Reaction-diffusion spots as a model for autopoiesis

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We analyse pattern formation in reaction-diffusion systems from an autopoietic point of view, emphasising the commonalities between living organisms and a certain class of so-called dissipative structures, namely those (such as spot patterns or hurricanes) in which there are more-or-less clearly defined unities, or individuals, which arise from the system's dynamics.

Previous authors have used cellular automata as a basis for studying the emergence of autonomous agent-like structures, but the continuous nature of reaction-diffusion systems gives them a substantial advantage over discrete cellular automata as it enables systems to be perturbed by an arbitrarily small amount. Since reaction-diffusion systems are simulations of physical/chemical systems the resulting model agents must obey the relevant thermodynamic constraints, an aspect of living systems that has generated a lot of recent discussion in the autopoietic literature.

The Gray-Scott model is perhaps the simplest reaction-diffusion system that can create complex patterns; it models a single type of autocatalyst feeding on a 'food' chemical that is continually added to the system; both are able to diffuse on a two-dimensional surface. One of the patterns that can be formed consists of blurred but individuated "spots" of autocatalyst separated by regions in which the autocatalyst is absent. We take a single spot as the basis for our model agent.

With the autopoietic description in mind we perform three experiments. Firstly, we put these spots into situations where there is a spatial gradient of the food molecule and find that they tend to move along it, usually away from areas where the level of food is too low for their survival. The relationship between constitution and behaviour is fundamental to the autopoietic theory, and this result opens the possibility of studying the interface between the two empirically.

Secondly we vary the rules of the system, allowing a different set of chemical reactions, which can result in agents with a more complex anatomy than just a single spot, and even a very limited form of heredity.

Finally we find that individuated spots are very likely to arise when there is a negative feedback between the whole system's activity and its overall supply of food. This situation is common in natural systems, and our result suggests a direction for further research into the conditions under which individuated unities are likely to occur in general.