNON VS GIBBS

$$H(X) = -\sum_{x} p(x) \log p(x)$$

$$S = -k_B \sum_{i} p_i \ln p_i$$

MUTUAL INFORMATION

X



Y

$H(X)$

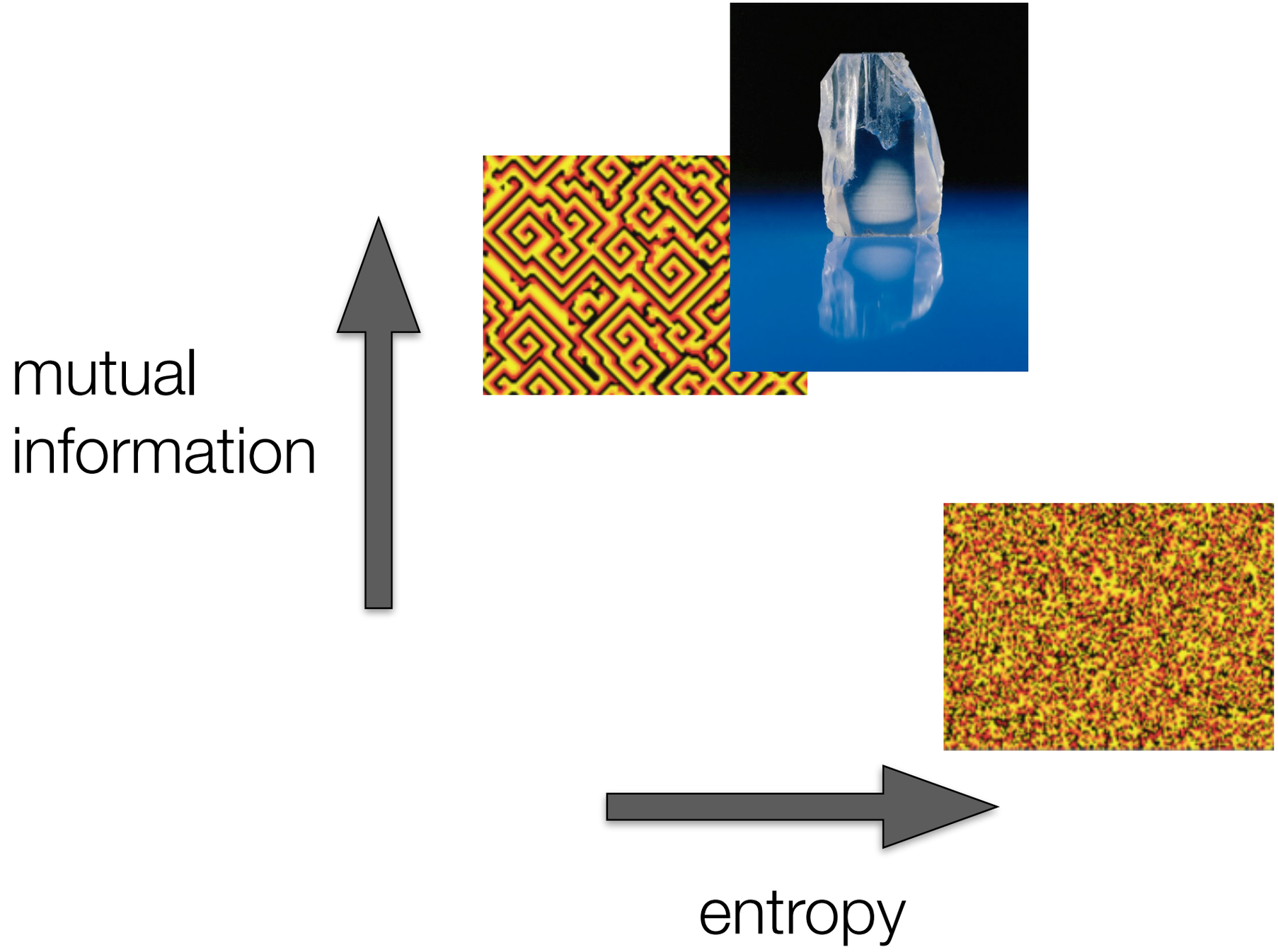
$H(Y)$

$$I(X;Y) = \sum_{x,y} p(xy) \log \frac{p(xy)}{p(x)p(y)}$$

$$I(X;Y) = H(X) + H(Y) - H(X,Y)$$

- Is complexity really between order and randomness?
- **Why is information relevant for complex systems?**
- What have scientists done to show this?

MUTUAL INFORMATION MEASURES CORRELATIONS



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53859	16.3236161021867	0	0	0	18.6387276852569	0	17.5504866117
09474	16.3790678766315	0	0	0	18.3198799821994	16.9959688673299	16.4622455382
74714	0	0	0	0	17.7653622377514	0	
10826	0	0	0	0	17.599006914417	16.5315602563547	16.9335856210
66441	16.9474485646907	0	0	0	17.1900500778866	0	
45491	0	0	0	15.401730352042	15.9285222092675	0	14.8056237767
'35739	17.252433324137	0	0	0	18.9090550856753	0	17.4049257038
05227	0	0	0	0	17.9594434483082	0	12.0122406391
65109	0	0	0	0	16.5523546717715	0	17.1345983034
20546	16.4137252356595	0	0	0	18.3891947002554	0	11.5478320281
55243	16.3929308202427	0	0	0	16.3652049330203	0	17.0999409444
77451	0	0	0	16.7533673541339	17.6405957452506	0	15.9285222092
37092	15.9909054555179	0	0	0	16.5870120307995	0	16.2820272713
94091	0	0	0	0	17.5088977809442	0	
44328	0	0	0	0	0	0	
51154	0	0	0	0	0	0	
74746	0	0	0	0	18.2367023205322	0	15.436387711
09347	15.5264968445428	0	0	16.1295348916299	16.5731490871883	0	13.8352177239
17715	18.0772784690034	0	0	17.8831972584466	19.1793824860937	0	16.4275881792
80314	0	0	0	17.460377478305	12.2063218496606	0	
05195	16.9959688673299	0	0	0	16.1156719480187	0	16.0671516453
27498	16.8504079594123	0	0	0	17.6267328016394	0	15.0759511771
83145	17.9247860892802	0	0	0	0	0	
54017	0	0	0	0	18.6248647416457	0	17.1761871342
84371	15.7067151114884	0	0	0	17.2662962677482	0	16.2404384405

Interaction as correlation as information

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Ladyman and Wiesner
Princeton University Press
to be published 2017

INFORMATION PROVIDES A UNIVERSAL LANGUAGE FOR ALL COMPLEX SYSTEMS.

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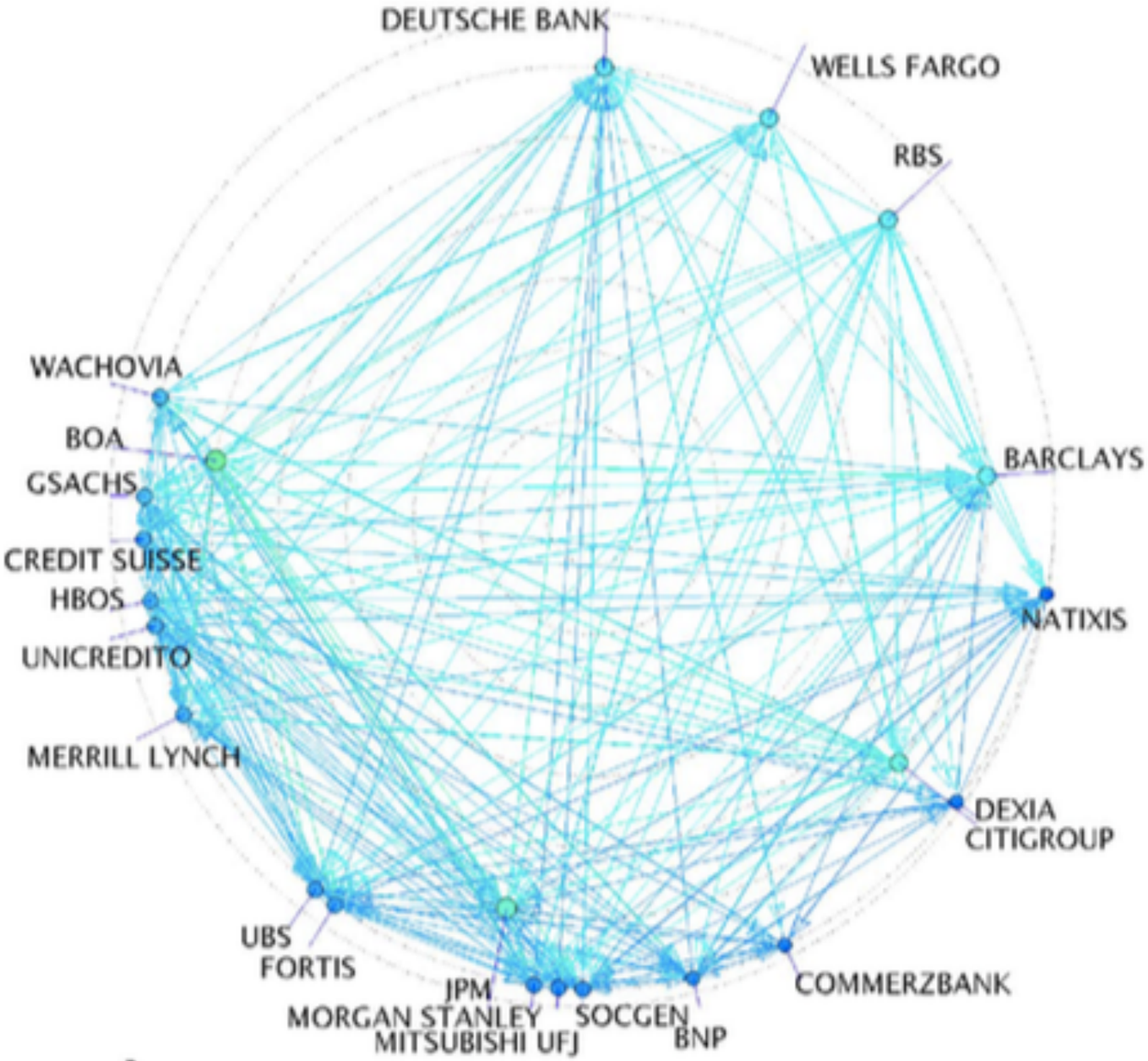

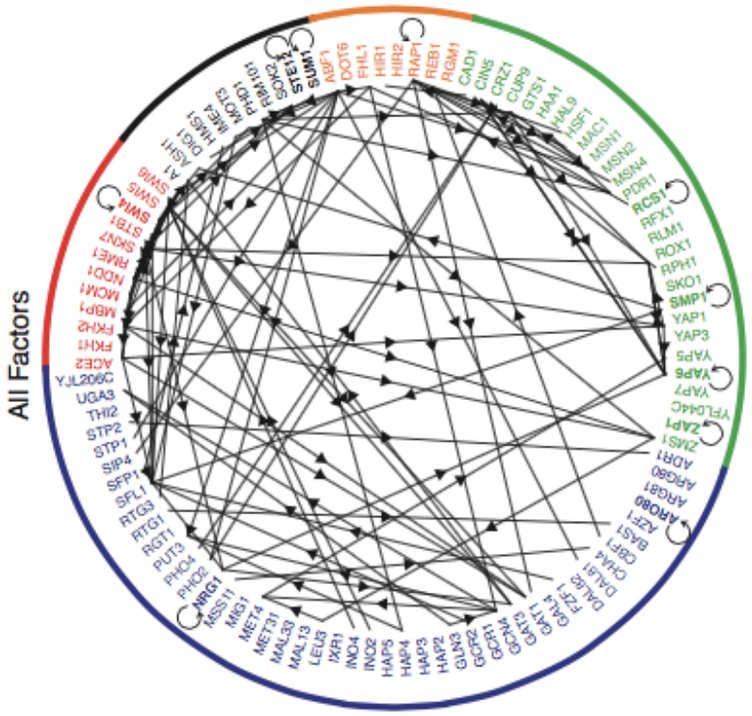

Network theory as universal language for complex systems.

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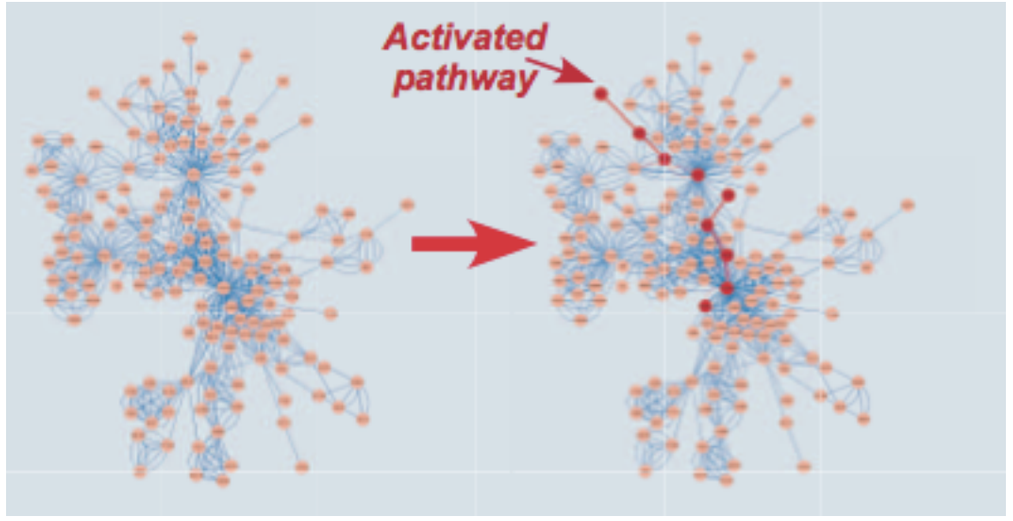
3RD PART

- Notes on what is a complex system
- Information mathematically and conceptually
- **Examples of information analysis of complex systems**



MODEL GLASS FORMERS

Dunleavy, Andrew J., K Wiesner, R Yamamoto, and CP Royall. ‘Mutual Information Reveals Multiple Structural Relaxation Mechanisms in a Model Glass Former’. Nature Communications (2015).

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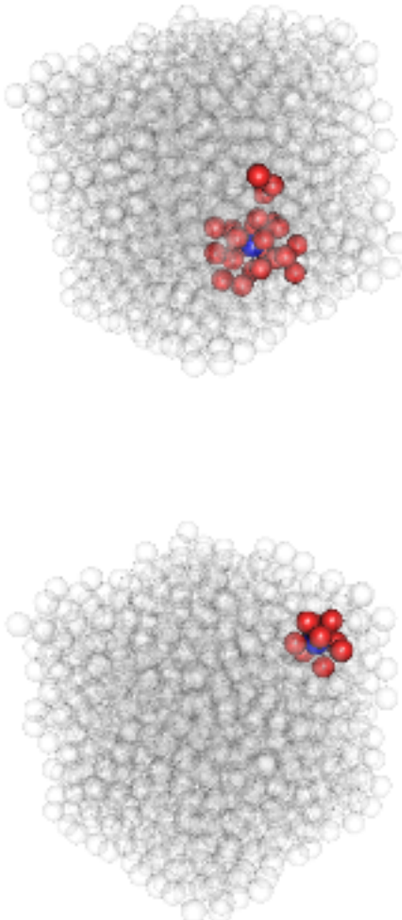
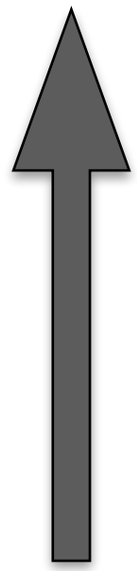
MUTUAL INFORMATION: SIGNATURE OF COLLECTIVE MOTION

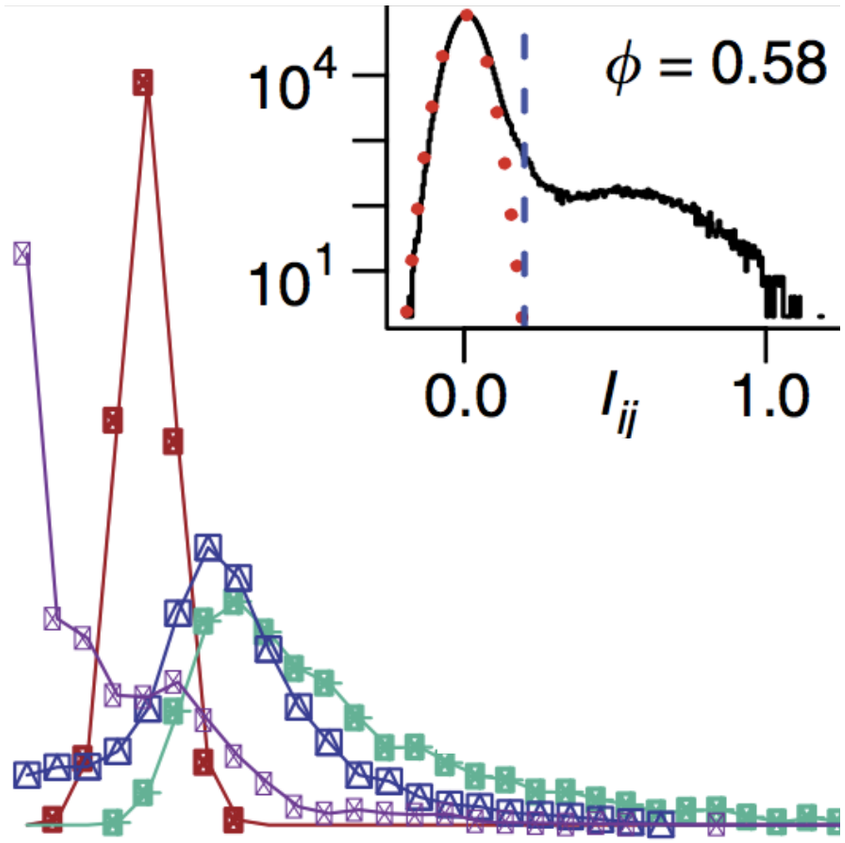




600

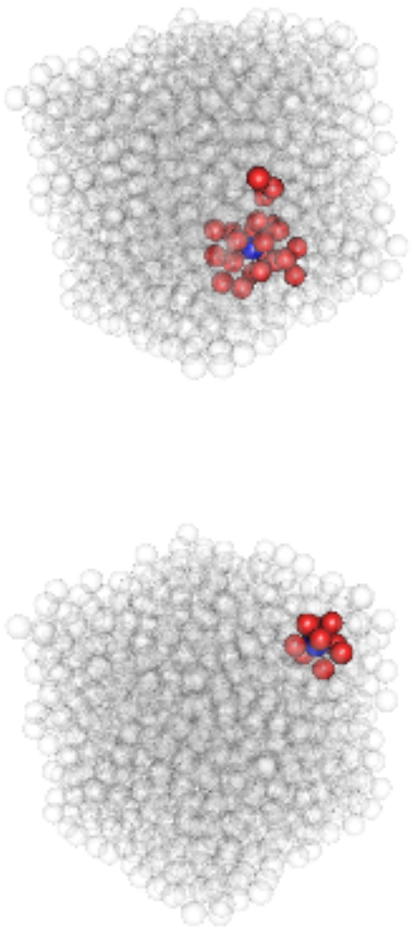
Number of correlated particles

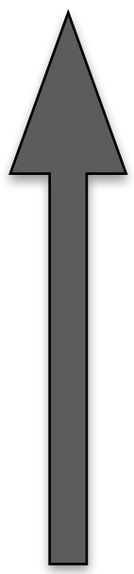
0



time

MUTUAL INFORMATION REVEALS COLLECTIVE MOTION





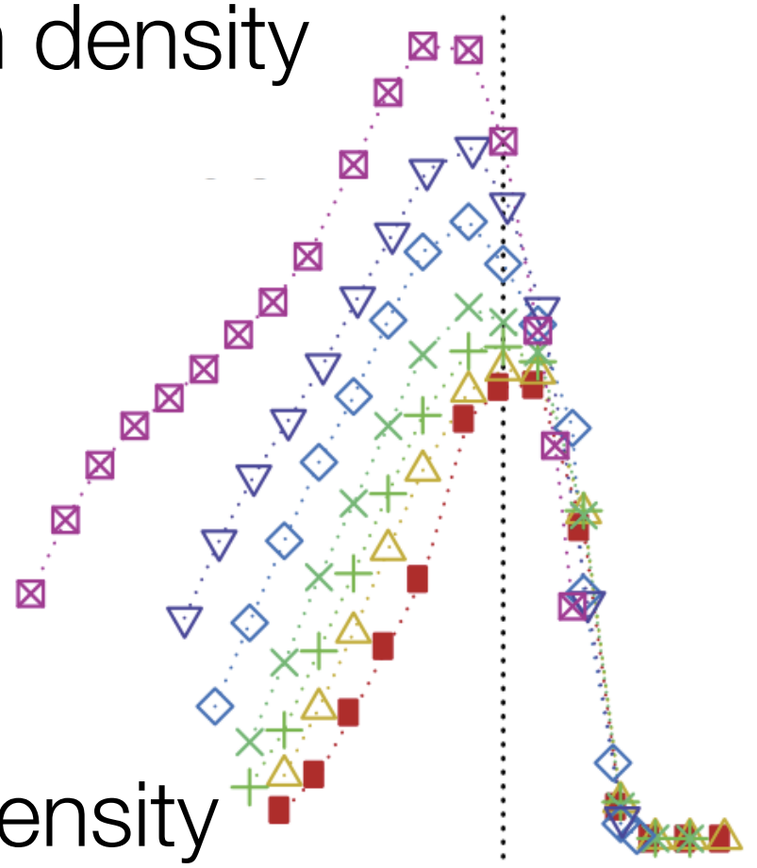
20

Number of correlated particles

0

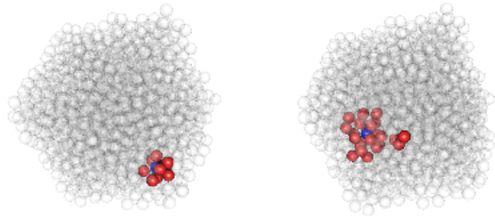
high density

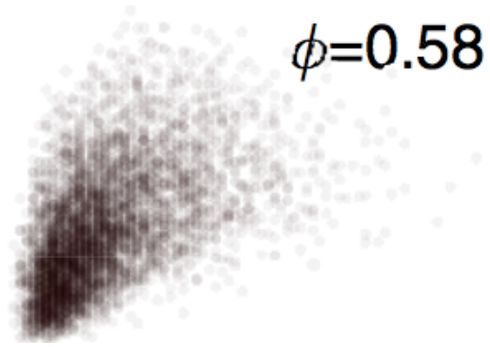
low density



normalised time

TWO TYPES OF PARTICLES





Number of
correlated particles

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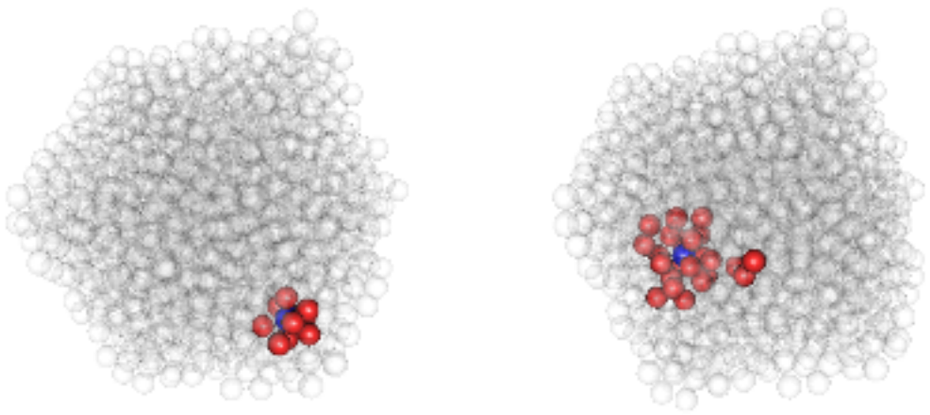
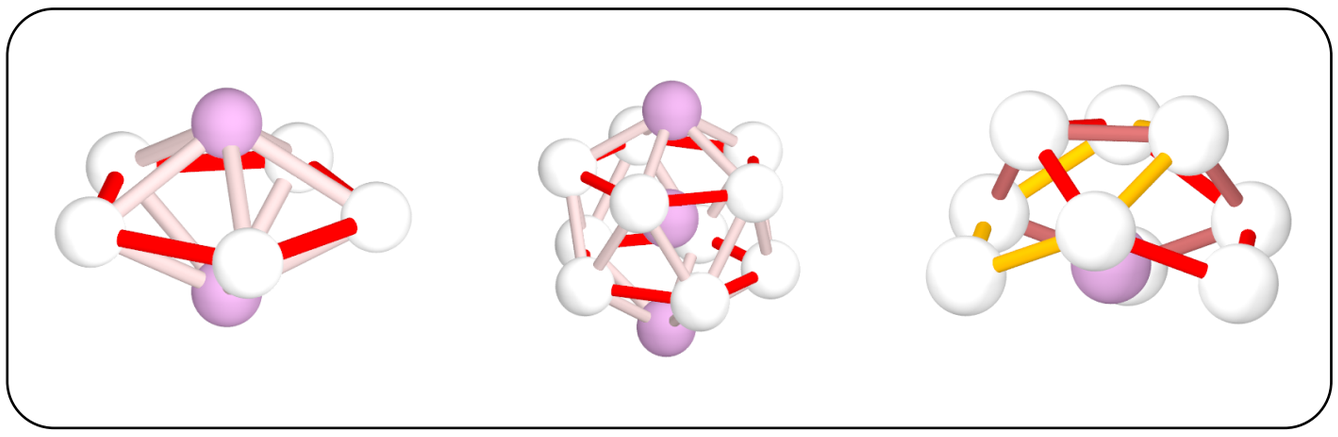
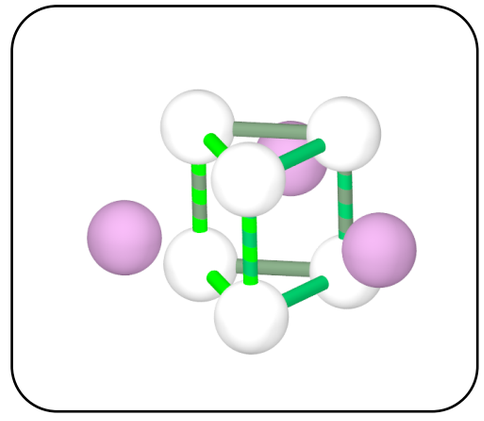
MUTUAL INFORMATION PREDICTS MAJOR PLAYERS IN RELAXATION MECHANISM

Dunleavy, Andrew J., K Wiesner, R Yamamoto, and CP Royall. 'Mutual Information Reveals Multiple Structural Relaxation Mechanisms in a Model Glass Former'. Nature Communications (2015).



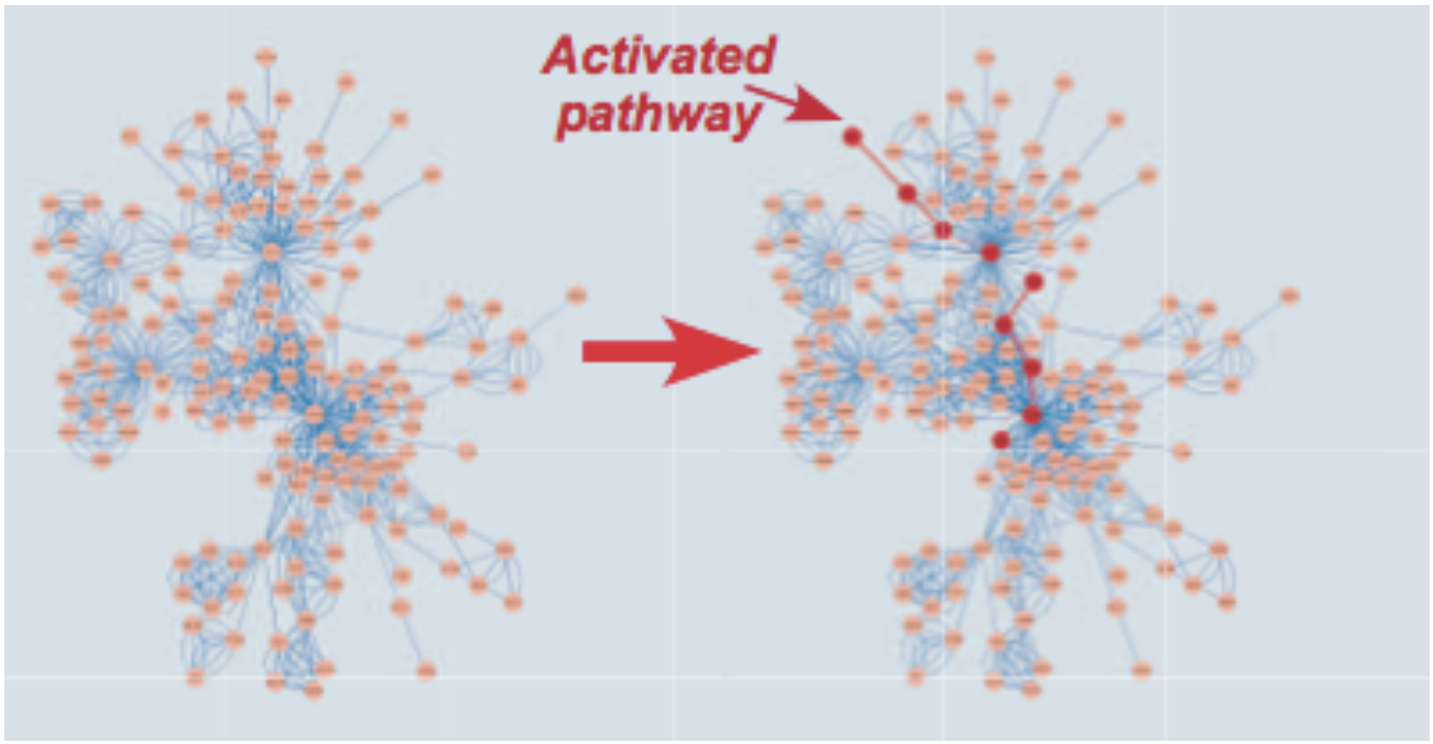
late movers





early movers

STEM CELL DIFFERENTIATION



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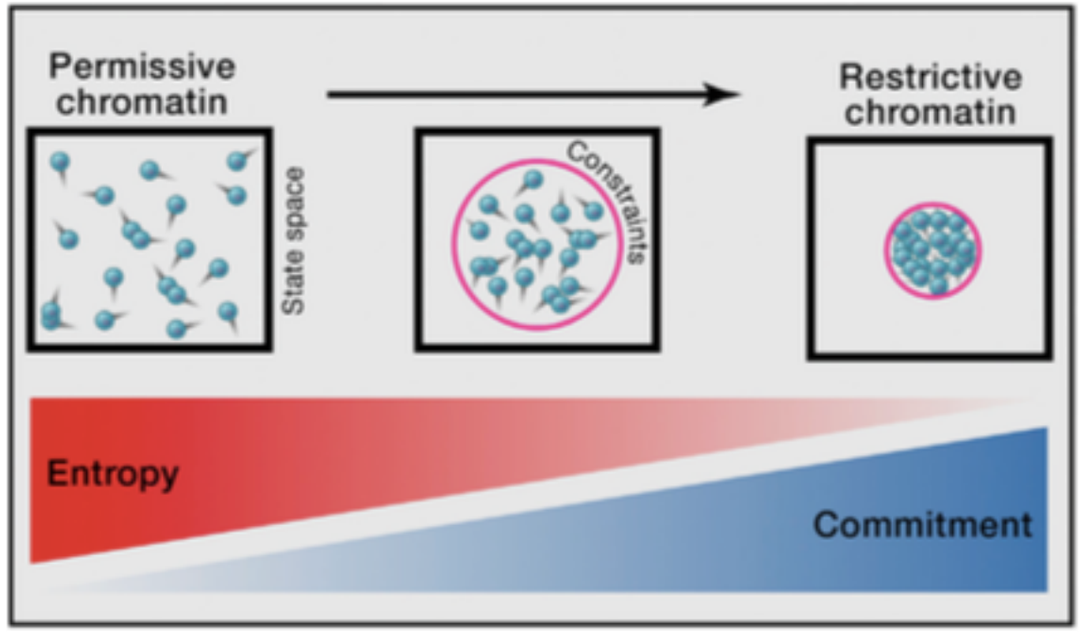
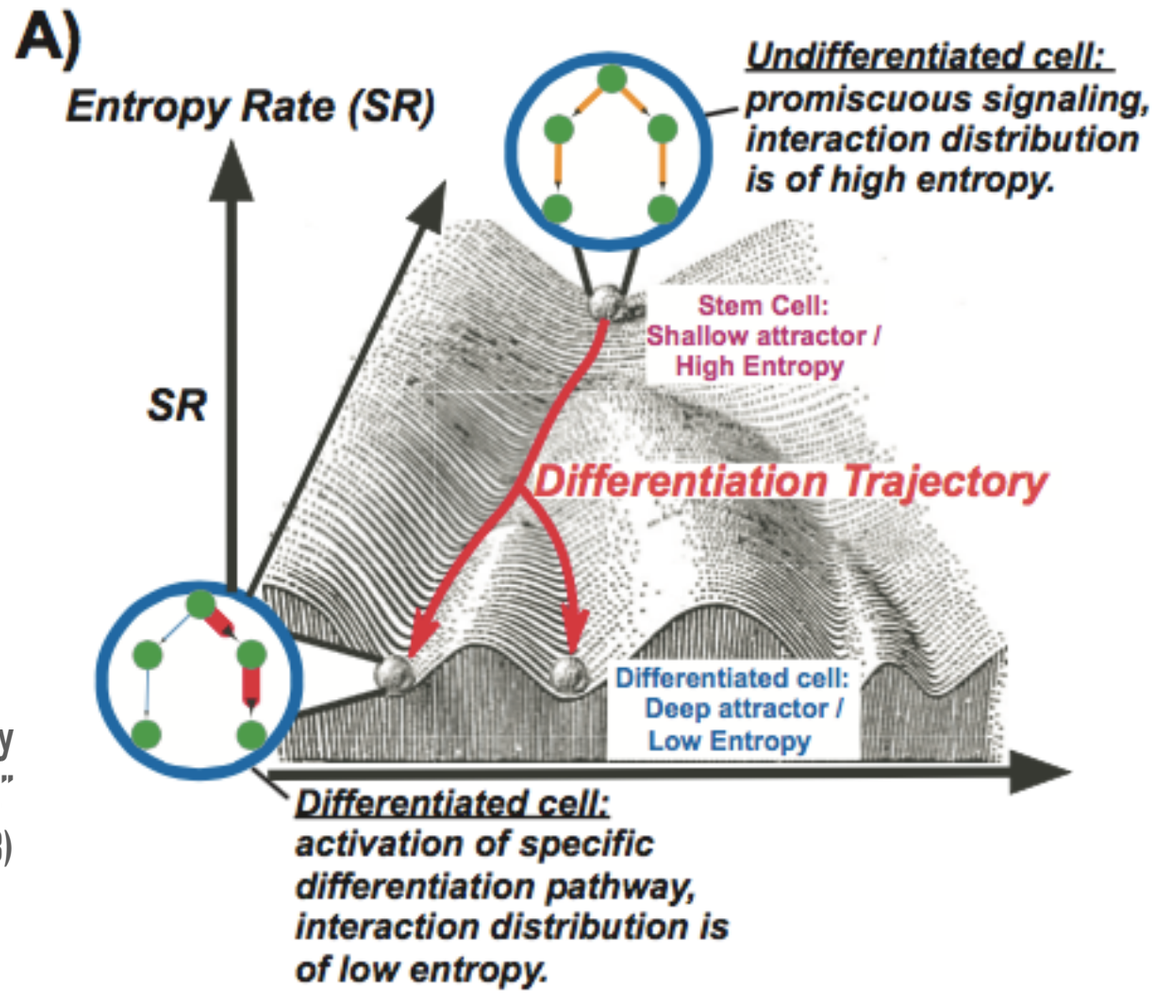
ENTROPY HYPOTHESIS



MacArthur, Ben D., and Ihor R. Lemischka.
"Statistical Mechanics of Pluripotency." Cell (2013)



Banerji, Christopher et al. "Cellular Network Entropy as the Energy Potential in Waddington's Differentiation Landscape." Scientific Reports (2013)

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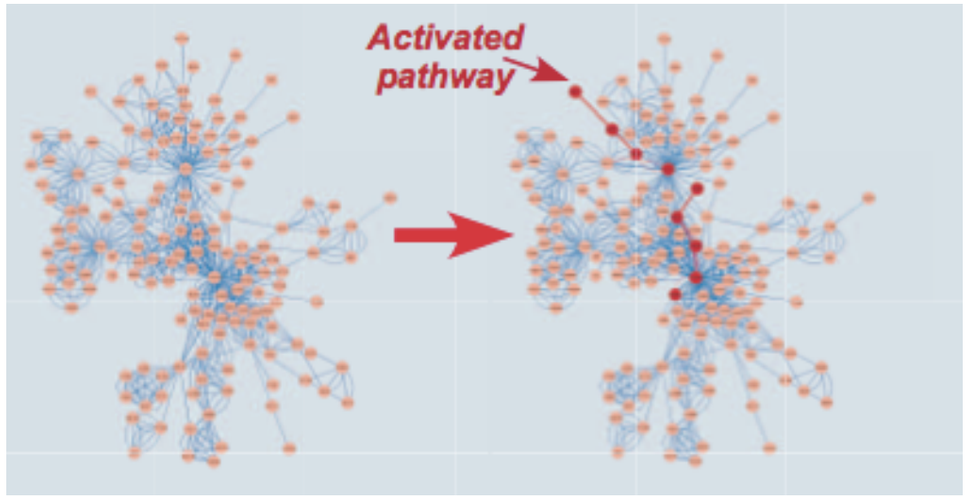
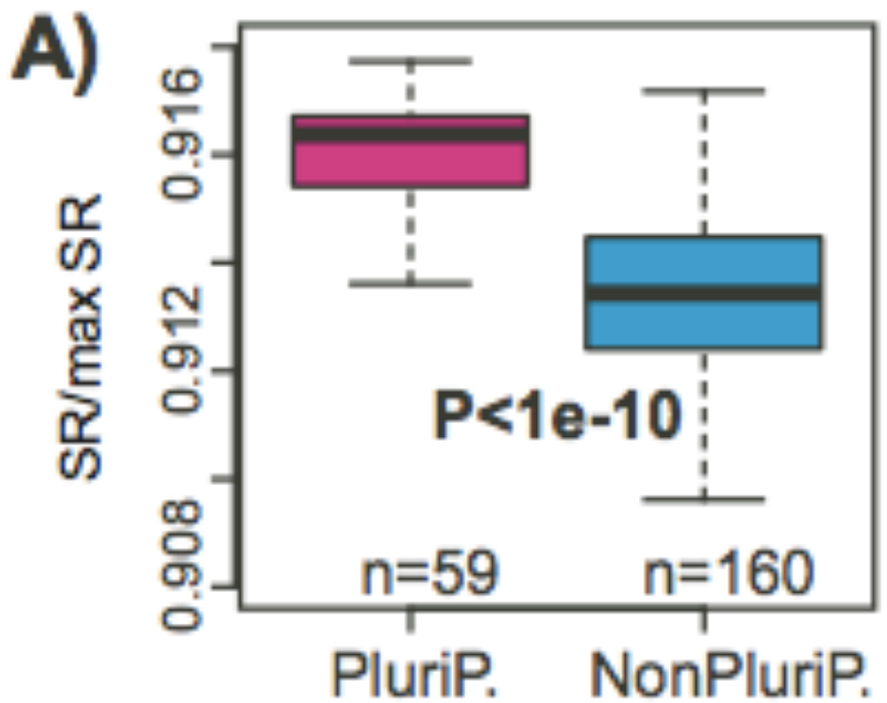
NETWORK ENTROPY CORRELATES WITH PLURIPOTENCY

Banerji, Christopher et al. “Cellular Network Entropy as the Energy Potential in Waddington’s Differentiation Landscape.” Scientific Reports (2013)





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CONCLUSIONS

- Information is useful because of abstraction of interactions
- Information can measure order and disorder
- Complex systems science is possible because of abstraction to similar mathematical constructs

- Is complexity is really between order and randomness, complexity measures are not.
- Information is a universal language for complex systems.
- Scientists are beginning to quantify this.