The role of information in complex systems
Self-organisation in stem cells and glass formers

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One property of complex systems: structure on the macroscopic level which does not exist on the microscopic level (*)

(*) for more on features of complex systems, see J Layman and K Wiesner, What is a complex system?, book to be published in 2018
Identifying moments and mechanisms of self-organisation using entropy glass formation

glass formation

stem cell differentiation

Lymphocytes
Granulocytes
Monocytes
Megakaryocytes
Erythrocytes
Lymphocytes
Granulocytes
Monocytes
Megakaryocytes
Erythrocytes

Identifying moments and mechanisms of self-organisation using entropy
Example 1: Glass formation in colloidal system
Mutual Information Reveals Multiple Structural Relaxation Mechanisms in a Model Glass Former

Mutual information in a colloidal system

The diagram illustrates the number of correlated particles over time. The y-axis represents the number of correlated particles on a logarithmic scale, with values ranging from $10^0$ to $10^4$. The x-axis represents time. A inset graph shows the mutual information $I_{ij}$ with a peak at $\phi = 0.58$. The right side of the diagram highlights particles with high mutual information.
Particles with significant mutual information

number of correlated partners later

number of correlated partners early on
Mutual information predicts major players in relaxation mechanism

late movers

early movers
New length scale, based on mutual information

\[ I(r, t) = \frac{\sum_{ij} I_{ij}(t) \delta(r - |x_i(0) - x_i(0)|)}{\sum_{ij} \delta(r - |x_i(0) - x_i(0)|)} \]

Fit an exponential function to define the length scale \( \xi_{exp} \):

\[ I(r, t) \propto e^{-r/\xi_{exp}} \]
To summarise example 1

- The mutual information between movements of particles did indicate where a structural transition was taking place.
- And it lead to a mechanistic explanation of the transition.
Example 1: Differentiating stem cell
Statistical mechanics analogy for stem cell development

Hematopoietic stem cells – Entropic landscape of differentiation

Experimental data for entropy measurements
Entropy of gene expression

• Binary random variable $X$:
  
  $X = 0$ if ‘gene off’, $X = 1$ if ‘gene on’

• Binary entropy:

  $$H(X) = - \sum_{x \in \{0,1\}} P(x) \log_2 P(x)$$
Sum of binary entropies of expression levels (179 genes)
To summarise example 2

- Our observations are contrary to the expected continuous decrease of entropy. Instead we saw a significant increase in entropy during an intermediate stage before the entropy decreased, slightly below the initial value, in the last stages of the process as it was measured in these experiments.
Conclusions

- The data of a liquid forming a glass were analysed using mutual information. We introduced a new length scale based on the mutual information. We were able to suggest a mechanism behind the glass forming process.

- The data of hematopietic stem cell differentiation was analysed using the Shannon entropy. Contrary to the general expectation, we found an increase in entropy toward the transition point before a decrease toward the final stages.
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• References:


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