Chapter 7
From Local Growth to Global Optimization in Insect Built Networks

Andrea Perna
Complex Systems Institute of Paris, France & Uppsala University, Sweden

Pascale Kuntz
Site Ecole Polytechnique de l’Université de Nantes, France

Guy Theraulaz
Université de Toulouse, France & CNRS, France

Christian Jost
Université de Toulouse, France & CNRS, France

ABSTRACT

Social insect colonies build large net-like systems: gallery and trail networks. Many such networks appear to show near-optimal performance. Focusing on the network system inside termite nests we address the question how simple agents with probabilistic behaviour can control and optimize the growth of a structure with size several magnitude orders above their perceptual range. We identify two major classes of mechanisms: (i) purely local mechanisms, which involve the arrangement of simple motifs according to predetermined rules of behaviour and (ii) local estimation of global quantities, where sizes, lengths, and numbers are estimated from densities, concentrations, and traffic. Theoretical considerations suggest that purely local mechanisms work better during early network formation and are less likely to fall into local optima. On the contrary, estimation of global properties is only possible on functional networks and is more likely to work through pruning. This latter mechanism may contribute to restore network functionalities following unpredicted changes of external conditions or network topology. An analysis of the network properties of Cubitermes termite nests supports the role of both classes of mechanisms, possibly in interplay with environmental conditions acting as a template.

DOI: 10.4018/978-1-61350-092-7.ch007
From Local Growth to Global Optimization in Insect Built Networks

ARE INSECT-MADE NET-LIKE STRUCTURES OPTIMAL?

The nests of social insects are among the most impressive objects built by animals, and this for several reasons. First, they can be extremely big: up to several magnitude orders bigger than insects themselves. Second, they usually present a coherent and harmonious global organization even at the larger scale. Third, they are not produced by extremely intelligent animals, but by tiny insects with somewhat noisy, seemingly unpredictable behaviour. These properties make insect nests particularly interesting in a perspective of bio-inspiration.

If these structures optimize some functionality, then we can imagine mimicking insect behaviour to build efficient artificial systems that accomplish similar functionalities.

How do the insects come to build such complex structures?

The question allows for two different interpretations: the first focuses on the evolutionary history of insects while the second focuses on the building mechanisms:

1. By what evolutionary processes social insects have acquired the capability of building complex structures?
2. What building mechanisms and actions at the individual level lead to the formation of the global structure?

Let us illustrate the two interpretations with an example dealing with nest building, if not directly with network like structures. In an emblematic chapter of “The Origin of Species” Charles Darwin (1859, chapter 6) thinks about honeybee combs and states that:

He must be a dull man who can examine the exquisite structure of a comb, so beautifully adapted to its end, without enthusiastic admiration.

We hear from mathematicians that bees have practically solved a recondite problem, and have made their cells of the proper shape to hold the greatest possible amount of honey, with the least possible consumption of precious wax in their construction. (...) it seems at first quite inconceivable how they can make all the necessary angles and planes, or even perceive when they are correctly made.

Darwin’s explanation is in terms of natural selection: in the same chapter he argues that “cells constructed like those of the bee or the wasp gain in strength, and save much in labour and space”. It is natural that the instincts of bees must have undergone “numerous, successive, slight modifications” that led to the construction of more and more efficient structures (Darwin, 1859).

An alternative discussion of the very same phenomenon, but this time focusing on building mechanisms is found in D’Arcy Thompson’s “On Growth and Form” (Thompson, 1992):

the direct effort of the wasp or bee may be supposed to be limited (...) to the making of little hemispherical cups, as thin as the nature of the material permits, and packing these little round cups as close as possible together. It is then conceivable, and indeed probable, that the symmetrical tensions of the semi-fluid films should suffice (however retarded by viscosity) to bring the whole system into equilibrium, that is to say into the configuration which the comb actually assumes.

For Darwin, bees make combs with minimal surface-volume ratio because this configuration confers the maximum selective advantage; for D’Arcy Thompson, the minimal surfaces appear because this is the configuration naturally assumed by semi-fluid films, be they soap-bubbles, cells of a segmenting egg or honey combs.

In principle there is no contradiction between the two explanations: bees could benefit from having cells with minimum surface to volume ratio
Related Content

Cognitively Inspired Neural Network for Recognition of Situations
[www.igi-global.com/article/cognitively-inspired-neural-network-recognition/41943?camid=4v1a](www.igi-global.com/article/cognitively-inspired-neural-network-recognition/41943?camid=4v1a)

The Planning Net: A Structure to Improve Planning Solvers with Petri Nets
[www.igi-global.com/article/the-planning-net/126481?camid=4v1a](www.igi-global.com/article/the-planning-net/126481?camid=4v1a)

Nonlinear Stochastic Differential Equations Method for Reverse Engineering of Gene Regulatory Network
[www.igi-global.com/chapter/nonlinear-stochastic-differential-equations-method/38237?camid=4v1a](www.igi-global.com/chapter/nonlinear-stochastic-differential-equations-method/38237?camid=4v1a)

Object Tracking by Multiple State Management and Eigenbackground Segmentation
[www.igi-global.com/article/object-tracking-multiple-state-management/52613?camid=4v1a](www.igi-global.com/article/object-tracking-multiple-state-management/52613?camid=4v1a)