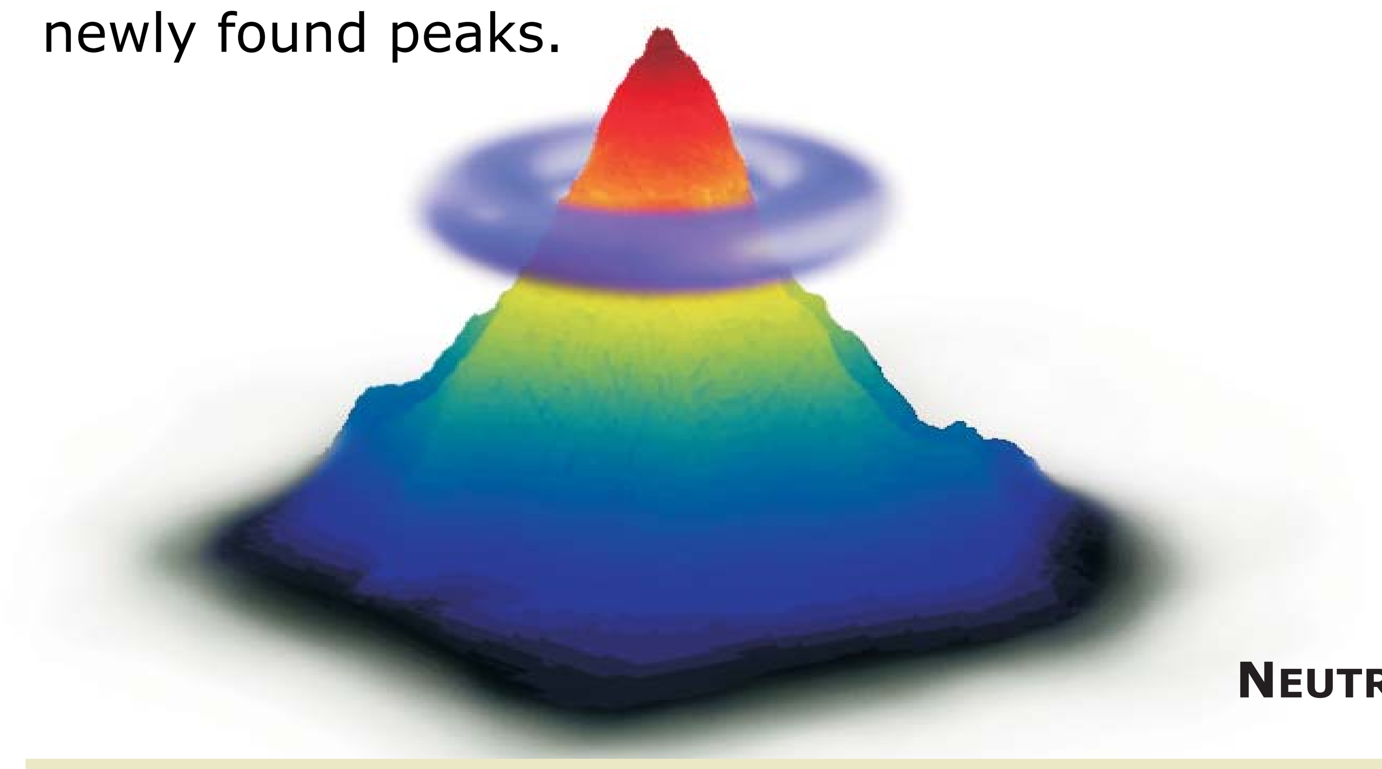
Neutral Emergence

Andrew Weeks . Department of Computer Science . University of York . Heslington . York . YO10 5DD . UK . aweeks@cs.york.ac.uk

Neutral emergence seeks to apply concepts from neutral evolution to emergent phenomena, examining their implications and whether neutral emergence is inevitable.

Neutral Evolution

Neutral evolution suggests that the mapping from the genotype to the phenotype is complex, and that changes can occur in the genome that have no discernable impact on the organism's ability to survive. It is thought that this redundancy between layers allows populations to explore more of the fitness landscape at little cost, and then climb newly found peaks.



Neutral Evolution

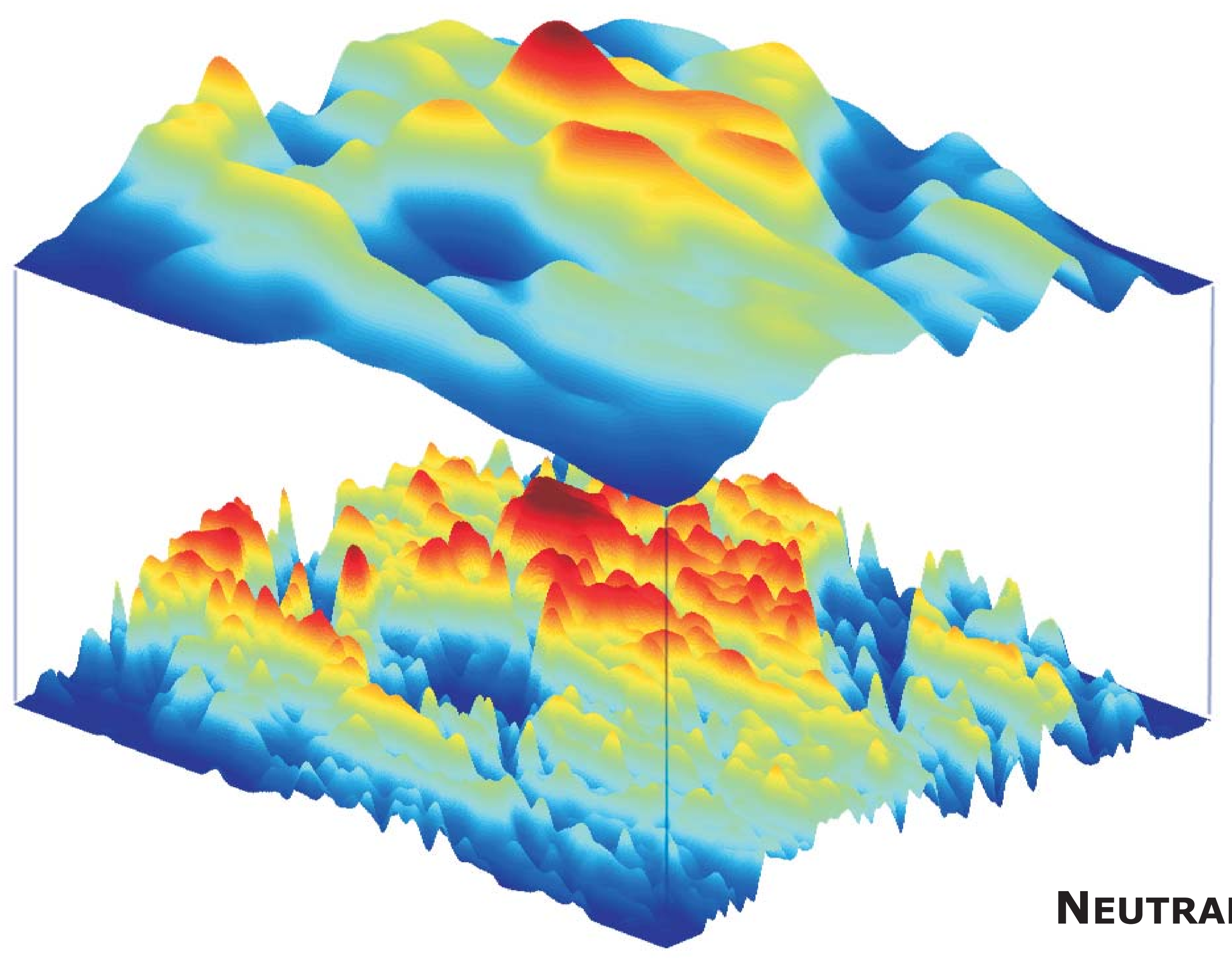
Emergence

Emergence is the process of forming complex patterns from simple rules. There are many examples around us: termite mounds, friction, the internet and poker are all recognised as having or being emergent phenomena. For a phenomenon to be described as emergent, it should generally be unpredictable from a lower level description. One well known emergence test [Ronald, Sipper, Capcarrère 1999]:

- Local interactions are described in language L1.
- Global behaviour is observed in language L2.
- If L2 cannot easily be deduced from L1, the system is emergent.

Mutual Information

[Adami 1998] looked at the transfer of information from the environment to simple replicating strings. The strings (genomes) acquire information about the environment when a random mutation leaves them better able to reproduce. Information entering the genome can be seen as a measurement which increases the correlation between the string and environment, and decreases the conditional entropy of both.



Neutral Emergence

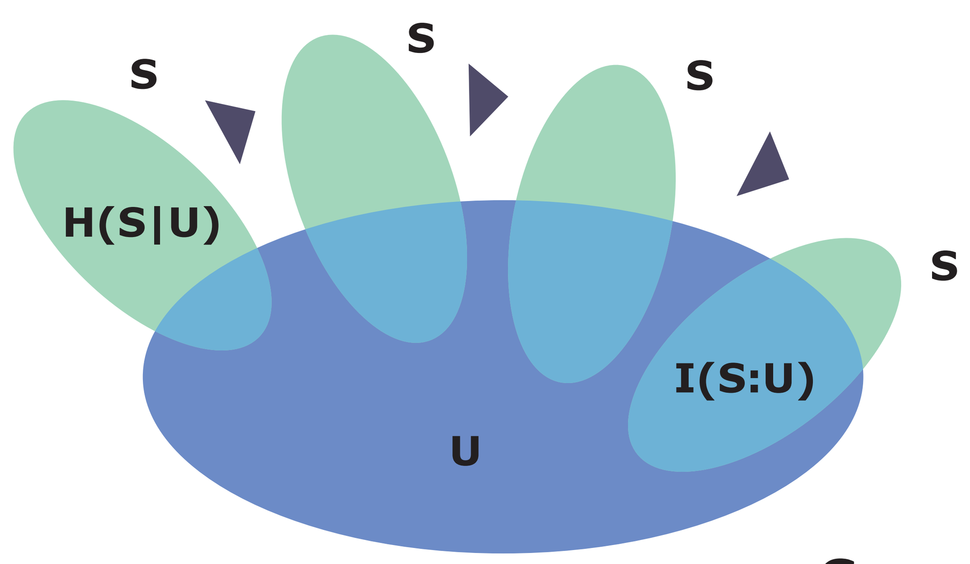
$$H(U) = I(U : X) + H(U|X)$$

Environment entropy (constant) = mutual information (gained by measurement) + conditional entropy

As it is a statistical concept, it is not possible to measure the entropy of just one string. Instead, the Kolmogorov complexity of a string can be used, which defines how easily a string can be obtained through computation. The Kolmogorov complexity is measured relative to the environment, which allows the mutual complexity to be defined.

$$K(S) = K(S : U) + K(S|U)$$

Environment complexity (constant) = mutual complexity (gained by measurement) + conditional complexity



Gaining Mutual Information

Quantitative Emergence

There is a direct analogy between this model and the description of emergence given before. Replace the environment by L1 and the genome by L2 and one has an example of an automatic emergent system. In other words, it suggests that emergent systems can be created using standard evolutionary (or other) techniques. This also implies that, to maintain a complete picture of the environment and avoid emergence, the model must be at least as complex as its surroundings.

Neutral Emergence

An emergent system has an incomplete mapping between it and environment: some environmental behaviours will be indistinguishable to the system. But this is almost exactly the definition of neutral evolution given above; this is neutral emergence.

Similarly to neutral evolution, neutral emergence should allow a system to explore its environment more widely without reducing the effectiveness of its existing model. The model can thus be adapted gracefully to introduce new behaviours. In short, it is not brittle.

An incomplete mapping will inevitably have attractor basins of multiple low level (environment) behaviours 'draining' into the same high level behaviour. Any of these low level solutions will satisfy a specification, but some will probably be more stable. A small perturbation could knock an unstable solution onto an adjacent attractor with radically different properties. Stressing the model should centre it within the desired basin, which would make the model robust in the face of mutations (implementation or manufacture errors, environmental factors, and so on). This is a far stronger statement than can be made about formally proven systems, which do not guarantee any level of performance with even the smallest change.

The above ideas suggest that

- There is nothing magical about emergence, or developing emergent systems.
- Emergent systems can be made more robust than conventionally developed systems.
- Creating useful emergent systems need not be a difficult problem; emergent systems can be generated automatically.
- The language of dynamical systems can also usefully be applied to 'conventional' evolutionary searches.

Further work

- Develop models of concrete problems that could exploit neutral emergence to determine how valid and effective the concept is.
- Explore the possibility of using ideas from dynamical systems to develop novel search techniques. In particular, examine the dynamical structure of developmental systems over time, drawing on origin of life theories.