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A FAUSTIAN EXCHANGE: WHAT IS IT TO BE HUMAN IN THE ERA OF UBIQUITOUS TECHNOLOGY?

Morphogenesis, morphology and men: pattern formation from embryo to mind

Celebrating Alan Turing's centenary

Siddharth Ramakrishnan

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Abstract In 1952, Alan Turing published his last work on the concept of embryonic morphogenesis, propounding a computational framework for pattern formation within the developing embryo. This concept of morphogenesis and the concept of embryo pattern formation based on chemical diffusion patterns were corroborated with the discovery of the Homeobox or Hox genes. In the following decades, Hox gene research has expanded and is now shown to underlie the variety of morphological novelties that we experience in nature, the patterning of structural aspects of different organs including the brain and also mutant animals that may in the future give rise to novel speciation. Turing had the foresight and vision and with his work created the field of computational biology and mathematical modeling in biological systems. In this paper, we will discuss the concept of Hox genes, their role in patterning the embryo, how it relates to Turing's concept of morphogenesis and what further insights they may provide.

Keywords Hox genes · Morphogenesis · Development · Morphological novelties

1 Introduction

When we look around us, we see a wide range of organisms—tentacled snails, elephants with trunks, elongated snakes, plumed birds and tailed monkeys. Two main questions arise from mere observation—(1) How do such complex body plans emerge from a mass of cells that constitute the dividing zygote? (2) How does such variation in body patterning occur during evolution? Research in the field of evolution and development (Evo-Devo) has implicated a set of genes, termed the Homeobox or Hox genes, for both these phenomena (Carroll et al. 2004). While the first report of such genes dates back to 1941, during the time of Alan Turing, their predominant role in shaping the developing embryo, regionalization of body parts including the brain and potential shaping of morphological differences were realized quite recently and are still under investigation (Lewis 1978; Pick and Heffer 2012).

Turing (1952) described how simple nonequilibrium chemical reactions could cause distinct patterns to be formed in time and space, and speculated that morphogens could underlie biological morphogenesis. While the functioning of Hox genes is attributed to a different "gradient" model of morphogenesis, some recent studies have postulated a possible compatibility of the Turing Morphogen model to this system (Kondo and Miura 2010). However, what is undeniable is the impact of the 1952 Turing paper that laid the foundations for mathematical and computational biology, where mathematical equations could be used to comprehend and explain biological processes. In this paper, we will briefly describe the role of Hox genes in body patterning and evolving morphogenesis, a discussion of Turing's chemical morphogens and their relevance in current research and finally speculate on extrapolating a chemical basis of morphogenesis to a chemical basis of individuality.

1.1 What are Hox genes?

Hox genes are a set of toolkit genes that define body plans in most animals studied to date. They were first identified

S. Ramakrishnan (✉)
Neuroscience Program, Department of Biology,
University of Puget Sound, 1500 N Warner St #1012,
Tacoma, WA 98416-1012, USA
e-mail: sramakrishnan@pugetsound.edu