The information dynamics of phase changes in random Boolean networks

Author: Joseph Lizier, jlizier@it.usyd.edu.au
Supervisor: Prof. Albert Zomaya; Dr. Mikhail Prokopenko (CSIRO)
School of Information Technologies

1. Aim

To study the phase transition in ordered-critical-chaotic behaviour in Random Boolean Networks (RBNs):

- as models of Gene Regulatory Networks (GRNs),
- from the perspective of distributed computation.

2. Random Boolean Networks

Discrete dynamical models of nodes [1]:

- In a directed network structure,
- which is determined at random from an average in-degree /K;
- With Boolean states,
- Updated synchronously in discrete time,
- using heterogeneous random update functions.

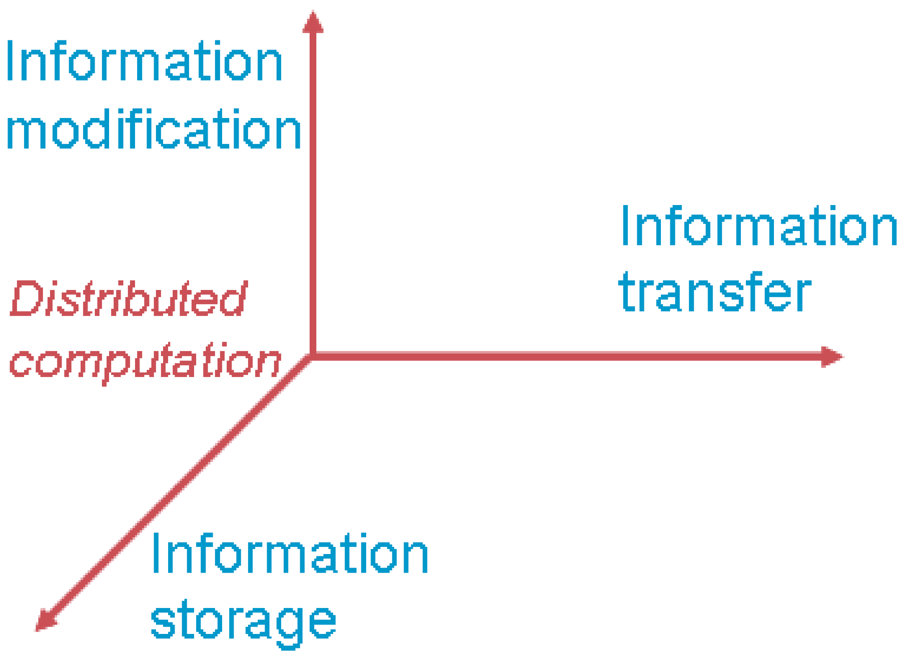
RBNs exhibit a well known phase transition from ordered-chaotic behaviour as a function of the connectivity /K:

(quantified with respect to δ - the Hamming distance between the final attractors of two initial networks states differentiated by only a single node's state)

Connectivity /K	Low /K < 2	Mid /K ≈ 2	High /K > 2
Phase	Ordered	Critical	Chaotic
Sensitivity to initial conditions	Low $\delta < 0$	Critical $\delta \approx 0$	High $\delta > 0$
Convergence of similar macro states	Strong	Uncertain	Highly divergent

3. Why study RBNs?

- Their popularity as models of GRNs: network attractor represents cell type.
- Generality as network models with a large sample space – permits study of **dynamics** of networks rather than topology.
- Ideal platform for studying generalised phase transitions in networks.



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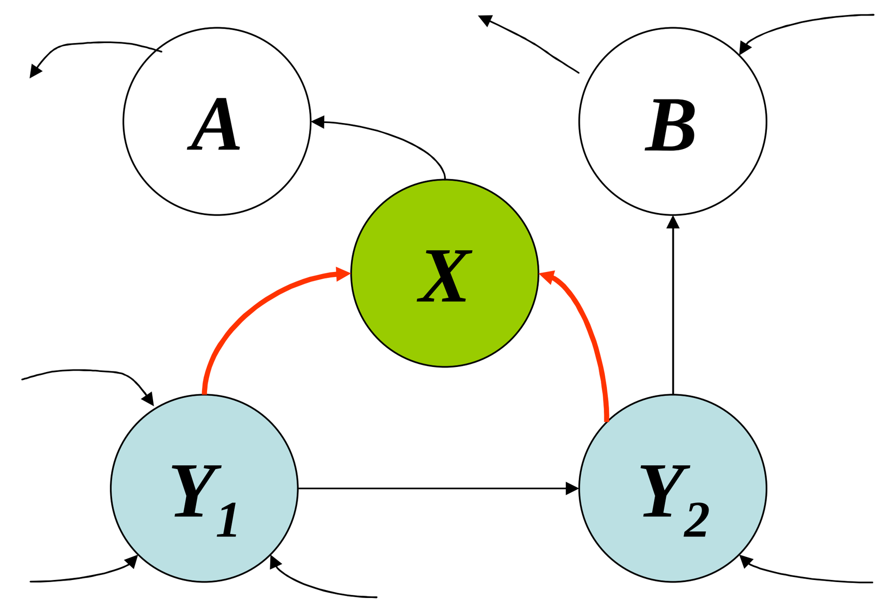


4. Why study information dynamics in RBNs?

- Topology is well-established but time-series dynamics less understood.
- Much conjecture on phase transitions in information propagation and processing b/w ordered and chaotic regimes in RB and other nets.
- Our perspective of computation aligns with popularly held notions of information dynamics.
- Computation performed by the RBN to determine attractor has meaning as determination of cell type by GRNs.

5. Information dynamics

- **Information storage**: info in past of an agent relevant to predicting its future [2].
- Active info storage = mutual info between past *k* steps and next step:

$$A_X(k) = I(X', X^{(k)})$$

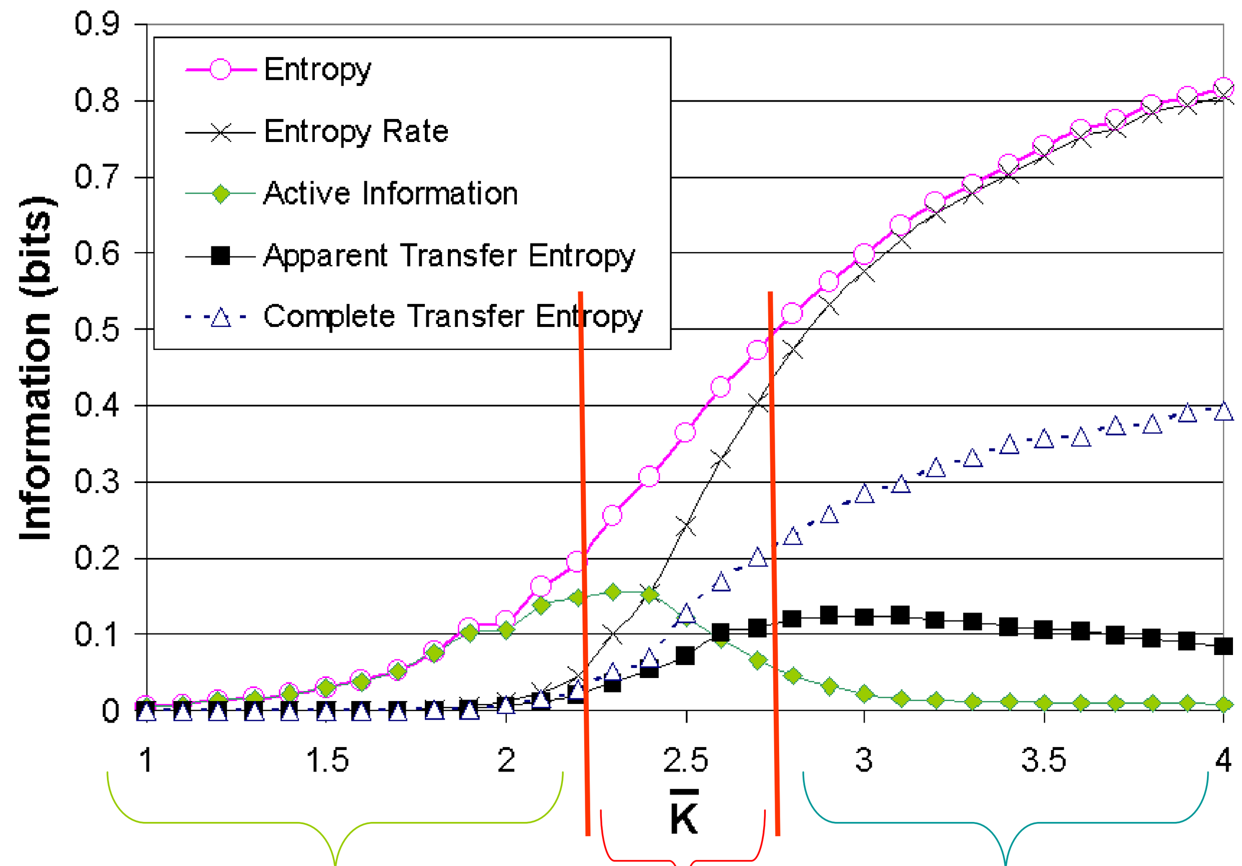
- **Information transfer**: info provided by a source about destination's next state that was not contained in the past of the destination. [2]
- Apparent transfer entropy = mutual information between source and destination conditioned on the past of the destination, e.g.

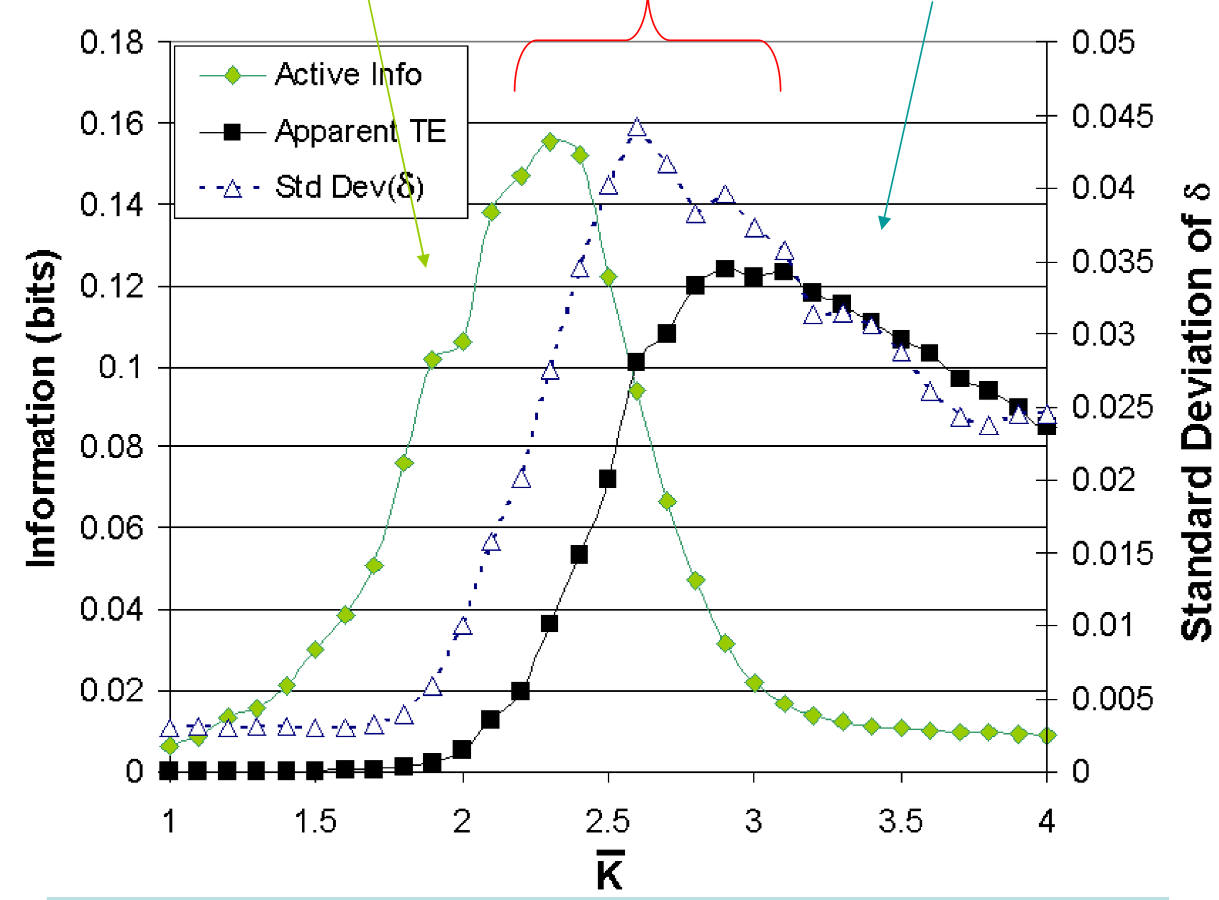
$$T_{Y_1 \to X}(k) = I(Y_1, X'; X^{(k)})$$

- Complete transfer entropy also conditions on other causal information sources:

$$T_{Y_1 \to X}(k) = I(Y_1, X'; X^{(k)}, Y_2)$$

6. Results and Conclusion





1. Info storage maximised just on ordered side of critical regime.
2. (Coherent) info transfer maximised just on chaotic side of critical regime.
3. Balance near critical phase
4. Info modifications continues to increase into the chaotic regime.

→ Pertinent to phase txs in other systems

→ With evidence that GRNs operate at critical regime, implies that GRNs have evolved to facilitate maximum coherent computational capability.

References

1. C. Gershenson, "Introduction to Random Boolean Networks," Int. Conf. on Simulation and Synthesis of Artificial Life (AlifeIX), Boston, 2004.
2. J.T. Lizier, M. Prokopenko, and A. Y. Zomaya, "The information dynamics of phase transitions in random Boolean networks," Int. Conf. on Simulation and Synthesis of Artificial Life (AlifeXI), Winchester, 2008.

Advanced Nets Research Group
Eden
CSIRO
The University of Sydney